SHINKAI 6500 / YOKOSUKA CRUISES (YK99-07, -08) AROUND HAWAIIAN ISLANDS

ONBOARD REPORT

Aug. 1 – Aug. 25 (YK99-07)
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Japan Marine Science and Technology Center
(JAMSTEC)

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1. INTRODUCTION

The Hawaiian Islands are the most well developed example of volcanism generated by a hot spot or up welling mantle plume. The United States Geological Survey (USGS), the University of Hawaii (UH) and other US institutions are surveying the geology conducting, geophysics and other earth science investigations of the islands. The deep sea areas surrounding the islands remain relatively unstudied because of the difficulty accessing them. In many areas important geologic features occur below the operating depth of current US research submersibles. Therefore, some Japanese and US scientists interested in the earth science of the Hawaiian Islands discussed the potential for cooperative work using JAMSTEC's deep-sea research capability. Based on these discussions, Japanese scientists developed a two-year cooperative research plan as one of JAMSTEC's deepsea programs, to use 11 km-depth capable ROV KAIKO and its mother ship R/V KAIREI in 1998 and SHINKAI 6500 and her mother ship R/V YOKOSUKA in 1999.

As the first step of this plan, JAMSTEC conducted geological and geophysical research cruises around the Hawaiian Islands using ROV KAIKO and R/V KAIREI during August 24 to September 19, 1998. To organize this cruise, JAMSTEC and the UH School of Ocean and Earth Science and Technology (SOEST) drafted an implementing agreement setting out the goals and boundaries of the proposed cooperative research program. UH and USGS scientists participated in this cruise under that arrangement.

The main research areas for the 1998 KAIKO/KAIREI cruise are follows:

1) Nuuanu Slide (Northeast of Island of Oahu)
2) Loihi Seamount (Southeast of Island of Hawaii)
3) Hilina Slump, Kilauea volcano (South of Island of Hawaii)

During the cruise 10 KAIKO dives were conducted to observe sea floor geology, 10 dredge hauls, and 6 piston cores were collected for laboratory research. We also surveyed the topography of the entire Nuuanu and Hilina regions (including Loihi Seamount) using KAIREI's Sea BEAM 2112 sonar system. The preliminary results from this cruise are attached in appendix.

In 1999, plans were made to use SHINKAI 6500 and its mothership R/V YOKOSUKA for the second phase of the planed two year research program. To organize this cruise, JAMSTEC and the School of Ocean and Earth Science and Technology (SOEST) drafted an implementing agreement setting out the goals and boundaries of the proposed research program. Under this revised arrangement for the second year cooperative research, UH, USGS and MBARI scientists were designated to participate.

Based on the KAIKO/KAIREI cruise results discussed at subsequent meeting of the principle investigators it was to continue with investigations of areas studied in 1998

and to add the North Arch volcanic field and Kilauea East Rift (Puna Ridge) to research agenda.
The research objectives of YOKOSUKA/SHINAKAI 6500 cruises, conducted from August 1 to September 23 1999 are as follows:

1) Nuuanu Slide, Koolau Volcano (North of Oahu) and its north arch:
__The Nuuanu Landslide located north of the island of Oahu is the largest landslide around Hawaiian islands. The main objectives of the_ research are to identify the origin and age of the landslide, and to observe the deep structure and the materials of the Koolau volcano. There are some large newly formed lava flows farther north of the Nuuanu slide. The other objective is to identified the nature of the lava flow.
2) Loihi Seamount (Southeast of Hawaii):
Loihi Seamount, located on the southern flank of the Island of Hawaii is an active submarine volcano which represents the early stage of Hawaiian hot spot volcanoes. The main objective is to conduct geological research on the volcano, and to study the hydrothermal vents located at the depth between 4800 and 2000m.
3) Hilina Slump and east rift zone, Kilauea volcano (South of Hawaii):
The Hilina Slump is an active landslide body located on the southern flank of the Island of Hawaii. The main objective is to conduct geological research on the landslide deposit. Kilauea east rift is currently active. Approximate 60% of this rift is submarine and basic objectives are to obtain geologic data relevant to Kilauea rift zone processes.

We acknowledge Captain Tanaka and the entire crew of YOKOSUKA and Operation Manager Imai and SHINKAI 6500 operation team for their highly skilled operation and kind support during this research cruise.

2. SCIENTIFIC OBJECTIVES

2-1. Loihi Submarine Volcano: Objectives

The Loihi submarine volcano is the latest manifestation of the Hawaiian Hot Spot volcanism. Loihi extends from a water depth of over 5000 meters at its base to a summit depth of 975 meters. Seismic evidence shows a concentration of earthquake activity at depths of about 10 and 20 kilometers beneath sea level. Extensive bathymetric surveys using shipboard multi-beam sounding systems show the edifice of the submarine volcano to be narrow and aligned approximately in a north to south direction. The eastern and western slopes appear to have been eroded by a continuing process of mass wasting. Bottom photography, shipboard dredging, extensive traverses by submersibles from the summit down to a water depth of 2000 meters and more limited traverses by submersible at water depths between 5000 and 3000 meters have shown that sporadic volcanism had taken place at the summit and along the north and south rifts of the volcano.

Petrographic and geochemical studies of rocks collected by submersible and by shipboard dredging showed that both alkali and tholeiitic basalts are intermingled along the sample range and that some of the youngest basalts sampled from the summit are alkalic in composition. The most consistent volcanism on Loihi appears to have taken place along the South Rift and the summit. Picrites have been collected from the base of the South Rift but not from the summit. Geological evidence has placed hydrothermal activity taking place from the summit to the base of Loihi. In 1996, the summit of Loihi underwent an unexpected collapse. A summit hydrothermal venting site, located on the 975 meter deep Peles Cone, collapsed, and in place of the cone, a 300 meter deep pit crater was formed. About 0.1 cubic kilometers of magma must have vacated the summit portion of the volcano in order to form the pit crater.

A number of fundamental questions relating to hot spot plumes and hot spot volcanism are raised by the events on Loihi, these include:

1. What are the dynamics of the mantle plume and the magmatic plumbing of Loihi that lead to the almost parallel eruptions of both alkali and tholeiitic lavas?
2. How is the presence of picrite lavas at the base of the South Rift related to the absence of picrite lavas on the summit?
3. What portions of the magmatic plumbing of Loihi are being tapped by the eruptions that have taken place along the South rift?
4. Since the geochemistry of the rocks sampled from Loihi today shows substantial differences from those sampled from Kilauea, what portions of the Hot Spot plume are giving rise to the magma of Loihi?
5. Since Loihi represents the youngest stages in the growth of the Hawaiian Islands, is the

South Rift of Loihi analogous to the early evolutionary stages of a young Kilauea East Rift zone?

The fundamental questions being raised here are largely petrological, geochemical and volcanological in nature and can only be answered through careful field sampling of candidate rock specimens coupled to a program of careful site observation and mapping. Clearly, such an effort can be conducted only with deep submergence facilities such as ROV's and submersibles. The ultimate objective in obtaining the carefully selected and site-mapped specimens from the South Rift of Loihi is to place the geologist at the critical areas of the ocean floor on Loihi. Without the use of a deep diving submersible such as the SHINKAI 6500, the fundamental questions regarding the evolution of a submarine volcano such as Loihi and therefore the evolution of the Hawaiian volcanoes cannot be answered.

2-2. Geology and Scientific Importance of Kilauea's Submarine East Rift Zone (Puna Ridge)

Geology

A rift zone is one of the most common volcanic features constructed on both subaerial (e.g., Hawaii, Iceland, etc.) and submarine volcanoes (e.g., Loihi and other seamounts, mid-ocean ridge segments). The morphological characteristics of a rift zone are typically used to infer the internal architecture of volcanoes. Both of these facts underscore the broad applicability of studying the Puna Ridge, and the importance of fully understanding the formation and evolution of a volcanic rift zone. Currently, the controls on the injection and transport of magma along a rift zone, the role of magma storage within the dike system, and the controls on the shapes, sizes, and styles of lava deposits are not well known.

Kilauea's subaerial rift zone system is one of the best studied in the world (e.g. Tilling and Dvorak, 1993; and references therein). The volcano is fed from a central magma chamber (or system of magma conduits) beneath the summit (e.g., Ryan et al., 1981; Ryan, 1988). Lava is erupted at the summit and/or one of the volcano's two rift zones, the South West Rift Zone (SWRZ) and the East Rift Zone (ERZ). The onset of a rift zone eruption is marked by seismicity that migrates from the summit region down one or the other rift zone to the site of eruption, where the early phase of eruption is normally through a fissure that may be several hundreds of meters long (e.g., Klein et al., 1987; Wolfe et al., 1987). If fissure eruptions persist they normally become confined to a single vent. Since 1983 eruptions have been continuously occurring along the ERZ centered at either the Pu`u `O`O or Kupaianaha vents (e.g., Wolfe et al., 1987; Mangan et al., 1995), and has produced more than 1 km^3 of lava to date. Surface deformation associated with the seismic activity (e.g.

Pollard et al., 1983), the fissure eruptions, and the observation of dikes within the eroded cores of Hawaiian volcanoes (e.g., Walker, 1987) indicate that rift-zone eruptions are dike-fed, and that the seismic activity is associated with magma moving through the underlying magma conduit system. The subaerial ERZ is 55 km in length and the zone of eruptive fissures, and hence of active dike intrusion, ranges in width from 1.5 to 3 km (Holcomb, 1987; Moore and Trusdell, 1991).

Since the 1950's the average magma supply rate to Kilauea during long term eruptions has been ~3 m^3/s (Tilling and Dvorak, 1993). The Mauna Ulu eruption is a good example of eruptive volumes and styles during a long-lived eruption. Between 1972 and 1974 about 160 x 10^6 m^3 of lava was erupted (Tilling et al., 1987). The cone of Mauna Ulu was built to a height of ~120 m above pre-1969 topography. Channels and a tube system typically transported lava 3-5 km from the summit of Mauna Ulu, and some lava flowed as much as 10 km from the vent to the shoreline (Tilling et al., 1987; Peterson et al., 1994). The surface area covered by lava during the eruption was about 45 km^2. Much of the lava erupted during this time was in the form of pahoehoe flows, formed during slow, steady eruption from the vent at 1-5 m^3/s (Peterson et al., 1994).

Puna Ridge, the submarine extension of Kilauea's ERZ, runs ~75 km from the shoreline to its distal end. Over its length, it is 55-130 km from the summit magma reservoir, and plunges from sea level to a depth of 5400 m. SeaBeam bathymetry data have been collected over its entire length (Clague et al., 1994). These data, along with deep-tow side-scan sonar images of the Puna Ridge at its distal end (Lonsdale, 1989), photographic imagery (Moore and Fiske, 1969; Clague et al., 1988; Lonsdale, 1989), submersible dive observations (Fornari et al., 1978), and a recently completed study using deep-towed 120 kHz sidescan, ARGO II bottom photography, seafloor magnetics, and rock sampling (Smith et al., 1998) confirm that the Puna Ridge crest is a constructional volcanic feature and that the crest is the location of dike intrusions and fissure eruptions. Existing sea surface magnetic data show an elongate, normally-polarized magnetic anomaly centered over the axis of the Puna Ridge, consistent with the presence of a 11-km wide, 70-km long, nearly-vertical magnetic source, presumably representing the dike complex along the ridge (Malahoff and McCoy, 1967). This characteristic magnetic anomaly high disappears at ~4500 m water depth.

Eruptions appear to be less frequent on the Puna Ridge than on the subaerial ERZ. Holcomb (1987) estimated that 70% of the subaerial portion of Kilauea is younger than ~500 years. Based on palagonite thicknesses, Clague et al. (1995) estimated that dredged lavas from the Puna Ridge range from 700 to 24,000 years in age, and most are 2000 to 7000 years old. The most recent submarine eruptions are thought to have occurred in 1790, 1884, and 1924. The 1884 eruption was witnessed just offshore at 20 m water depth. In 1790 and 1924, explosions at the summit of Kilauea are thought to have been associated with magma withdrawal from the summit reservoir and it was inferred that they fed submarine eruptions on the Puna Ridge (Stearns and Macdonald, 1946).

Though both the subaerial ERZ and the Puna Ridge are constructed in the same way, by lavas erupted from a rift zone, there are clear morphological differences between them, which must reflect the differences between subaerial and submarine volcanology. For example, the longitudinal slope of the subaerial portion of the ERZ is fairly constant at ~23 m/km (Lonsdale, 1989), while that of the upper part of the Puna Ridge is much steeper, at ~51 m/km. Fialko and Rubin (1998) suggested that longitudinal slopes of rift zones may be an important factor in driving dike intrusion along the length of the rift. Their model would predict that the ratio of longitudinal slopes in the subaerial and submarine environments should be approximately $\alpha_s/\alpha_{pr} = (\rho_L - \rho_w)/(\rho_L)$ where α_s and α_{pr} are subaerial and submarine slope angles, respectively; and ρ_L and ρ_w are lava and water density, respectively. The observed ratio for the initial change in slope immediately offshore is $\alpha_s/\alpha_{pr} = 0.45$, while that predicted by their relationship is about 0.6. Below 2700 m the longitudinal slope of the Puna Ridge steepens further to ~95 m/km, but the cause of this second steepening is not understood.

The styles of volcanic features on the lateral slopes of the rift zone change significantly as the crest of the rift dips below sea level. Lavas erupted from the subaerial ERZ form smooth, low angle slopes, except where interrupted by faults. These slopes are gently dipping low-relief lava flow surfaces, and where they reach beyond the shoreline they are believed to be submarine debris flows formed as the lava breaks upon flowing into the water (e.g., Moore et al., 1973). Large edifices are not commonly constructed. By contrast, the lateral slopes of the Puna Ridge are both steeper (~200 m/km) than the subaerial slopes of the ERZ (~50 m/km), and also topographically irregular on a scale of 1-2 km. Lava flow features on the flanks of the Puna Ridge include large semi-circular flat-topped features that have diameters of 1 km or more and sides several hundreds of meters high. These flat-topped features often appear to form staircases of features one on top of the next. Many of them have pit craters in their tops that can be resolved by multibeam bathymetry. Scattered along the crest of the Puna Ridge are volcanic cones (Lonsdale, 1989) that presumably represent primary eruptive vents. The large flat-topped vent located on the rift axis ~10 km from the shoreline is unique along the length of the Puna Ridge. It is about 200 m high, similar to heights that the subaerial Pu`u `O`o cone has reached, although the submarine cone has a much larger volume because of its flat top.

On the Puna Ridge the lateral slopes of lava deposition range between 160-240 m/km. These slopes do not change significantly with distance from the shoreline until a water depth of about 4500 m (below which dikes may not propagate), suggesting that the slopes have remained the same throughout the construction of the ridge. This in turn indicates that lavas are added uniformly to the flanks averaged over time, thus maintaining the lateral slopes. These slopes must thus reflect the volcanic processes that take place during the construction of the submarine ridge. The slopes of the Puna Ridge extend, where the ridge is close to sea level at its upper end, for more than 15 km down to the deep ocean floor. The morphology of the flanks of the ridge must therefore represent a characteristic of submarine basaltic flows.

Scientifically Important Questions

Some fundamental scientific questions to be addressed are:

1) *How are dikes able to propagate 55-130 km from Kilauea's summit to feed the Puna Ridge?* The lateral extent of dikes is most likely controlled by the size of the summit reservoir and its resupply rate, the recent history of magma intrusion into the dike system, and/or the stress conditions along the ridge. To provide constraints on these controls, data on small-scale tectonic and volcanic morphology, high-resolution magnetic structure, and geochemistry are important to map out eruption volume, rate, style, lava composition and age, and the distributions of faults, fissures, and graben as a function of distance along the Puna Ridge. These data can be compared to the subaerial ERZ.
2) *How are the deep terraces formed?* An intriguing aspect of the Puna Ridge is the presence of a series of large terraces at ~3000 - 5500 m water depth, the deepest portion of the Ridge. This deep zone represents a change in volcanic morphology from a preponderance of cratered, individual smaller benches above to the construction of large lava terraces or benches toward the distal end. The point where this volcanic morphology changes also marks a break in along-axis slope from 51 m/km along the shallower portion to 95 m/km in the deeper end of the Puna Ridge. Possible explanations for the change in slope include changes in magma supply and effusion rates, and significant changes in lava properties, such as those related to the increase in ambient pressure. Understanding the processes important in constructing slopes, and the overall shape of a rift zone, are important to understanding the construction of any basaltic volcano.
3) *What is the effect of environmental conditions on the shapes and styles of volcanic features?* Morphology is used as a primary basis for understanding the internal structure of subaerial volcanoes, seamounts, and the oceanic crust, yet we do not fully understand how volcanic features are modulated by their eruptive environment. The Puna Ridge provides an ideal location to investigate how eruption styles vary from the

well-known subaerial ERZ styles, to those erupted in a shallow water environment, to those in a deep water environment. Physical parameters such as effusion rate, lava viscosity, cooling rate, underlying slope, etc. may exert the primary controls on lava deposit morphology.

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2-3. Submarine Landslides and Magmatic Processes of Koolau and East Molokai Volcanoes

Objectives

The Hawaiian Islands are products of a mantle plume, which is thought to have originated at a boundary layer deep within the mantle. Thus, the volcanism associated with plumes provides a window into the deeper mantle and the possibility of access to the geochemical record of plate recycling and mantle evolution. The Hawaiian plume is the Earth's hottest, most productive and most thoroughly studied mantle plume. But debates still continue about the heterogeneity within the evolution of Hawaiian volcanoes.

Giant landslides are now widely recognized along the flanks of many oceanic volcanoes, such as Hawaii, Marquesas, La Reunion, Galapagos, and Canary Islands. The abundance of landslides demonstrates that mass-wasting processes play an important role in the construction and evolution of oceanic-island volcanoes. Not only do such processes modify the surfaces and slopes of the islands, they also are closely linked with major geologic hazards, including earthquakes associated with slope failure, large-scale submergence or emergence of coastlines, and massive tsunamis which can destroy life and property. Due to the unpredictable and sporadic nature of such massive landslides, the processes and timing associated with these events remain poorly understood. The significance of landslide features in the evolution of volcanic islands, and their extraordinary destructive potential, make it imperative that we understand their history and behavior. One objective of this JAMSTEC cooperative program is to explore the evolution of oceanic islands including their growth and degradation. A focus on landslide deposits and the scars they produce provides a window into Hawaiian volcanoes.

The northeast flank of Oahu appears to be the source area of one of the largest landslides on Earth, the Nuuanu debris avalanche (Moore et al., 1994). The offshore expression of this slide is an extensive, rubbly field of debris extending across the Hawaiian Deep and Arch. Numerous large, irregular blocky mountains protrude up to 1.8 km above the abyssal sediments, and are thought to be fragments of the volcanic edifice carried downslope during flank collapse. Little bathymetric, side-scan sonar, or seismic data were available for this area prior to the JAMSTEC 1998 KAIREI cruise, and little was known about the structure, morphology, or source areas of the slide debris. The magnitude of the slide suggests that the Koolau Volcano has been deeply incised, exposing an extensive stratigraphic section through the volcano. Adjacent to Nuuanu slide is the Wailua slide from East Molokai. These submarine debris-avalanche complexes were derived from the north slopes of Oahu and Molokai islands. The Wailua landslide debris from the younger volcano on Molokai may be partially covered by the Nuuanu slide (Naka et al. 1998), contrary to previous expectations. However, the age relationships between these two slides have not been established and resolving this question is one of the goals of our research.

The Nuuanu and Wailua landslides provide outstanding research opportunities: 1) to study the mechanics of giant landslide formation and 2) to determine the early magmatic history of Koolau and the Molokai volcanoes. Although some of the world's largest landslides have formed on the flanks of Hawaiian volcanoes, the mechanics of their formation are poorly understood. Koolau Volcano is Hawaii's most geochemically distinct volcano and its origin remains a mystery.

The 1999 program for SHINKAI 6500 dives in Hawaii was designed to study hotspot magmatism and the relationships between volcanism and large-scale landsliding. Oceanic islands generate enormous landslides that represent a major tsunami hazard for the Pacific Basin. The proposed dives will study both the debris from the landslides and the internal structure of the volcanoes that are dissected by them. This project is a continuation of the highly successful 1998 joint Japanese-U.S. Hawaii program, which utilized the R/V KAIREI and the KAIKO ROV on landslide and volcanologic research of importance to both countries.

Another objective of the 1999 program is to the remarkable bathymetric map made during the 1998 JAMSTEC cruise by extending the bathymetric survey to the west, north and south sides of the seafloor between the two landslides areas. This region has never been surveyed with multibeam system and we are expecting to discover many important features about Hawaiian volcanoes from this surveying. This detailed map will improve our ability to interpret the geology and history of the northern offshore portions of Oahu and Molokai islands.

Finally, this collaborative Japanese-US marine program will foster international cooperation on fundamental Earth science problems that are of mutual interest.

2-4. The North Arch Volcanic Field

Introduction

The North Arch Volcanic Field was discovered in 1986 during surveys around the Hawaiian Islands using the GLORIA sonar system (Clague et al., 1990). The flow field covers about 25,000 km^2 and probably has a volume between 250 and 1,000 km^3. It consists mainly of thin sheet flows of alkalic basalt to basanite composition that apparently erupted from broad low-relief lava shields. In addition, the eastern part of the field also has at least a dozen small steep pillow/hyaloclastite vent structures of nephelinite to alkalic basalt composition. A single flow, apparently erupted from an unidentified lava shield in the southern part of the flow field, covers about 3,600 km^2 and has an estimated volume of 36 to 72 km^3, or roughly the output of Kilauea Volcano during 360 to 720 years of continuous eruption. The single flow also represents about 15% of the area of the entire flow field, suggesting that the field of sheet flows could have been formed by relatively few eruptions. However, the vents for only a few of these eruptions are evident in the GLORIA data and SeaBeam bathymetric data obtained from the NGDC. Another flow has been constrained within a graben formed parallel to the Cretaceous East Pacific Rise and has flowed about 110 km northward down a gradient of about 2 m/km. Such flow characteristics demonstrate the low viscosities these flows have and suggest that, despite the large geochemical differences, these flows may serve as rheologic analogs to Archean komatiite flows, which were also low viscosity flows emplaced under water.

The lavas are geochemically similar to rejuvenated stage lavas from the Hawaiian Islands, such as the Honolulu Volcanics on Oahu and the Koloa Volcanics on Kauai. However, because the North Arch lavas were erupted and quenched under 4+ km of seawater, they have retained much of their pre-eruptive volatile component (H_2O, CO_2, S, Cl, noble-gases) and initial volatile contents of the lavas and their source rocks can be estimated using closed system degassing models (Dixon et al., 1997). In addition, the lavas were transported through the upper mantle far from the center of the Hawaiian plume through lithosphere unmodified by the passage of prior tholeiitic or alkalic lavas. The similarity of the North Arch lavas and the rejuvenated stage lavas on the islands suggests that these lavas are modified little by reactions in the lithosphere.

The sheet flows have ages, estimated from paleomagnetic properties of sediment cores and palagonite thicknesses on recovered glasses, ranging from 0.5 to 1.15 Ma, whereas preliminary ^{40}Ar-^{39}Ar dates on three vent samples range from 0.9 to 1.4 with a less reliable date on a fourth sample perhaps as old as 1.8 Ma. A single sheet flow sample recovered from a separate flow field to the east of the main flows is estimated to be about 1.6 Ma. Some sheet flows lie above and some below the deposits of the Wailau landslide from Molokai, and therefore bracket the timing of the landslide to be between roughly 0.5 and 1.6 Ma.

Shinkai 6500 Program Objectives

This program has a range of scientific goals. One of the major objectives of the Shinkai 6500 program is to recover several sheet flow samples that are large enough to date so we can directly calibrate the palagonite ages estimated for the remaining samples. New ages will better define the duration of volcanic activity in the North Arch and provide more reliable age control on the timing of the Wailau landslide. Most of the remaining objectives are volcanologic in nature and include characterization of eruption and degassing dynamics for different types of basaltic eruptions under 4 km of seawater. A crater roughly 1 km in diameter, identified from the GLORIA data, provides an opportunity to mesa the thickness of lava in the region and to refine the volume estimates for the entire flow field. We will also determine the rheology of the sheet flows, and develop models for their eruption and emplacement. Observations from the Shinkai 6500, chemical and physical analyses of recovered samples, and interpretation of the SeaBeam bathymetric and side-scan data will form the basis of our study.

The two dive targets have changed from those in the initial proposal, due to both logistical and scientific reasons. The dive we had proposed to do on the narrow flow in the northern part of the flow field is so far north that we could not transit to the next dive site overnight. We have changed this dive to collect a suite of samples within a 1-km diameter pit crater adjacent to a low broad lava shield. We want to define any geochemical changes during such long-lived eruptions that will lead to better understanding of the magma generation and magma transport dynamics. In addition, we will be able to evaluate the timing of gas loss that leads to the emplacement of bubble-free sheet flows by examining and analyzing some near-vent samples. This will be our second dive. The first dive target has two objectives, to sample pillow lava, sheet flows, and hyaloclastite from a vent in the southern part of the flow field, and to observe the distributions and sequence of the different lava morphologies.

2-5. Hilina Slump

Introduction to Overall Research Program

One major objective of the collaborative U.S.-Japanese SHINKAI dive program is to explore the evolution of oceanic islands including their growth and degradation. A focus on landslide deposits and the scars they produce provides a window into Hawaiian volcanoes. This will provide an opportunity to reconstruct the deformational sequence of Hawaiian slides and to better constrain static and kinematic models for landslide initiation and movement, and to provide data for the development of models for destructive landslide-generated tsunamis. Seafloor mapping of the U.S. Exclusive Economic Zone (EEZ) using the GLORIA side-scan sonar system has revealed the presence of more than 68 giant landslides along the flanks of the Hawaiian volcanoes. We hope to gain greater insight into the landslide processes and to assess the potential hazards they present to human life and property in Hawaii and around the Pacific Rim from the associated earthquakes and tsunamis. The SHINKAI dives will be focused on clarifying the structure, morphology, and lithology of the submarine flanks of Hawaiian volcanoes, in order to understand the growth and degradation of the oceanic island volcanoes.

Hilina Slump and Island of Hawaii Volcanoes

A key part of this work is the submersible investigation of the Hilina slump, an active landslide (Lipman et al., 1985) at least 40 km wide on the southeast flank of the currently active Kilauea volcano. The submarine south flank of Kilauea has been mapped by recent detailed multibeam bathymetric maps (scale, 1:150,000; contour interval, 10 m; Chadwick, et al., 1993). The entire south flank of the island of Hawaii shows evidence for slumping and collapse (Lipman et al., 1990). This proto-slump has now broken into two slumps that are buttressed in the middle by Loihi Seamount. These slumps are the Punaluu slump west of Loihi and the Hilina slump east of Loihi. The presence of debris avalanche deposits along adjacent island flanks indicates that similar slumps have failed catastrophically, opening up the possibility of such failure along the south flank of Kilauea.

The subaerial south flank of Kilauea is presently creeping steadily seaward at rates of up to 10 cm/yr (Owen et al., 1995). In 1868 and 1975 this region abruptly several to tens of meters during major earthquakes (M7.9 and M7.2, respectively) with attendant destructive tsunamis. The tsunamis generated in both 1868 and 1975 resulted in extensive damage and fatalities on Hawaii, and the 1975 tsunami produced minor damage in California (Tilling et al., 1976). The continuous creep and incremental movements of the south flank of Kilauea are apparently driven by both magmatic processes within the active volcano and by gravitational loading (Swanson et al., 1976; Owen et al., 1995). However, the structure of the mobile flank is poorly constrained, and the mechanisms by which slowly creeping slumps fail catastrophically and the precursors to such activity are unknown. Insight into these questions can be gained from submersible surveys of the submarine portions of the volcano flanks and landslides, which prior to the 1998 Kairei survey of the islands, had never been observed directly

The results of the 1998 KAIKO dives onto the deformed flanks and adjacent seafloor of Hawaii provide critical motivation to return to this area with the manned deep submersible SHINKAI 6500 in 1999. Many of the original questions relating to the mechanics and history of deformation along the flanks are still unanswered, and in addition, new ones have been raised. For example, what is the volcanic flank really composed of? The presence of indurated volcanic sandstones throughout the deep portions of the south flank of Kilauea suggests that the distal slopes of Hawaiian volcanoes are largely composed of sediment. This possibility has implications for the mechanical strength and long-term stability of the deforming flanks. However, the occurrence of primary volcanic rocks upslope of the sedimentary strata on Kilauea suggests that the transition from volcanic to clastic environment may be relatively complicated. In order to interpret the evolution of the islands, and the kinematics of the deforming flanks, it is important to know the location and nature of this transition. The observations made during the KAIREI cruise, and results of geochemical and petrographic analyses of the rocks collected, provide models and ideas to test through observations and samples collected during the SHINKAI 6500 submersible.

Some preliminary results of KAIREI 1998 program

Four dives by the KAIKO ROV, during the Japanese-USA cruise in September 1998, newly documented a variety of important features.

<u>Stratigraphy and structure</u>

(1) A mid-slope bench is bounded seaward by a 2-km-high scarp consisting of indurated volcanic sandstone and mudstone, at least along its western extent.

(2) The largest (12 km long, 700 m high) of several isolated NE-trending ridges, 5-10 km seaward of the basal Hilina scarp from which they appear to have detached, consists of similarly indurated sedimentary rocks, in which variable dips define open folds or discontinuities between structural domains. (3) In contrast, the steep submarine slope above the mid-slope bench to the east consists of pillow breccias derived from Kilauea.

The contrast between pillow-breccias of the Kilauea slope and the sandstone-mudstone of the mid-slope bench suggests that prior interpretations that the bench is a downfaulted part of the volcanic slope of Kilauea that slumped along Hilina faults may be incorrect. Instead, the sedimentary rocks may completely underlie the Kilauea pillow-breccia platform or interfinger abruptly with its lower distal margin. The volcaniclastic sediments near the base of the volcano appear to have been thickened by shortening along the toe of the Hilina slump and possibly truncated by slumping that generated the isolated ridges below it.

Basalt petrology.

Early chemical results for glass rinds of basalt-pillow and glass-sandstone samples collected during the KAIKO dives on scarps of the Hilina slump have also provided some unexpected results that provide new insights for the poorly understood processes of Hawaiian island growth: (1) All pillow lavas from the submarine primary slope of Kilauea (dive 95) were erupted in deep water, as indicated by high Sulfur contents of pillow-margin glasses. Such results indicate that these lavas represent relatively early eruptions from Kilauea, before the rift zone was above sea level, and place narrow constraints on the inception age and growth rate for this volcano. (2) The only two basalt clasts with glass from the frontal scarp of the Hilina slump (dive 98) are alkalic basalts. One was erupted subaerially, as indicated by low Sulfur content, and seemingly must have been derived from a volcano on Hawaii Island that predates Kilauea, perhaps Mauna Kea? (3) Grains of basaltic glass in the Hilina sandstones, analyzed by microprobe, also include both tholeiitic and alkalic compositions, suggesting sources in addition to Kilauea.

Successful interpretation of these stratigraphic, structural, and petrologic features, for which questions still outnumber answers, has critical implications for understanding the primary depositional growth of the submarine flanks of oceanic volcanic islands, and also for structural evolution of the Hilina slump system and development of large slumps elsewhere in the Hawaiian chain and on other oceanic islands. We must (a) locate the transition between sediments evident within the western mid-slope bench into pillow breccias of Kilauea observed above the eastern mid-slope bench, (b) define the structure and stratigraphy of the frontal scarp of the bench, especially by correlating dive observations with multichannel seismic lines across the flank, and (c) collect additional samples for petrology of pillow fragments to determine source volcanoes and depositional environments across the entire south flank area.

Objectives of SHINKAI 6500 Dives

The SHINKAI 6500 dives will focus on the deep parts of the Hilina slump. These dives will ascend cliffs on the lower blocks and scarps of the landslide front for detailed collection of stratigraphically-controlled samples, and make observations of structural features of the slump blocks, and attempt to interpret age relations of the submarine unites. Specific targets include:

(1) The over-steepened slope of the outer mid-slope bench: KAIKO dives revealed that the mid-slope bench was composed of volcaniclastic sandstones and breccias. Seismic reflection data across the bench suggest that the bench is structurally thickened by imbrication of thrust sheets, apparently composed of bedded strata. SHINKAI dives up the incised scarps of the bench will allow us to make detailed stratigraphic and structural observations to test these interpretations, and enable us to analyze the chemistry of the volcanic clasts to determine source volcano and relative age.

(2) Low-relief terraces at the base of the outer slope: These sinuous features may be small thrust sheets involving sediments presently accumulating in front of the volcanic flank. Similar stratigraphic and structural objectives exist for these as for (1).

(3) Broad terraces at the base of the Puna Ridge extension of Kilauea: These terraces may reflect the earliest stages of bench development and growth. As they lie at the base of a submarine volcanic edifice, the Puna Ridge, it is likely that they will be constructed of primary volcanic breccias. Dives upon these features will allow us to make comparisons between bench-like features along the Hilina slump, and those developed in a primary volcanic setting.

(4) Hummocky morphology on the Punalu'u slump, along the south flank of Mauna Loa: The origin of this feature has been hotly debated: is it a submarine extension of the Kilauea southwest rift zone, a zone of intense deformation comparable to the Hilina slump and mid-slope bench to the east, or is it a primary submarine volcanic feature. Samples collected from this area will be examined to test these ideas.

Samples will be analyzed chemically and petrographically in order to clarify the composition of the rocks that make up the landslide, in particular, to determine whether Mauna Loa lavas are present, as well as Kilauea lavas, and to document the long term geochemical evolution of these volcanoes. Analytical methods will include major and minor elements for bulk-rock samples by XRF and INAA methods, glass compositions by electron-probe, and ion-probe analysis, and volatile contents by FTIR measurement. We will use a combination of dating techniques, including U-disequilibrium, K-Ar, and $^{40}Ar/^{39}Ar$ methods, to determine the sedimentation rate for the surficial sediments that cover the slump blocks. We will use submersible visual/video data and marine seismic reflection data to interpret the structure of the slump blocks, and depth to the detachment.

We will also use examine recent and indurated sediment samples to characterize the past and present depositional environments along the south flank.

We will look for samples that show evidence for deformation (microfaulting, brecciation, grain fabrics, veining, etc.), that can be thin sectioned and examined petrographically. Some of these samples can be used for physical properties measurement (including grain density, porosity, acoustic velocity, and shear strength) to yield information on degree of consolidation, stress history of the rocks and sediments, and to constrain acoustic velocities for seismic interpretation.

Interpretations are underway of an extensive multichannel seismic reflection survey conducted by G. Moore and J. Morgan over the south flank of Hawaii, in particular the Hilina slump; these allow first-order predictions about the types of materials that may outcrop at the seafloor along the flanks and in the slide blocks, that can be used to guide dives using SHINKAI 6500, particularly across the oversteepened toe seaward of the mid-slope bench and the incised flank above the bench. Conversely, the results of the SHINKAI dives will provide important ground truth for the geophysical data, enabling more accurate interpretations and better constrained models.

SeaBeam Multibeam Mapping around the Big Island

We propose to continue multibeam mapping of the seafloor around the island of Hawaii, taking advantage of service days and nighttime transits between dives. Particular targets around Hawaii include the Hilo Ridge, the submarine flank of Kohala/Mauna Kea volcanoes, and seamounts, submarine terraces, and landslide features along the west flank of the island. The medium resolution bathymetry and side-scan sonar images provided by SeaBeam mapping will be used to interpret the structure and morphology of the landslide features around the islands.

2-6. **Loihi Hydrothermal Fluids and Mineral Precipitates**

Purposes:

1. To determine the size, distribution, structure, and precipitation (growth) rate of hydrothermal deposits.
2. To identify the hydrothermal precipitates and determine their chemical characteristics.
3. To estimate the extent of hydrothermal activity and measure the physical and chemical properties of the effluent.

4. To investigate the evidence of microbial activity and estimate the contribution for selective concentration and precipitation of elements (e.g. Fe).
5. To collect altered host rocks from the hydrothermal system and investigate the addition and removal of elements due to hydrothermal alteration.

We will explore the characteristics of the deepest portion of the Loihi hydrothermal system during this survey. We will conduct a survey of the deep water (4800 m) hydrothermal system and combine it with the well known summit hydrothermal system data to better understand variations of elemental cycles of the complete Loihi hydrothermal system. We can then estimate the importance of this hydrothermal system to the global fluxes of elements in seawater. Another objective is to understand the depth dependence on characteristics of hydrothermal deposits. Water depth is supposed to have a significant effect on volatile and other element concentrations and the mobility of metals. We will focus on the investigation of mode of occurrence, chemical composition and mineral assemblage of the hydrothermal deposits. Finally, we will compare the characteristics of arc-back arc and hotspot hydrothermal systems. We will clarify the differences between the two systems and interpret what causes these differences (e.g. host rock chemistry, magmatic gas input, etc.).

UNDER WAY SURVEY

SeaBeam 2112 multibeam sonar

The SeaBeam 2112 multibeam sonar seafloor mapping system was run every night from August 01 to September 22 except while in port. Dedicated surveying took place for 12-14 hours every night, roughly between 1800 to 0600 or 0800, depending on if a dive site survey needed to be run. Several maintenance days were also dedicated to SeaBeam surveying. Typical survey speeds ranged from 10-15 knots, depending on sea conditions.

A typical swath width for these depths (3000-5000 m) was 10 km. Lines were run mostly to the NE and SW. The NW lines were almost directly head seas, but this was often the most efficient orientation to complete the survey. Closer spacing was necessary on the NE heading lines due to rougher seas. The SeaBeam system would lose outer beams and/or report bad data there. Editing of the data was performed by Satake, Smith, Toizumi, and Hashimoto. Final grids and maps were prepared mostly by Satake and Smith.

Products from the SeaBeam system include standard contour maps, artificially illuminated bathymetry showing texture, beam amplitude, and sidescan data. The bathymetry data represents 120 data points per sonar ping, while the sidescan data contains 2000 pixels per ping. Both data types are included in the same binary SeaBeam file. The sidescan data is better at distinguishing between bare rock and sedimented areas, as well as highlighting small blocks, structural lineations, fault scarps, and steep slopes.

Nuuanu, Wailau, and North Arch areas

SeaBeam coverage was added to all perimeters of the 1998 *Kairei* survey over the Nuuanu and Wailau debris avalanche deposits during legs 1B and 2A. Notably, part of the Koolau platform west of Kahuku to nearly 158°30W was added to the database. Combined with the *Kairei* survey, a total of ~50,000 km^2 off the northern coasts of Oahu and Molokai have been mapped. The surveyed area comprising the Nuuanu and Wailau landslides was nearly doubled from last year, with the addition of ~15,000 km^2 over the North Arch lava flow which was mapped this year for the first time in detail. The sidescan component of the SeaBeam 2112 system proved invaluable on the North Arch because of the low relief and high backscattering nature of the lava flows.

Hilina, Loihi, Puna Ridge, Alika, and Mauna Kea/Kohala areas

The area mapped with SeaBeam was extended in all directions from the southeast flank of the island of Hawaii during legs 1A, 2A, and 2B. Combined with the *Kairei* survey, approximately 49,000 km^2 of the south, eastern, and northeastern seafloor around Hawaii island have been mapped with multibeam. The mostly flat region southeast of the Hilina slump was filled in out to 18°10'N and 154°W, the Puna Ridge survey was completed (north side), Hilo Ridge and the eastern submarine flanks of Mauna Kea and Kohala volcanoes were surveyed north to nearly 20°30'N. Additionally, ~4100 km^2 of the Alika II debris avalanche chute and deposit off the Kona (west) coast were re-mapped in order to gain the sidescan component which was absent in previous multibeam surveys of the slide complex using an early model SeaBeam system. A survey of the northern portion of the South Hawaii Fracture Zone was carried out, but its southeastern extent could not be completed because of transit time constraints during nighttime operations. Finally, attempts were made to make adjacent transit swaths over Mahukona submarine volcanic cone (west of Kohala). However, time constraints during rapid transits did not allow for much deviation from the straightest route between Oahu and Hawaii, thus little gain in coverage was accomplished. A total of ~21,000 km^2 of mapped area around the island of Hawaii this year was added to the *Kairei*'s ~18,000 km^2 already existing in our database.

Summary of the bathymetric map

The bulk of the surveying, which consisted of extending coverage of the Hilina, Nuuanu, Wailau, and Alika landslide deposits, did not produce as provocative a picture as the *Kairei* expedition and previous multibeam sonar surveys since we were mapping the lateral and distal portions. However, newly surveyed areas including the North Arch lava flows, Hilo ridge, and the eastern flanks of Mauna Kea and Kohala have provided some new data which looks quite intriguing at first glance.

SeaBeam 2112 multibeam sonar

The SeaBeam 2112 multibeam sonar seafloor mapping system was run every night from August 01 to September 22 except while in port. Dedicated surveying took place for 12-14 hours every night, roughly between 1800 to 0600 or 0800, depending on if a dive site survey needed to be run. Several maintenance days were also dedicated to SeaBeam surveying. Typical survey speeds ranged from 10-15 knots, depending on sea conditions.

A typical swath width for these depths (3000-5000 m) was 10 km. Lines were run mostly to the NE and SW. The NW lines were almost directly head seas, but this was often the most efficient orientation to complete the survey. Closer spacing was necessary on the NE heading lines due to rougher seas. The SeaBeam system would lose outer beams and/or report bad data there. Editing of the data was performed by Satake, Smith, Toizumi, and Hashimoto. Final grids and maps were prepared mostly by Satake and Smith.

Products from the SeaBeam system include standard contour maps, artificially illuminated bathymetry showing texture, beam amplitude, and sidescan data. The bathymetry data represents 120 data points per sonar ping, while the sidescan data contains 2000 pixels per ping. Both data types are included in the same binary SeaBeam file. The sidescan data is better at distinguishing between bare rock and sedimented areas, as well as highlighting small blocks, structural lineations, fault scarps, and steep slopes.

Nuuanu, Wailau, and North Arch areas

SeaBeam coverage was added to all perimeters of the 1998 *Kairei* survey over the Nuuanu and Wailau debris avalanche deposits during legs 1B and 2A. Notably, part of the Koolau platform west of Kahuku to nearly 158°30W was added to the database. Combined with the *Kairei* survey, a total of ~50,000 km^2 off the northern coasts of Oahu and Molokai have been mapped. The surveyed area comprising the Nuuanu and Wailau landslides was nearly doubled from last year, with the addition of ~15,000 km^2 over the North Arch lava flow which was mapped this year for the first time in detail. The sidescan component of the SeaBeam 2112 system proved invaluable on the North Arch because of the low relief and high backscattering nature of the lava flows.

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SINGLE CHANNEL SEISMIC

We surveyed Nuuanu Landslide area and Hilina slump area by using Single Channel Seismic(SCS) in YK99-08. The construction of the outline of Single Channel Seismic used for the "Figure SCS" is shown. We used G.I.GUN as the sound source and Hydrophone Streamer Cable as a receiving part of the submarine reflection wave. A reflection wave from under the bottom of the sea or the bottom of the sea received by Streamer Cable is processed to the filter and the amplification, and finally recorded by on board computer. The recorded data is reproduced by the computer and the thermal printer.
We surveyed two lines in each Nuuanu(Sep. 10)and Hilina(Sep.7).The result is shown in the "Figure SCS2".

Gravity

The LaCoste and Romberg shipboard gravity meter was used throughout the survey during the Leg 1(August 1 to 25). For the present we have not processed and analyzed the data set yet.

Magnetics

Magnetic data were collected by using a proton surface towed total field magnetometer with the sensor streamed about 400 meters behind the ship and a Shipboard Three-Component Magnetometer (STCM). The data collection carried out during the most case of transit from island to survey area, nights and maintenance days for SHINKAI 6500.

Chapter 4

SHINKAI 6500 DIVE

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1A

DIVE No.	490	DATE	1999/8/2
	NAME	AFFILIATION	
Japanese English	柴田　次夫 Tsugio Shibata	Department of Earth Sciences Faculty of Science, Okayama University	
SPECIALTY	Petrology		
PURPOSE	Geological mapping and rock sampling		
AREA	Loihi Seamount, located 34km south of the Island of Hawaii		
SITE	Basal region of Loihi South Rift		

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	18°44.5' N	155°11.4' W	11:59	4684 m
LEAVING	18°45.7' N	155°11.4' W	15:18	4256 m

DIVE DISTANCE:	2500 m	DEEPEST POINT:	4684 m

DIVE SUMMARY

We landed on the south-dipping slope at the depth of 4684m. From this point, we took a course due north along a small, protruding ridge and made a nearly straight, northward traverse of ca. 2.5km. This dive achieved the following objectives:

1) In order to obtain information for geological mapping, we observed and videotaped volcanic constructions, tectonic features, and sediment distributions on the small, protruding ridge between the water depth of 4680 and 4198m at the basal portion of Loihi South Rift. The visual observation during the dive revealed that lava flows with different ages occur in the area.
2) We collected rock specimens at 9 sites for further petrological and geochemical studies on shore. On-board descriptions indicate that these rock specimens are mostly picrites with abundant olivine phenocrysts and glassy rind.
3) We left a marker at the site where we ended our survey.

PAYLOAD	2 sample baskets, 1 sample container with lid, 3 push core sampler, 1 temperature probe, 1 marker
VISUAL RECORDS	VTR1 2 　 VTR2 2 　 STILL CAMERA 400 　 ONBOARD CAMERA YES
SAMPLE	Organisms: 　 Rocks: 9 　 Cores: 　 Water: cc Sediments: 　 Others: 　 TOTAL:
VIDEO HIGHLIGHTS	1）Lava flows with different ages 　 2）Lava tubes 　 3）Pillow buds
KEY WORD	Picritic Basalt, Loihi South Rift, Magmatic Evolution

DIVE SUMMARY AND RESULTS

Abstract

Dive #490 was conducted in the area at the basal portion of Loihi South Rift on August 2, 1999. We landed on the south-dipping slope at the depth of 4684m. This landing site is located in the depth zone intermediate between those of the two KAIKO dives (K94 and K96) conducted last year. From this point, we took a course due north along a small, protruding ridge and made a nearly straight, northward traverse of ca. 2.5km. This dive achieved the following objectives:

(1) In order to obtain information for geological mapping, we observed and videotaped volcanic constructions, tectonic features, and sediment distributions on the small, protruding ridge between the water depth of 4680 and 4198m at the basal portion of Loihi South Rift. The visual observation during the dive revealed that lava flows with different ages occur in the area.

(2) We collected rock specimens at 9 sites for further petrological and geochemical studies on shore. On-board descriptions indicate that these rock specimens are mostly picrites with abundant olivine phenocrysts and glassy rind.

(3) We left a marker (#1) at the site where we ended our survey.

概要

しんかい 6500 の第 490 潜航を 1999 年 8 月 2 日にロイヒ海山南リフト基底部で実施した。この潜航では，水深 4684m のロイヒ海山基底部南斜面に着底し，そこから北方に向かって斜面を登りつつ約 2.5km にわたって潜航調査をおこなった。この潜航調査において以下の成果を得た。

(1) 火山地形や溶岩流の形態，堆積物の分布，テクトニックな構造などについて目視観察をおこなうとともにビデオ映像，スチル写真として記録した。また，被覆する堆積物の厚さや溶岩流の表面の状態に基づいて，噴出時期の異なる溶岩流の存在を推定した。

(2) しんかい 6500 の調査トラックに沿い，およそ 100～300m 離れた 9 地点から岩石を採取した。これらの岩石は，火山ガラスのリムを有し，多量のカンラン石斑晶を伴うピクライト質玄武岩である。

(3) 離底点にマーカー(＃1)を設置した。

Video Highlights (Dive #490, 2 August 1999)

(1) Start: 12:12:20, End: 12:12:45; Camera #2

This portion of video-recording shows that barely sedimented pillow lavas rest directly on the lobate pillow lavas that are covered with sediment completely. It is thus inferred that two generations of lava flows occur here. This is located ca. 150m north of the landing site.

(2) Start: 13:59:13, End: 14:00:00; Camera #2

This portion of video-recording shows elongated lava tubes aligned subparallel to each other. These lava tubes are draped over a slope, pointing southward. These lava tubes can be used to infer lava flow directions.

(3) Start: 14:43:50, End: 14:48:08; Camera #2

This portion of video-recording shows how Shinkai 6500 collects a rock sample with the manipulator. The sample being collected is a piece of pillow finger or pillow bud sticking out on the lava flow surface.

Dive Results

Purpose and Dive Plan

The prime objective of Dive 490 was to obtain geologic information in the area along the southward extension of the South Rift at the basal part of Loihi volcano and to collect well-located rock samples there. It is our intention to use these collected samples for examining and better defining spatial distributions as well as stratigraphic relation of lava flows with different magmatic lineages.

We planned to land on the seafloor at 18º44.5'N, 155º11.2'W and then to steer SHINKAI 6500 approximately to the north as faraway as possible until the survey time runs out. This survey line is located on a small ridge-like topographic feature at the water depth of ca. 4700m or shallower in the southern basal apron of Loihi volcano; in addition, it is located in the depth zone intermediate between those of the two KAIKO dives (K94 and K96) conducted last year. The survey lines of the above three dives (i.e., two KAIKO and one SHINKAI dives) are aligned north-south in echelon. Among other reasons, this particular target site was selected, based on the following: (1) in contrast to the shallower portions of Loihi volcano, its deeper parts are relatively less explored and few submersible dives were made over the water depth of 2000m; hence, the rock samples collected so far are not well located; (2) the bulk rock chemistry of picritic samples obtained during the two KAIKO dives indicate that the lava flows exposed in these two dive areas show different magmatic lineages; so, the rock samples to be collected was going to be an invaluable supplement to the existing rock collection; and (3) it is suggested that this area might be the site where lavas could have been extruded during the 1996 summit collapse of Loihi (A. Malahoff, personal communication); thus, if this is the case, we expect very fresh lava flows are exposed in this area.

The main purpose of this dive is threefold:

1. Observe and videotape volcanic constructions, tectonic features, and sediment distributions along the survey line, in order to obtain information on the geology of the basal part of the Loihi South Rift
2. Collect fresh rock samples to study petrologic character of magma erupted at the deeper parts of the South Rift
3. Attempt finding a new hydrothermal venting site and, if any, to measure fluid temperatures and set a marker for another Shinkai dive.

Payloads:

1. Sample basket	2
2. Sample container with lid	1
3. Push core sampler	3
4. Temperature probe	1

Topography

The Kairei SeaBeam map indicates that the South Rift of Loihi volcano is well defined as topographic highs at depths shallower than 3100m. Below this depth, however, the rift zone is not clearly defined in terms of topography since the rift zone becomes wider like a fan as it deepens and there exists no distinct topographic high in this area. The two small ridges we surveyed during the two Kairei dives (K94 and K96) are possible southern extensions of the Loihi South Rift. During these dives, however, we very rarely observed along-strike (i.e., parallel to the ridge direction) fissures and fault escarpments; and hence we are presently not sure if either of the two small ridges corresponds to the currently active rift zone. The small ridge we surveyed during this Shinkai Dive #490 is also a possible southern extension of the South Rift. During Dive #490, we did not observe any along-strike fissures and/or fault escarpments; thus, it again appears that this small ridge does not correspond to the currently active rift zone.

Shinkai 6500 landed about 100m off the target point at the depth of 4684m. From this point, we started climbing up the slope northward. The overall topography we encountered along the survey line is southward-dipping, generally steep slopes, as we may expect from the dive site that is located at the southern basal apron of Loihi volcano. The point where we left the bottom was the shallowest we encountered during this dive; thus, the topographic profile along the nearly straight Shinkai track is rather regular and simple, becoming shallower northward with minor steps, benches, and shallow topographic depressions.

At several locations, we came across topographic depressions with several tens of meters across and ca. 20 to 50 meters deep. As we simply crossed the depressions, we were not able to define if these are topographically circular pits or elongated troughs/trenches. It appears that the walls of these depressions are generally very steep, being nearly vertical in many places, and we observed pillow lavas and lava tubes piled up on the walls. These pillow lavas are mostly intact, though some show broken surfaces. Although the exact nature of these depressions is not certain at present, it is unlikely that these are collapsed lava lakes. This inference is based on the observation that there are no horizontal ledges on the walls.

Geology

The seafloor at the landing site is covered almost completely by a thin blanket of light-gray sediment. Sediments are ubiquitously present throughout the area surveyed during this dive; however, the sediment thickness is not uniform and changes from place to place. The changes in thickness are not regular and simple. In some places, the sediment blanket is thick enough to cover the surface textures of lava flows completely and to fill the spaces and pockets in between pillow lavas, so that we could not see the striations, cracks, roughness or other lava flow surface features. In other places, sediments are barely present and the fresh glassy surface of lava flows are well exposed. The sediment covered zones alternate intricately with the less sedimented zones along the survey line; however, as pointed out in Video Highlights, in some places we noted that barely sedimented pillow lavas rest directly on the lobate pillow lavas that are covered with sediment completely. From this sort of observation, we infer that at least three generations of lava flows occur in this area; i.e., (1) completely sediment-covered lava flows, (2) those with less sediment and visible surface textures, and (3) barely sedimented lava flows. In several places, however, it is difficult to define which one of these three categories the lava flows belong to with visual observation alone. Also, the third lava flows are characterized by numerous fingers or pillow buds protruding on the lava flow surface, which were oozed out through cracks after the outer rind of lava flows solidified. The first and second lava flows occur alternately in the area up to ca. 1400m from the starting point. From there, we have the second lava flows alone exposing in the area of approximately 300m length along the survey line, and then the third lava flows occur toward the point where we concluded our observation.

The site where we ended our observation is situated only ca. 600m away from and on the same south-dipping slope as the area we surveyed during KAIKO dive #94. The observation we made during the KAIKO dive indicates that barely sedimented, young pillow lavas outcrop on this south-dipping slope. It is thus most likely that the lava flow field of the above third category represents a continuation of that observed during the KAIKO dive.

Generally, the lava morphologies we encountered during this dive are represented by pillow lavas or lava tubes on steep escarpments and nearly vertical cliff, and they are represented by lobate pillows on gentler slopes. As the area surveyed during this dive is predominantly characterized by steep slopes, pillow lavas and lava tubes overwhelm the other types of lava morphology. Also, lava protrusion is commonly observed throughout this area. This type of lava morphology is formed while the outer rind of lava flows has solidified but the magma inside is still molten. As the pressure of the inside magma increases, it breaks the outer rind and oozes out like toothpaste. Since steep slopes provide a favorable situation for such lava protrusion as accumulating magma on the slope increases its pressure, we infer that the lava flows of this area extruded on the slopes similar to what we observed during the dive. In a few cases, lava tubes tend to align subparallel to each other. In this regard, most remarkable is the draping, elongated lava tubes that occur on the gentle slope about 1400m north of the landing site. These lava tubes elongate approximately north-south, pointing southward; apparently, this may suggest that molten magma was supplied from north and flowed down the slope southward. Very rarely we spotted a small area of wrinkled, folded sheet flows.

In several places, we came across a pile of basalt rubble. The basalt rubble is commonly found at the foot of wall of topographic depressions. No sediment cover is observed on the basalt rubble. In addition, we observed a chaotic mixture of basalt boulders to finer grained material (landslide debris) on the slope over the pile of basalt rubble.

During the dive, we encountered neither open fissures nor obvious fault escarpments. As noted already, we came across several topographic depressions, and these could be of tectonic origin.

Although we noted yellow stains on the side of pillow lavas in some places, we did not came across any active hydrothermal area, nor dead chimneys or other remnants of hydrothermal activity.

Biology

During the dive, we spotted only a couple of red shrimps and deep-sea fishes; organisms not indicative of hydrothermal areas, however.

Video Log DIVE #490, 2 August 1999, #2 Camera (Observer: T. Shibata)			
Time	Depth (m)	Sub. Heading (°)	Descriptions
			(Videotape #3/4)
11:59:00	4680	336	Ocean floor in sight.
11:59:10	4684	330	Landed at the target point. Rounded, intact pillow lavas with slight sediment.
12:01:30	4684	286	Started rock sampling.
12:04:36	4683	288	Completed sampling- sample #1.

12:07:40	4682		Set the heading north and started steering.
12:08:30	4677	320	Elongated, slightly flattened pillow lavas covered almost completely with thin veneer of sediment.
12:12:27	4670	0	Moved into a pillow lava field with relatively slight sediment.
12:12:46	4666	0	Pillow lava protrusion. Its morphology indicates it protruded after its outer shell had been solidified and cracked.
12:13:47	4664	0	Steep escarpment with intact pillow lavas.
12:15:42	4655	359	Rounded pillow lavas with thinner sediment cover.
12:20:58	4657	307	Collected a piece of pillow lava- sample #2. Also, pillow lava protrusion.
12:23:58	4651	314	Resumed steering.
12:25:02	4648	0	Elongated pillow lavas and lava tubes in subparalell alignment on the steep slope. Some pillow lavas show distinct striations.
12:27:27	4646	0	Elongated, intact pillow lavas on the gentle slope.
12:28:35	4641	0	Steep escarpment with intact pillow lavas. This was seen only through the observer's window.
12:30:15	4651	2	Pillow field with thick sediment.
12:31:50	4649	357	Elongated pillow lavas and lava tubes with relatively thick sediment.
12:32:08	4646	1	Basalt rubble with broken pillow fragments.
12:33:14	4632	0	Chaotic mixture of large blocks (pillow lava) to fine-grained material.
12:34:25	4619	357	Lost the view of seafloor out of sight.
12:35:14	4610	1	Elongated pillow lavas with various sizes.
12:36:30	4607	0	Intact, elongated pillow lavas. Some show protrusion morphology.
12:38:36	4598	352	Flattened, lobate pillow lavas on the gentle slope.
12:38:56	4597	340	Started rock sampling.
12:40:13	4598	316	Collected a piece of pillow lava- sample #3. Cracks on the surface of pillows (due to inflation?) are visible.
12:43:10	4598	14	Relatively flat area with rounded, flattened pillows. Thin veneer of sediment cover.
12:46:33	4594	0	ca. 13m-deep depression with 100m width
12:47:09	4595	0	Lost the view of seafloor out of sight.
12:48:18	4612	0	Went down to the bottom of the depression. Basalt rubble at the foot of the wall.
12:52:19	4584	1	The rubble zone changed into that of a chaotic mixture with large blocks (pillow lava) to fine-grained material.
12:55:30	4574		Attempted collecting a sediment sample by using the push corer.
12:59:00	4573	113	Gave up collecting a push core sample.
12:59:29	4571	118	Basalt rubble with broken pillow fragments.
13:01:20	4558	8	Rounded pillow lavas exposed on the vertical wall. Some pillows show broken surfaces.
13:01:40	4549	358	Lost the view of seafloor out of sight.
13:02:39	4541	28	Elongated pillow lavas. Some are broken.
13:04:18	4518	1	Nearly vertical cliff. Broken pillow lavas.
13:05:07	4507	359	Piles of intact pillow lavas and lava tubes.
13:06:55	4504	6	Started rock sampling.
13:15:13	4501	13	Collected a rock sample- sample #4.

13:15:20	4500	17	Lobate pillow lavas with thin veneer of sediment cover.
13:17:40	4502	359	Depression with ca. 270m in width in the direction of movement. Lost the view of seafloor out of sight.
13:23:16	4531	359	Arrived at the bottom of the depression. Talus deposit.
13:23:53	4529	353	Talus deposit.
13:24:38	4522	2	Broken lobate pillow lavas with sediment cover.
13:25:39	4520	0	Pillow lavas showing protrusion morphology.
13:26:04	4519	0	Intact pillow lavas.
13:27:23	4518	6	Fissure trending NNW.
13:27:56	4518	359	Lobate pillow lavas with thin veneer of sediment cover.
13:28:56	4515	1	Pillow lavas. Some show protrusion morphology.
13:31:59	4496	359	This portion of seafloor is deeper than the surroundings.
13:33:00	4494	1	Lost the view of seafloor out of sight.
13:33:55	4494	4	Intact, elongated pillow lava field.
13:35:42	4492	12	Started rock sampling.
13:38:40	4493	0	Collected a rock sample- sample #5.
13:41:44	4484	0	Intact, elongated or rounded pillow lavas.
13:42:52	4478	1	Lobate pillow lavas with thin veneer of sediment cover.
13:44:41	4480	0	Yellow stains on the surface of pillow lavas.
13:51:30	4440	0	Lobate pillow lavas.
13:51:35			(EOT)
			(Videotape #4/4)
13:52:23	4441	359	Flattened pillow lava field. Some show protrusion morphology.
13:53:56	4432	359	Depression.
13:54:00	4432	359	Lost the view of seafloor out of sight.
13:55:19	4433	0	Pillow lavas on a steep cliff.
13:55:35	4434	359	Lost the view of seafloor out of sight.
13:55:52	4435	1	Lobate pillow lavas and lava tubes.
13:59:23	4442	0	Lava tubes aligned parallel to each other were draped over a slope.
13:59:44	4440	2	Inflated lava tube.
14:00:15	4438	4	Basalt rubble.
14:02:00	4434	350	Stopped for rock sampling.
14:07:37	4426	343	Collected a piece of pillow lava- sample #6
14:10:58	4418	1	Resumed steering. Lava tube filed.
14:11:44	4416	349	Set the heading at 350 °
14:12:20	4418	351	Pillow lavas.
14:13:50	4413	350	Wrinkled, folded surfaces on sheet flows. Also, broken sheet flows.
14:14:22	4412	350	Intact pillow lavas.
14:17:10	4399	349	Stopped for rock sampling.
14:22:11	4400	309	Collected a piece of pillow lava- sample #7
14:23:54	4396	319	Depression.
14:24:16	4393	341	Lost the view of seafloor out of sight.
14:29:36	4406	340	Edge of depression.
14:29:48	4405	340	Pillow lavas with fingers.
14:30:08	4404	338	Pillow lava with distinct striations on the surface.
14:33:41	4400	342	Yellow stains on the surface of inflated pillow lava.
14:34:30	4400	325	Stopped for rock sampling.

14:39:13	4395	331	Gave up rock sampling.
14:39:40	4393	337	Resumed steering. Pillow lavas with fingers sticking out.
14:43:37	4383	20	Stopped for rock sampling.
14:48:08	4383	334	Collected a piece of pillow finger- sample #8.
14:50:41	4381	350	Resumed steering.
14:55:43	4346	350	Lobate pillow lavas and lava tubes.
14:55:55	4345	350	Collapsed pit (lobate pillow)
14:58:44	4326	351	Basalt rubble.
14:59:18	4320	332	Stopped for rock sampling.
15:00:46	4318	283	Collected a piece of pillow lava from a pile of basalt rubble- sample #9.
15:03:58	4310	13	Resumed steering.
15:07:36	4291	349	Pillow lavas with fingers.
15:14:45	4265	325	Left a marker (#1) at this site.
15:17:45	4256	32	Wrinkled, folded surfaces on sheet flows.
15:18:10	4255	33	Left the bottom.
15:18:32	4248	33	Seafloor out of sight.
15:19:40	4198	39	End of video-recording.

Dive Log Sheet of SHINKAI 6500
HAWAII Leg 1A

DIVE No.	6K-491	DATE	99/8/3
	NAME	AFFILIATION	
Japanese English	海野　進 Susumu UMINO	静岡大学理学部生物地球環境科学科 Department of Biology and Geosciences Shizuoka University	
SPECIALTY	Volcanology		
PURPOSE	To examine constituents of conical mounds on the south rift zone of Loihi and to see how lava flow morphology changes with topography		
AREA	Lower south rift zone of Loihi Seamount		
SITE			

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	18° 45.9' N	155° 9.7' W	11:56	4334 m
LEAVING	18° 46.2' N	155° 10.7' W	15:29	4044 m

DIVE DISTANCE:	2600 m	DEEPEST POINT:	4334 m

DIVE SUMMARY

Dive track was along an ESE-WNW-trending ridge passing through two small cones, located to the east of the shield cone surveyed by ROV Kaiko last year (K94). Both cones are fringed with elongate pillow flows directing downslope, capped by bulbous to lobate pillows and pahoehoe lobes. Sheet flows with wrinkled surfaces and inflated pahoehoe lobes were seen on the summit and mid-slope of the east cone. Within a single compound flow, lava morphology was observed to change according to the slope of the basement from elongate pillows through bulbous pillows to inflated pahoehoe lobes and lobate sheets. However, the summit of the west cone is mainly covered with bulbous pillows and lobate pahoehoe flows, suggestive of diminishing effusion rate at the end of the eruption.

PAYLOAD								
VISUAL RECORDS	VTR1	2	VTR2	2	STILL CAMERA	400	ONBOARD CAMERA	NO

SAMPLE	Organisms:	Rocks: 7	Cores:	Water: cc
	Sediments:	Others:	TOTAL: 7	
VIDEO HIGHLIGHTS	1）11:58-12:09	2）12:11-12:14	3）12:52-13:00	
KEY WORD	Shield cone, lava morphology, pahoehoe lobe, pillow lava, sheet flow			

Results of Dive #491

Date: Aug 3, 1999
Place: Lower south rift zone of Loihi seamount
Pilot: Yoshitaka SASAKI Co-pilot: Itaru KAWAMA
Observer: Susumu UMINO

Abstract

Dive track was along an ESE-WNW-trending ridge passing through two small cones, located to the east of the shield cone surveyed by ROV Kaiko last year (K94). Both cones are fringed with elongate pillow flows directing downslope, capped by bulbous to lobate pillows and pahoehoe lobes. Sheet flows with wrinkled surfaces and inflated pahoehoe lobes were seen on the summit and mid-slope of the east cone. Within a single compound flow, lava morphology was observed to change according to the slope of the basement from elongate pillows through bulbous pillows to inflated pahoehoe lobes and lobate sheets. However, the summit of the west cone is mainly covered with bulbous pillows and lobate pahoehoe flows, suggestive of diminishing effusion rate at the end of the eruption.

要旨

潜航は第９４かいこう潜航調査（K94）によって探査された小円錐状溶岩丘から東南東に延びる尾根を形成する２つの小丘にそって行われた．東西どちらの小丘も斜面と裾野は伸長した枕状溶岩で覆われ，頂上平坦部には丸みをおびた枕状溶岩やパホエホエ溶岩が見られる．同一の噴火で形成されたと考えられる溶岩中でも，基底面の傾斜に伴って溶岩形態が系統的に変化する様子が観察された．従って，溶岩形態を左右する要因としては噴出率だけでなく，傾斜が重要であることが明らかとなった．しかしながら，西側の小丘頂上は主として丸みをおびた枕状溶岩で覆われている．これは噴火最末期へ向けて噴出率が低下したためと思われる．

Video Highlights

11:58-12:09 Camera 1 & 2: Channellized sheet flow with wrinkled surface; broken levee on the left, covered by elongate pillows.
12:09 Camera 1 & 2: Broken pillow rubble at the bottom of pillow flow front
12:11-12:14 Camera 1 & 2: Intact elongate pillows; white materials along cracks and between pillows (zeolite?).
12:16-12:35 Camera 1 & 2: Elongate and lobate pillows covering pahoehoe lobes; Some pillows are hollow.
12:52-13:00 Camera 1 & 2: Hummocky terrain on the ridge, covered with inflated & hollow lobes, lobate sheet flows. Some hollow lobes are collapsed.
13:50-13:53 Camera 1 & 2: Knobby & corrugated bulbous pillows; Knobby abundant
13:53 Camera 1 & 2: Tangled knobby & elongate pillows
13:58 Camera 1 & 2: Wrinkled, folded sheet beneath pahoehoe & pillows; gradually changed from pillow field downslope
14:18-14:25 Camera 1 & 2: Inflated pahoehoe lobes with sporadic wrinkled surfaces; yellowish materials along cracks and between lobes

Purpose of Dive#491

SeaBEAM survey on the south rift zone of Loihi seamount by Kairei cruise KR98 revealed a prominent topographic similarity exists between the Loihi south rift and the Puna Ridge, submerged extension of the East Rift Zone of Kilauea. Both rift zones have a dense population of conical seamounts up to 2 km in diameter, which is less common in the subaerial portion of the rift zones. These features are also common to slow spreading ridges such as the Mid-Atlantic Ridge and the Reykjanes Ridge. Therefore, the existence of such conical seamounts is very important in understanding surface volcanic activity on the submarine part of the rift zone. Dives onto two such conical seamounts by unmanned submersible Kaiko showed that both features are constructive volcanic landforms mainly consisting of pillow lava. One of the cone has a summit crater filled by lobate sheets and pahoehoe lobes, overflowing downslope as pillow flows. Thus these are cone-shaped lava shields with central vents. Typical volume of the shield cones is 0.02-0.3 km^3, suggesting long sustained eruptions of several months to several years.

The purpose of the dive is: 1) To make sure if these conical seamounts are discrete shield cones, 2) to know the constituents of the seamounts and the mode of occurrence with special reference to its relationship with the position in the volcanic edifice, 3) to obtain basic data on flow lobe morphology to estimate supply rate of lava and eruptive periods.

Dive Results

Dive was done along an ESE-WNW-trending ridge passing through the summits of two small cones, which continues to the shield cone surveyed by ROV Kaiko last year (K94). This ridge might be a downrift extension of the south rift zone of Loihi seamount. After landing on a upper northeast slope of the east cone (at the depth of 4334 m), I went up to the summit of the cone and moved further to the west along the ridge until encountering the edge of the slope of the west cone. Turning around to the northeastern side of the cone, I went straight up to the summit. Then I changed heading to the west and proceeded to the slope of the K94 shield cone. I went up to the mid-slope before taking off.

Slopes of both cones are mainly covered with elongate pillows, while flat areas on the summit and ridge are underlain by bulbous pillows, sheet flows and subaqueous pahoehoe lobes. Elongate pillows on moderate to steep slopes are well oriented and directed to the summit, suggesting central vent on the top of each cone. With decreasing slope, lava morphology successively changes from elongate pillows through bulbous pillows, and to pahoehoe lobes and lobate sheets in a short distance. No apparent time gap exists among the lava sequence such as erosional contact, inter-lava sediment, or structural discontinuity, suggests that these lava types are different parts of the same compound flow. Thus, the morphological variation was mainly caused by the difference in the slope of the basement. This must be taken into account when considering the relationship between flow lobe morphology and supply rates of lava.

However, a wrinkled sheet flow was observed at the landing site in the mid-slope of the east cone, which is overlain by elongate pillows and rubble flowing downslope. This shows that the slope of the cone consists of not only pillow lava but also more fluid sheet flows with higher extrusion rates. It is suggested that the cone was formed by at least two eruptive episodes or a long sustained eruption through which effusion rates of lava significantly reduced. On the northern edge of a terrace between the east and west cones, pahoehoe sheets are covered with elongate pillows flowing down from the west. This may be a part of a buried volcanic edifice beneath the west cone.

On top of the west cone is widely covered with pahoehoe lobes and bulbous pillows, which differs from the tops of K94 and the east cones. These lavas would be the final product in the waning stage of the eruption.

Apparent alteration products are white veins (presumably of zeolite) seen on cracks of pillows exposed at the mid-slope of the east cone, and yellowish materials along cracks and between pillows on top of the west cone.

Supply Rate of Pillow Lava

I have done some geometrical measurements on some flow lobes using laser pointers as a reference scale. Optic axes of laser are set 5-cm apart and parallel to each other. Two beams were radiated on the object through the observer's window of the submersible. I selected inflated pillow lobes and measured maximum length, width and height of the lobes and the thickness of brittle fractured crust. Volumes of individual lobes were calculated assuming a cylindrical shape. Solidification time for the crust was calculated by one-dimensional conduction model including heat flux via circulation of water and radiation. Physical parameters and formulae used in the calculation were followed Umino et al. (1999). Supply rate of lava is given by the volume of the lobe divided by the solidification time of the crust.

There is a systematic correlation between the supply rate and the lobe volume. Subaqueous pahoehoe lobes have a consistently higher supply rate than subaerial ones at a given volume. All pillow lobes measured by Shinkai have very small volumes of 0.006-0.1 m^3 and variable supply rates of lava from 0.002-0.05 m^3/min, but most has 0.03-0.04 m^3/min. This supply rate is even higher than the subaqueous pahoehoe lobes. This is apparently inconsistent with the previous view that pillow lava has lower extrusion rates than pahoehoe-like sheet lobes. This is probably due to the effect of the slope: pillow lobe data have been obtained from moderate to steep slopes, while pahoehoe lobes occur on gentle and horizontal area. It is concluded that the slope is as effective as the supply rate of lava in determinig the flow lobe morphology.

Time	Depth	Heading	Field	Flow direction	Description
11:56	4334		Sheet flow		Arrived at the bottom. Broken sheet flows, light sediment
11:58-12:09	4334	**Stop**	Sheet flow:330°-270°; Pillow rubble:<270°	120°-160°	Channellized sheet flow with wrinkled surface; broken levee on the left, covered by elongate pillows
12:09	4310	270°	Pillow rubble		Broken pillow rubble at the bottom of pillow flow front
12:11	4300	264°	Elongate pillow	136°-82°	Intact elongate pillows; white materials along cracks and between pillows (zeolite?)
12:14	4298	266°	Pahoehoe		Pahoehoe flow lobes on top of the ridge; Some inflated lobes
12:16-12:35	4300	**Stop**	Elongate pillow-pahoehoe	150°	Elongate and lobate pillows covering pahoehoe lobes; Some pillows are hollow
12:35-12:40	4298	320°	Elongate-lobate pillows		Change heading; transitional from pillow to pahoehoe along the eastern edge of the ridge
12:40-12:43	4295	310°	Depression		Swim over a valley
12:43	4315	311°	Elongate pillows	130°	Climbing a steep scarf of elongated, tubular pillow mound >23m high obliquely to the flow direction; pillows are 25-40 cm across
12:47-12:50	4299	310°-> 280°	Elongate pillows	0°-10°	Change heading to upflow direction
12:50	4292	230°	Pahoehoe		Pahoehoe lobes on flat area; plates w/distinct ropey surface textures in places, moderate sediment thickness; collapsed lava tubes
12:51-12:52	4289	230°-70°	(Pahoehoe-lobate sheet)		Turning above a depression on the ridge of lobate sheet flow
12:52	4292	300°->75°	Pahoehoe-lobate sheet		Hummocky terrain on the ridge, covered with inflated & hollow lobes, lobate sheet flows
12:54-13:00	4291	**Stop**	Pahoehoe-lobate sheet		Collapsed hollow pahoehoe lobe
13:00	4290-4300	309°	Pahoehoe-lobate		Change heading; Lobate-wrinkled sheet

			sheet		flows, with collapsed pits.
13:05	4306	309°	Pillowed cone		Pillowed cone on the left, covered by pahoehoe-lobate sheet on the bottom
13:07	4312	309°	Wrinkled sheet		Wrinkled-lobate sheet flow, covering pillow lava
13:09	4316	309°	Pillows		Bulbous-knobby pillows on flat area
13:13	4322	308°	Pillowed slope	80°-120°	Elongate & knobby pillows of the western ridge; steep slope; Water unclear
13:14-13:27	4307	**Stop**	ditto		ditto
13:27	4297	309°	ditto	110°	Elongate pillows with some bulbous and flat streams
13:31	4279	310°	Pahoehoe-pillow transition	90°-130°	Wrinkled sheets under bulbous pillows; pahoehoe lobes changing into elongate pillows downward
13:33	4269	310°	Pahoehoe-sheet		Lobate sheets with boulbous pillows on top; wrinkled surfaces below pillows
13:34	4270	295°	ditto		Change direction
13:35	4271	290°	ditto		
13:37	4274	311°	Talus		Pillow rubble below steep pillow flow front
13:38	4274	309°	Pillowed slope	129°	Elongated, irregular shaped pillows exposed on steep scarf (60°-70°)
13:45	4236	311°	Pillow-pahoehoe transition	50°	Streams of pahoehoe flows among elongate and bulbous pillows
13:47	4239	311°	ditto		Elongate pillows and pahoehoe lobes from the left; swim over
13:50	4268	271°	Complex pillows	10°-20°	Change heading; knobby & corrugated bulbous pillows; Knobby abundant
13:53	4255	270°	Pillowed slope	45°-90°	Tangled knobby & elongate pillows
13:54	4251	270°	ditto	90°-110°	Well oriented eongated pillows, with occasional tangled mass of bulbrous & elongates
13:57	4217	271°-251°	ditto	160°	Smooth pillow flows on moderate slope (40°-50°); collapsed pillows draning lava inside;change heading
13:58	4202	250°	Complex field of sheet-pillow flows		Wrinkled, folded sheet beneath pahoehoe & pillows; gradually changed from pillow field downslope

14:00	4186	250°	Undirected pillows		Bulbous & lobate pillows on gentle slope; flow direction unstable; some knobby pillows protruding out from bulbous pillows
14:08	4177	251°	Pillowed slope	110°	Well oriented elongate pillows
14:09	4178	250°	ditto	110°	ditto
14:11-14:12	4175	250°->320°	Transition pillow-pahoehoe	160°-140°	Change heading; flattened pillows-pahoehoe on gentle slope
14:17	4127	327°	ditto		ditto
14:18-14:25	4123		Pahoehoe		Inflated pahoehoe lobes with sporadic wrinkled surfaces; yellowish materials along cracks and between lobes
14:25	4121	270°	ditto		ditto
14:27-14:30	4121-4141	270°-253°	Pahoehoe & bulbous		Getting down along a slope of pillows onto a col; turning left on bottom
14:35-14:42	4137	**Stop**	Pahoehoe & bulbous	220°-240°	Thick pahoehoe streams with occasional bulbous pillows covering a moderate slope
14:45	4134	270°			change course to 270
14:52	4139	271			bulbous pillows, some flattened; light to moderate sediment
14:55	4132	271			"
14:59-15:07	4126	**Stop**	Bulbous & knobby pillows		Bulbous & knobby pillows on gentle slope
15:07	4114	270°	ditto		Bulbous & knobby pillows with some sheet-like pahoehoe
15:12	4081	270°	Lobate pahoehoe		Lobate pahoehoe-pillow lava on gentle slope
15:15	4077	270°	Bulbous & knobby pillows	20°-90°	Change lava field with steepening of slope (30°); ship drifted by N-ward stream
15:19-15:24	4047	**Stop**	Bulbous & elongate pillows		Elongate pillow with less well defined orientation; bulbous pillows abundant
15:25	4044	244°	Elongate pillows	70°	
15:29	4044				Off bottom

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1A

DIVE No.	**492**	DATE	1999 August 4

	NAME	AFFILIATION
Japanese	ケヴィン　ジョンソン Kevin Johnson	Bishop Museum Dept. of Geology 1525 Bernice St.

SPECIALTY	Igneous Petrology and Geochemistry
PURPOSE	Geological mapping and sampling of volcanic structures
AREA	Northeastern end of the submarine portion of Kilauea's East Rift Zone (Puna Ridge)
SITE	Deep terraces on NE end of Puna Ridge

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	19° 48.5' N	154° 17.74' W	11:53	4202 m
LEAVING	19° 47.78' N	154° 19.36' W	15:42	3953 m

DIVE DISTANCE:	3100 m	DEEPEST POINT:	4202 m

DIVE SUMMARY

The plan for Dive #492 was to land on the distal end of the deeper of two adjacent terraces and to observe, describe, and sample a series of pillow mounds that characterize the volcanic morphology of this lower bench. We would then proceed upslope to the upper terrace. The upper terrace appeared smooth in 120 kHz deep-towed sidescan sonar with very gentle contours. We planned to describe and sample the lavas making up this surface, and to observe a large pit crater in the middle of the terrace. The purposes of this dive were:

1. Compare the volcanic morphology of the two adjacent terraces.
2. Sample lavas from the features on the two terraces to determine the relationship between the terraces and compare the ages of thee two terraces.
3. Look for any signs of recent volcanic activity or hydrothermalism.

PAYLOAD	temperature probe, 3 push cores, 2 sample baskets, 1 covered sample box
VISUAL RECORDS	VTR1 2 tapes VTR2 2 tapes STILL CAMERA 400 ONBOARD CAMERA YES

SAMPLE	Organisms:	Rocks: 6	Cores:	Water: cc
	Sediments:	Others:	TOTAL: 6	

VIDEO HIGHLIGHTS	1) 12:34:30 - 12:35:30	2) 13:11:13 - 13:13:25	3) 15:03:09 - 15:04:09

KEY WORDS	pillow lava, pillow mound, sheet flow, lobate pillow, lava tube, pit crater, hydrothermal

Dive #492 Report

Date: August 4, 1999 Place: Puna Ridge, Kilauea East Rift Zone
19˚48.5'N, 154˚17.8'W

Pilot: Suzuki Co-pilot: Iijima

Observer: Kevin Johnson (Bishop Museum and University of Hawaii)

Abstract

Dive #492 started at the lower end of a large terrace on the axis of the NE Puna Ridge at a depth of 4200 m. The purpose of the dive was to observe and sample two adjacent terraces, which have very different surface morphology as previously imaged by deep-towed 120 kHz sidescan sonar images.

The results of the dive show that the deeper terrace, occupying the NE half of the dive, is dominantly made up of a large number of individual pillow mounds ranging in height between 10 m and 60 m. Eight such mounds were encountered during the dive and rocks were collected from three of them. The shallower terrace, in the SW half of the dive, is predominantly surfaced by flattened, inflated lobate pillows and sheet flows and contains a 400 m-wide, 60 m-deep pit crater. Rock samples were taken from three locations on this upper terrace.

Water temperature anomalies were observed in the CTD data at three areas. The first anomaly is approximately 0.02-0.03˚ C and is associated with the first pillow mound. The second anomaly, which is broad and gradually reaches about 0.02˚ C, is associated with the transition slope between the lower and upper terraces. The third anomaly is also about 0.02˚ C and is centered over the pit crater.

Video Highlights (camera #2)

(1) 12:34:30 – 12:35:30
Example of pillow mound characteristic of the lower bench volcanic morphology

(2) 13:11:13 – 13:13:25
Sampling operation for pillow lava

(3) 15:03:09 – 15:04:09
Deep tensional crack along S wall of crater

Purposes of Dive

(1) Observe and describe the morphology and landforms of two large benches or terraces characterizing the deep portion of the Puna Ridge

(2) Sample rocks to determine relationship between lower and upper bench magmatic activity

(3) Collect samples for comparison with subaerial East Rift Zone lavas to help understand rift zone magma transport processes

(4) Look for water column temperature anomalies for evidence of hydrothermal activity

(5) Use observations to compare volcanic eruption processes in the deep portions and the subaerial portions of the East Rift Zone

Payload

2 – sample baskets
1 – sample container with lid
1 – temperature probe
3 – push corers

Summary of Dive Operation

Dive Plan

The plan for Dive #492 was to land on the distal end of the deeper of two successive benches or terraces and drive upslope to observe and describe a series of pillow mounds that characterize the volcanic morphology of this lower bench. The plan was to sample these pillow mounds and then to continue up the transition slope from the lower terrace to the upper terrace. The upper terrace appeared in high resolution 120 kHz sidescan records to be smooth surfaced with very gentle contours. The dive plan was to describe the nature of the lavas making up this surface, to sample them, and to observe a large pit crater in the middle of the terrace.

The purposes of this dive were:

1. To compare the volcanic morphology of the two adjacent terraces.
2. To sample lavas from the features on the terraces in order to:
   a. Determine the relationship between lavas forming the two terraces.
   b. Compare the ages of the lavas forming the two terraces.
3. Look for any signs of recent volcanic activity or hydrothermalism.

Topography

SeaBeam maps collected on this and previous surveys of this area showed rough topography with 20 m features on the lower terrace and smooth topography with a 20 m deep pit crater on the upper terrace. Dive 492 revealed a much more complex topographic character than was shown on these maps.

The lower terrace is made up of a large number of pillow mounds ranging in height from 10 m to 60 m tall that appear to have formed on the flanks of a large central edifice that makes up most of the lower terrace and rises 150 – 200 m. We encountered eight pillow mounds over the course of the dive. The flanks of the mounds are quite steep and they are spaced within 100 – 200 m of one another along the dive track. The surface of the terrace on which the mounds are built is itself rather steeply sloped relative to the upper terrace (Figure Dive 492-1, lower figure). We didn't observe any large cracks or fissures on this lower terrace.

In contrast to the large relief of the lower terrace, the upper terrace is quite level, except for a large pit crater in the center portion of the terrace. The transition from lower terrace pillow mound morphology to upper mound lobate pillow and sheet flow morphology is abrupt. The grade is very gentle and the surface is smooth. A large pit crater some 400 m across and 60 m deep was encountered in the center of the upper terrace.

Geology

Most of the seafloor in the dive area is coated with a thin dusting of sediment, but this coating is almost non-existent in many places, especially on the lower terrace. Pillow mounds on the lower terrace are characterized by steep sides that are covered with oriented, elongate pillow lava flows, and rounded summits with bulbous pillow lavas. Many of the elongate pillows are broken from the steep slopes. In general, lava tubes were not observed in association with the pillow mounds. Most pillow lavas on the lower terrace displayed well-defined extrusion striations and glassy surfaces. We infer that the lavas exposed in the pillow mound structures on the lower terrace are young relative to the lavas of the upper terrace since sediment cover is somewhat more pronounced on the latter.

The lava surfaces on the upper terrace appeared to be older than those of the lower terrace based on smoothness of the surfaces, more sediment cover, and lack of clear surface textures on the flows. However, lava samples taken from the upper terrace contained glassy rinds, so it may be that the mode of emplacement of these lavas made them appear to be older than they really are. The lava flows on the upper terrace are mainly large, flattened lobate pillows and inflated sheet flows with smooth, glassy surfaces. The surface of the upper terrace contains many collapse features such as skylights, pits, exposed lava tubes, and sunken flow surfaces. These features are characteristic of subaerial lava flows on Kilauea and indicate inflation of the flows from continued emplacement of lava under the hardened outermost crust of the flow.

We drove through a large collapse pit crater that occupies the central portion of the upper terrace. It is 400 m across and about 60 m deep. Its floor is made up of pillow and sheet flow rubble from the collapsed roof, and there is a 20 m high remnant lava mound in the central floor of the crater. The walls of the crater appear to be slumping into the center along down-stepping scarps and there are several large cracks 3 – 5 m wide, 10 – 30 m long, and 5 – 15 m deep that are calving off large sections of the south crater wall. Numerous lava tubes 0.5 – 2 m across were visible in the walls of the crater.

While there were no active hydrothermal vents or biological indicators of hydrothermal activity observed, abundant evidence for hydrothermal activity was seen in the form of orange, yellow, and reddish coatings on cracked rock surfaces and whitish efflorescence around some cracks. In addition, CTPV data showed water temperature anomalies up to 0.3˚ C in several places along the dive track (Figure Dive 492-1, upper figure and 492-2). In the figures, the light grey line is temperature data sampled at one second intervals along track and the heavy black line is a 60-point moving average of the 1-second data to smooth out spurious data spikes. These anomalies appear to be associated with significant breaks in slope and with the collapse pit. The anomalies associated with breaks in slope may reveal hydrological pathways for water flowing along contacts between adjacent terraces. The anomaly associated with the pit crater may indicate heat escaping from inflated flows making up the upper terrace and exposed in the collapse pit.

Shinkai 6500 Dive #492 Log

		Position (m)			
Time	Depth	X	Y	Heading	Description
11:53:35	4200	770	1620	250	On bottom
11:54:00					Lobate sheet, inflated paheohoe, bulbous pillows
11:54:45	4201			257	Bulbous pillows w/clear extrusion striations, very light sediment
12:00:53	4202	740	1670	256	Base of pillow mound #1, elongated pillows and pillow fragments: begin Sample #1 collection
12:01:38	4202	731	1669	256	19˚48.4966'N 154˚17.7441'W Sample #1
12:10:50	4200			244	Complete sample collection, Sample 1 - broken pillow fragment
12:14:00	4199			251	Flank of steep pillow scarp , oriented elongate pillows 5-15m long no sed.
12:16:18	4177			250	Top of scarp, flattened, rounded pillows
12:18:40	4160			257	Wire? draped on bottom
12:21:30	4145	690	1570	251	Gently sloping bulbous pillow field; probably top of pillow mound
12:24:00	4140			250	Flattened pillows
12:24:33	4140			250	Top edge of scarp; edge of pillow mound
12:26:07	4148			251	Base of pillow mound #2
12:27:00	4135			250	Driving along S side of steep pillow mound with many oriented elongate pillows
12:28:00	4134			250	W end of pillow mound slope
12:28:40	4134			250	East-facing base of pillow mound #3
12:29:00	4130			245	Climbing steep slope of pillow mound with both bulbous and elongate pillows

12:30:55	4120	570	1330	251	Top of steep wall, but still climbing more gentle slope
12:32:00	4112			269	Lobate pahoehoe-pillows
12:32:50	4110			271	Top edge of scarp; edge of pillow mound
12:34:00	4112			270	Base of pillow mound #4
12:35:20	4101	550	1180	270	Intermingled bulbous and elongate pillows with well defined striations, light sediment dusting
12:36:00	4096			270	Skirting N flank of mound
12:37:16	4099			271	Base of pillow mound #5 slope
12:38:00	4091			270	Skirting N flank of mound
12:39:49	4097			270	Base of pillow mound #6
12:40:20	4096			265	Red shrimp - camera #1
12:42:10	4084	560	980	271	Bulbous & elongate pillows; N flank of pillow mound
12:43:52	4073			270	Edge of pillow mound #6
12:47:28	4094			270	Base of pillow mound #7; bulbous pillows grading to elongate upslope
12:51:24	4071			270	Collapsed lava tube skylight ~1 m across; many collapse features on pillow mound summit
12:52:00	4072	550	620	270	Lobate sheet morphology spanning upper portion/summit(?) of pillow mound #7
12:55:00	4070	550	570		Pillowy lobes on lobate sheet
13:11:13	4068	550	570	333	Sample #2 - elongate pillow field at top of pillow mound 7
13:14:00	4069	546	569.3		19˚48.3960'N 154˚18.3739'W Sample #2
13:17:00	4068			275	Leave sample-2 site; descend from pillow mound #7
13:25:40	4110			200	Bulbous and elongate pillows on base of pillow mound #8
13:27:00	4099			200	Top of pillow mound #8
13:28:30	4110			199	Descending pillow mound #8; bulbous pillows on level bottom

13:29:15	4111			199	Abrupt change to pillow talus on gentle slope, base of steep pillow scarp; shrimp
13:29:40	4111			199	Start of elongate pillows on slope; broken pillow cross-sections; lava tubes 0.5-1.0 m
13:32:10	4076			201	"Elephant trunk" elongate pillows
13:33:00	4065			201	Top of scarp - rounded pillows
13:35:00	4072			202	Bulbous pillows on flat bench surface
13:35:42	4072			202	Start of shallow slope to next bench; bulbous and elongate pillows
13:36:00	4070	30	410	199	Bulbous and elongate pillows on slope of bench
13:36:50	4061			205	Change course to 250
13:38:00	4052			252	Top of slope - bench surface; bulbous pillows
13:42:20	4059			246	Gradual slope with smooth, elongate pillows
13:44:00	4048			250	Transition to smooth, inflated, flattened lobate pillow lavas on sheet flows
13:44:14	4047			250	Collapsed lava tube skylight ~4 m across; many collapse features
13:45:40	4041	80	-150	250	Scattered, flattened pillow lavas on sheet flow; slam
13:46:43	4041			250	Base of slope, oriented elongate pillows
13:49:42	4010			250	Top of slope - elongate, broken pillows grading to bulbous pillows
13:50:00	4009	-40	-160	250	Bulbous pillows
13:51:15	4007			250	Change course to 240; lots of snow in the water column
13:56:00	4038	-260	-230	238	Bulbous and elongate pillows
14:02:38	4034	-240	-220	159	Closely spaced elongate and bulbous pillows; Sample #3 from crust of striated bulbous pillow
14:04:00	4035	-240	-217.3		19˚47.9699'N 154˚18.8245'W Sample #3
14:10:00	4035			270	Closely spaced elongate and lobate pillows (leave sample 3 site); Course 270

14:12:45	4035			269	Base of scarp - oriented elongate pillow lavas, many broken and hollow
14:17:00	3985			269	Break in slope; pillows more bulbous
14:18:50	3987			270	Base of slope, elongate and breadcrust pillows
14:20:26	3976	-270	-370	269	Stubby elongate and breadcrust bulbous pillow lavas on shallow slope
14:22:20	3964			269	Transition to smooth, flattened lobate pillow lavas on sheet flows
14:23:46	3964			265	Broken up pahoehoe flow surrounded by inflated smooth lobates and striated bulbous pillows
14:26:00	3956			265	Inflated smooth lobate and sheet flows with collapse features and many cracks
14:28:05	3955	-250	-630	265	Smooth sheet flows with rare ropey pahoehoe surfaces
14:28:44	3957			266	Collapsed roof of lava tube; broken up sheet flow surface
14:29:10	3957			268	View edge of large collapse pit in front of sub
14:30:00	3957			269	Reverse course to 030 for sampling
14:30:53	3956			347	View along N edge of crater - collapsing wall
14:32:00	3957	-220	-660	35	Broken shelly pahoehoe sheet flow - Sample #4
14:37:00	3958	-220.6	-658.6		19˚47.9804'N 154˚19.0772'W Sample #4
14:40:00	3954			346	Leave sample 4 site; heavy snowfall
14:44:36	3977			250	Descending into collapse crater, lava rubble on gently sloping floor of crater
14:45:52	3978			250	Drop-off to lower level of crater floor visible to left of sub; lava rubble
14:46:00	3977	-220	-760	250	Rubbly lava, probably an upper level collapse bench along N margin of crater
14:50:13	4013			250	Descent into gully along N side of pit crater, remnant 2-3 m high lava ridges and mounds
14:51:35	4008	-320	-890	250	Rubbly lava; floor sloping down to the left of the sub; cross central mound on crater floor
14:52:24	4002			250	Change course to 175

14:56:28	3998			171	Deepest part of crater - floor 4032 m
14:57:45	4003			177	Steep S wall of crater; brecciated pillows
15:02:07	3970			177	Layer cake section of thin (10 cm) sheet flows about 1.5 m thick exposed in crater wall
15:03:00	3958			177	Top of wall; truncated, flattened pillows in layers
15:03:35	3959			175	Large 2-3 m wide crack calving the block from the southern wall
15:04:30	3959	-510	-930	186	Large crack, pillow lobe oozing over edge of cliff
15:06:30	3961			162	Flat surface of very large flat lobate pillow, some truncated in wall, 1.5 - 2 m x-section
15:10:07	3960			173	Sample #5 - lobate pillow on S rim of the crater, 2 pieces
15:15:00	3961	-511.3	-921.4		19˚47.8228'N 154˚19.2277'W Sample #5
15:16:00	3959			265	Drop-off to right of sub - rubble; lobate pillows to left
15:16:40	3959			198	3 m-wide crack, large sliver calving from S edge of crater; layer upon layer of lobate pillows
15:17:12	3959			194	Bulbous and elongate pillows on slope at crater rim
15:18:15	3954			238	Top of slope, lobate pillows
15:19:00	3955			261	Lobate pillows broken in half along 2 m-wide, 2 m-deep NE-SW trending crack
15:20:00	3954			241	3 m-wide, 6 m-deep NE-SW trending crack
15:21:00	3955			238	Camera 2 - broken sheets and lobate pillow plates; camera 1 - crater S rim
15:22:12	3955			237	Crater S rim, drop-off to the right
15:23:00	3955			237	Camera 2 - lobate pillow lavas with interspersed sheet flows; camera 1 - crater S rim
15:23:17	3955			215	Camera 1 - step-wise down-dropping of S wall of crater visible
15:23:47	3956			222	Large lava tube 1.5 m-wide, 0.75 m-high exposed in uppermost wall of crater
15:24:04	3955			225	Large lava tube 2.5 m-wide, 1 m-high exposed in uppermost wall of crater

15:24:38	3957	-610	-1030	205	Pillow rubble at crater rim
15:26:50	3956			242	Camera 1 - large slivers of wall 10-20 m long 1-5 m wide calving into S side of crater
15:26:55	3956			239	S rim of crater, abundant yellow hydrothermal staining on fractured pillow blocks
15:27:00	3956			242	Driving along S rim of crater, large (1.5 - 2 m) collapsed blocks on slope
15:29:30	3956	-620	-1080	283	Broken lobate pillow lavas
15:29:53	3955			289	Large opening (3 m-across) of lava tube
15:38:00	3955			303	Sampling site #6, top edge of crack at SW rim of crater
15:39:40	3955			303	19°47.7795'N 154°19.3598'W Sample #6; plate of lobate pillow
15:41:30	3953	-591.2	-1152	318	Off bottom

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1A

DIVE No.	493	DATE	1999/8/8

	NAME	AFFILIATION
Japanese	柴田　次夫 Tsugio Shibata	Department of Earth Sciences Faculty of Science, Okayama University
SPECIALTY	Petrology	
PURPOSE	Geological mapping and rock sampling	
AREA	Loihi Seamount, located 34km south of the Island of Hawaii	
SITE	Eastern basal flank of Loihi Seamount	

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	18º53.1’ N	155º09.7’ W	11:55	4513 m
LEAVING	18º53.4’ N	155º11.0’ W	15:37	3770 m

DIVE DISTANCE:	2500 m	DEEPEST POINT:	4513 m

DIVE SUMMARY	We landed on the east-dipping, steep slope at the depth of 4513m. From this point, we took a course approximately westward, climbing up the very steep slope and made a nearly straight, westward traverse of ca. 2.5km up to the depth of 3770m. This dive achieved the following objectives: 4) In order to obtain information for early stages of volcanism at Loihi, we observed and videotaped volcanic constructions, tectonic features, and sediment distributions on the small, protruding ridge between the water depth of 4513 and 3770m at the basal portion of Loihi’s east flank. In spite of steep slopes (15º-20º), the area surveyed during this dive is generally covered with thick sediment.
PAYLOAD	2 sample baskets, 1 sample container with lid, 3 push core sampler, 1 temperature probe, 1 marker
VISUAL RECORDS	VTR1 2 VTR2 2 STILL CAMERA 400 ONBOARD CAMERA YES
SAMPLE	Organisms: Rocks: 7 Cores: 2 Water: cc Sediments: Others: TOTAL:
VIDEO HIGHLIGHTS	1) Nearly vertical escarpment 2) Basalt rubble 3) Silty to clayey sediments

KEY WORD	Picritic Basalt, Loihi's East Flank, Early Magmatic Stages

DIVE SUMMARY AND RESULTS

Abstract

Dive #493 was conducted at the basal portion of Loihi’s east flank on August 8, 1999. We landed on the east-dipping, steep slope at the depth of 4513m. From this point, we took a course approximately westward, climbing up the very steep slope and made a nearly straight, westward traverse of ca. 2.5km up to the depth of 3770m. This dive achieved the following objectives:

6) In order to obtain information for early stages of volcanism at Loihi, we observed and videotaped volcanic constructions, tectonic features, and sediment distributions on the small, protruding ridge between the water depth of 4513 and 3770m at the basal portion of Loihi’s east flank. In spite of steep slopes (15º-20º), the area surveyed during this dive is generally covered with thick sediment.
7) We collected rock specimens at 7 sites for further petrological and geochemical studies on shore. Also, we collected two sediment samples with the push core sampler. According to on-board descriptions, the rock specimens are moderately altered, two of them are picrites with abundant olivine phenocrysts, and the rest are sparsely phyric to aphyric basalts.

概要

1999 年 8 月 8 日，しんかい 6500 の第 493 潜航をロイヒ海山東斜面基底部において実施した。この潜航では，ロイヒ海山東側基底部の急斜面（水深 4513m）に着底し，そこから西方に急斜面を登りつつ約 2.5km におよぶ調査をおこなった。この潜航調査において以下の成果を得た。

(4) 水深 4513～3770m の範囲にわたって，火山地形や溶岩流の形態，堆積物の分布，テクトニックな構造などについて目視観察をおこなうとともにビデオ映像，スチル写真として記録した。急斜面にもかかわらず，調査地域は厚い堆積物に被覆され，基盤を構成する溶岩は著しく急な斜面にしか露出していない。
(5) しんかい 6500 の調査トラックに沿っておよそ 100～300m 離れた 7 地点から岩石を，また 2 地点から未固結堆積物を採取した。採取した岩石は，多量のカンラン石斑晶を伴うピクライト質玄武岩および無斑晶質玄武岩である。

Video Highlights **(Dive #493, 8 August, 1999)**

(4) Start: 14:30:33, End: 14:34:40; Camera #2

This portion of video-recording shows pillow lavas exposed on a nearly vertical cliff. Such cliffs are commonly found in the Dive #493 area. This is located at the water depth of ca. 3940m.

(5) Start: 13:54:25, End: 13:58:20; Camera #2

This portion of video-recording shows piles of basalt rubble with pillow lava fragments at the foot of steep slope. As you move up further, this basalt rubble zone is changed into the pillow lava zone. This is located at the water depth of ca. 4090m.

(6) Start: 11:56:53, End: 11:59:50; Camera #2

This portion of video-recording shows how Shinkai 6500 collects a sediment sample with the push core sampler. The sample being collected is light yellowish gray, silty to clayey ooze.

Dive Results

Purpose and Dive Plan

The prime objective of Dive #493 was to obtain geologic information concerning the basal region of Loihi's east flank and to collect well-located rock samples there. Previous submersible and ROV Kaiko dive efforts mostly went into the areas along theN-S trending, arcuate rift zone of Loihi volcano. In particular, the previous two Shinkai 6500 dives (#490, #491) of the present Leg and two Kaiko dives (#94, #96) were conducted in the area along the southward extension of the South Rift at the basal part of Loihi volcano. Very few dives were so far made on the west and east flanks of Loihi volcano, and even those that were conducted at these flanks were done at the depths shallower than 2000m. Thus, well-located geologic information and hard rock samples had not been obtained from these parts of Loihi volcano. In order to examine early stages of volcanism at Loihi, it is obvious that we have to sample volcanic products formed at the early stages of its growth process.

Dive 493 was our only chance in Leg1A devoted to explore the flanks of Loihi volcano. Thus, to utilize this opportunity fully, we planned to land on the seafloor at 18º53.1'N, 155º09.6'W and then to climb up the slope westward as faraway as possible until the survey time runs out. This particular landing site was chosen, so as to collect rock samples as old as possible and to reveal stratigraphic relations of basal lava flows with different lineage. This survey line is located on the steep slope that face eastward and also along a small, ridge-like topographic feature. The actual dive was carried out approximately as planned above.

The main purpose of this dive is twofold:

1. Observe and videotape volcanic constructions, tectonic features, and sediment distributions along the survey line, in order to obtain information on the geology of the basal part of the Loihi's east flank.
2. Collect hard rock samples to study petrologic character of magma erupted at the early stages of the growth of Loihi volcano.

Payloads:

6. Sample basket	2
7. Sample container with lid	1
8. Push core sampler	3
9. Temperature probe	1
10. Marker	1

Topography

Loihi Volcano shows the overall topography with an elongated, arcuate appearance, stretching approximately north-south over 35km, and its rift zone runs parallel to this north-south elongation. Except for this N-S trending rift zone, no other currently active rift zone is known at Loihi. However, we have a ridge-like topography with the trend of approximately east-west that runs across the summit of Loihi, and some researchers of Loihi suggest that this could be either a currently inactive rift zone or an abandoned, old rift zone (M. Garcia, personal communication). Dive #943 was conducted along this small, ridge-like topography on the east flank of Loihi. The observations made during the dive indicate that no topography that is related to rifting is present in the area surveyed; however, we encountered three small volcanic cones with the height of several meters. This may suggest that the area of Dive #493 is not only simply the slope where molten magma flowed down but also the site where eruption took place and hence a rift zone could be once located.

Shinkai 6500 landed about 150m off the target point at the depth of 4513m. From this point, we started climbing up the slope westward. The overall topography we encountered during the dive is eastward-dipping, generally steep slopes (15º-20º). Thus, as we moved westward, the water depth gets shallower monotonously with almost no up-and-downs. It is no small surprise to us that in spite of such generally steep slopes, we have very thick sediment accumulation (<50cm) in this area. This rather smooth topography of the Dive #493 area is thus partly due to sediment accumulation which masks ruggedness in topogarphy, but it is mostly due to no significant tectonic displacement apparently taking place in this area. The point where we left the bottom was the shallowest we encountered during this dive; the topographic profile along the nearly straight Shinkai track is regular and monotounous, becoming simply shallower westward with only changes in slope angles (generally 15º-20º but up to 90º).

Geology

The seafloor at the landing site is covered completely with a thick layer of light yellowish gray sediment (silty to clayey ooze). The Shinkai pilot who attempted collecting sediment with the push corer at this site suggests that the sediment thickness is probably close to 40-50cm. Except for very steep slopes (>ca.50º), sediments are ubiquitously present throughout the area surveyed during this dive, and it appears that the sediment thickness does not change significantly from place to place. In terms of sediment thickness alone, therefore, we could not divide the Dive #493 area into zones with different ages. As we discuss later, however, the first two rock samples (i.e., #1 and #2) collected at the depths deeper than

4300m are petrographically different from the rest of the rock samples collected shallower than 4300m — an indication for likely presence of lava flows with different lineages and hence different ages. The lava flow morphologies, collapsed pits, if any, and other volcanic constructions are all concealed under the cover of thick sediment, so that we were generally unable to observe outcrop characteristics of the hard rock basement during this dive. The observations we made on the hard rock basment are limited only in the areas with very steep slopes and hence may not be representative of the whole area surveyed. Also, with visual observation alone, we could not note any changes in sediment types along the survey line.

The lava flows we encountered during this dive occur exclusively in the form of rounded or elongated pillow lavas. Generally, these pillow lavas are broken and some of them show radial joints with rusty brown surfaces. All these pillow lavas are exposed on very steep slopes that, in sevral cases, have a dip close to ca. 90º. As was expected, the pillow lavas look much more old compared to those observed at the Loihi's South Rift. We did not encounter any other types of lava flow morphology in this area. As noted above, the first two rock samples we collected were petrographically diferent from the rest of the samples. The first two rock samples were collected at the depths below 4300m, and the rest were sampled at the depths above 4300m. There might exist a lithologic contact between lava flows with different lineages at the depth of ca. 4300m. On-board visual description indicates that the first two rocks are picrites with abundant olivine phenocrysts, but on the other hand the rest of the samples are sparsely phyric to aphyric basalts.

In several places, we came across piles of basalt rubble with cobble to boulder size pillow lava fragments. The basalt rubble is commonly found at the foot of nearly vertical cliffs and, as we moved up, the zone of basalt rubble is generally changed into the outcrop of broken pillow lavas. In most cases, we found moderate sediment covering the basalt rubble, suggesting that unlike those observed at the Loihi's South Rift the pileup of pillow lava fragments did not take place recently. It appears that these steep cliffs are not of tectonic origin, but are formed simply by loose pillow lavas falling off from the outcrops on the originally steep escarpment. During the dive, we encountered neither open fissures nor obvious fault escarpments. As noted already, we came across three volcanic cones.

Although we noted yellow stains on the side or broken surfaces of pillow lavas in some places, we did not came across any active hydrothermal area, nor dead chimneys or other remnants of hydrothermal activity.

Biology

During the dive, we spotted only a couple of red shrimps and several deep-sea fishes. They are not organisms indicative of active hydrothermal areas.

Video Log DIVE #493, 8 August 1999, #2 Camera (Observer: T. Shibata)			
Time	Depth (m)	Sub. Heading (°)	Descriptions
			(Videotape #3/4)
11:50:53	4510	354	Landed at the target point. Silty to clayey, yellowish gray sediment.
11:56:53	4513	231	Started sampling sediment with the push corer.
11:59:50	4513	200	Completed sampling- sample #1(black).
12:03:35	4509		Set the heading to 280ß and started steering.
12:08:59	4477	281	Pillow lavas are partly exposed here, but otherwise the seafloor is covered with thick sediment.
12:11:36	4470	234	Stopped for rock sampling.
12:23:09	4467	221	Collected a piece of pillow lava- sample #1
12:26:02	4465	253	Pillow lavas are dotted about, but otherwise the seafloor is covered with thick sediment.
12:33:13	4406	280	Lost the view of seafloor out of sight.
12:35:39	4411	280	Broken lava flows covered with thick sediment.
12:36:23	4410	229	Stopped for rock sampling.
12:46:58	4411	229	Collected a piece of pillow lava- sample #2.
12:53:43	4400	292	Completely sediment covered field.
12:55:56	4392	288	Pillow lavas are partly exposed here, but otherwise the seafloor is covered with thick sediment.
12:57:24	4382	292	Completely sediment covered field.
12:58:08	4376	292	Pillow fragments are dotted about on the thickly sediment covered field.
12:59:00	4367	292	Broken pillow lavas partly exposed in the thickly sediment covered field.
12:59:51	4358	292	Completely sediment covered field.
13:05:04	4299	293	Broken pillow lavas almost completely covered with thick sediment.
13:06:20	4293	292	Pillow fragments are dotted about on the thickly sediment covered field.
13:06:51	4290	291	Basalt rubble with broken pillow fragments and with moderate sediment blanket.
13:09:31	4273	295	Broken pillow lavas exposed on a steep cliff.

13:11:32	4263	295	Broken pillow lavas with moderate sediment blanket.
13:12:37	4263	297	Stopped for rock sampling.
13:22:21	4261	343	Collected a piece of pillow lava- sample #3
13:29:59	4231	291	Broken pillow lavas are dotted about on the thickly sediment covered field.
13:32:13	4215	290	Broken pillow lavas with moderate sediment blanket.
13:34:40	4193	295	Completely sediment covered field.
13:36:15	4182	290	Broken pillow lavas are exposed here and there in the thickly sediment covered field.
13:36:50	4177	290	Basalt rubble with broken pillow fragments and with moderate sediment blanket.
13:37:22	4171	293	Broken pillow lavas exposed on a steep cliff and covered with moderate sediment.
13:40:00	4152	280	Started rock sampling.
13:43:17	4153	320	Collected a piece of pillow lava- sample #4
13:46:25	4136	271	Resumed steering.
13:46:40	4133	270	Broken pillow lavas covered with moderate sediment.
13:46:46			(EOT)
			(Videotape #4/4)
13:47:42	4127	271	Broken pillow lavas covered with moderate sediment.
13:50:38	4117	270	Completely sediment covered field.
13:52:10	4113	271	Broken pillow lavas covered with moderate sediment.
13:52:35	4111	270	Completely sediment covered field.
13:54:29	4097	271	Basalt rubble with broken pillow fragments and with slight sediment.
13:58:39	4054	281	Broken pillow lavas covered with moderate sediment.
14:00:15	4050	307	Stopped for rock sampling.
14:09:21	4052	339	Collected a piece of pillow lava- sample #5.
14:12:44	4030	270	Resumed steering. Broken pillow lavas exposed on a steep escarpment.
14:20:46	4001	270	Lost the view of seafloor out of sight.
14:25:23	3996	270	Completely sediment covered field.
14:26:11	3991	271	Basalt rubble with broken pillow fragments and with slight sediment.
14:30:33	3939	269	Broken pillow lavas exposed on a nearly vertical cliff.
14:31:58	3937	305	Stopped for rock sampling.
14:39:08	3930	335	Rusty brown stains on the surface of pillow lavas.
14:46:25	3928	355	Gave up rock sampling.

14:50:04	3901	282	Broken pillow lavas with moderate sediment.
14:52:57	3888	307	Collected a piece of pillow lava- sample #6
14:55:03	3888	328	Resumed steering
14:57:30	3877	295	Top of a pile of basalt rubble.
14:57:54	3876	289	Lost the view of seafloor out of sight.
15:00:18	3867	287	Broken pillow lavas with moderate sediment.
15:03:09	3857	290	Completely sediment covered field.
15:06:55	3855	278	Stopped for sediment sampling.
15:09:50	3855	284	Collected sediment with the push core sampler.
15:11:20	3854	291	Thick sediment
15:12:22	3845	291	Broken pillow lavas with moderate sediment.
15:16:40	3805	288	Lost the view of seafloor out of sight.
15:17:29	3805	290	Thick sediment
15:21:31	3796	307	Pillow lavas with moderate sediment. Stopped for rock sampling.
15:34:46	3772	285	Collected a piece of pillow lava- sample #7.
15:36:30	3772	281	Left the bottom.
15:42:19	3522	315	End of video-recording.

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1A

DIVE No.	４９４	DATE	1999/8/9
	NAME	AFFILIATION	
Japanese	Alexander Malahoff	Department of Oceanography University of Hawaii.	
SPECIALTY	Marine Geology and Geophysics		
PURPOSE	Geological mapping and rock sampling of younger lava flows at intermediate depth range South Rift Loihi		
AREA	Loihi submarine volcano,located 34 kilometers south of the Island of Hawaii		
SITE	Rift flow at intermediate depth		
	LATITUDE	LONGITUDE	TIME / DEPTH
LANDING	18°49.9' N	155°13.1'W	11:10 / 2541 m
LEAVING	18°50.8'N	155°14.0'W	15:54 / 2171m
DIVE DISTANCE:	2500 m	DEEPEST POINT:	24700m
DIVE SUMMARY	We landed on the South Rift at a water depth of 2541 meters,ending the dive at a water depth of 2171 meters at the summit of a large volcanic cone.The volcanic coneappears to be the scource of much of the volcanic activity that produced the pillow lavas,tube lavas,and sheet flows mapped on this dive.Tubular lavas and pillows with numerous short squeezeout tubes were the dominant rock forms observed.On steep slopes many pillows gave rise to elephant trunk tubes extending out from the vertical walls.Crumpled sheet flows were frequently observed at the base of steep walls.Eight rock specimens were collected.Only a slight cover of sediments was seen to cover the top surface of the pillows.The age estimate of the flows observed and sampled during this dive is about 100 years,based on the type and extent of benthic organisms observed during this dive.We		
PAYLOAD	Two sample baskets,three push core samplers,one grab,one pinger one thermometer probe		
VISUAL RECORDS	VTR1 VTR2	STILL CAMERA 400	ONBOARD CAMERA YES
SAMPLE	Organisms:1 Rocks:8 Cores:1 Water: cc Sediments: Others: TOTAL:10		
VIDEO HIGHLIGHTS	1) Different flows 2) Flow morphologies 3) Crumpled sheets		

KEY WORD	South Rift neovolcanic structures,lava forms and lava types at intermediate water depths,

6K494 Dive Results

Objective for dive 494

The objective for dive 494 was to obtain visual observations and rock samples from the intermediate depth range of the south rift of Loihi. For the purposes of this study, the intermediate depth range spans the water depths from 4000 meters to 2000 meters. The interest in this depth range emerges from the observational fact that the base of Loihi is characterized by the presence of picrites while a mix of low olivine content alkali and tholeiitic basalts characterizes the summit. The hypothesis being pursued is that the distribution of olivine in the standing column of magma is governed by magma density and therefore that rock samples taken from the south rift should show a systematic decrease in the olivine content with a decrease in water depth. In our current distribution in the depth range for Loihi rock samples collected by submersible, there is a complete gap in data in the intermediate depth range. The eight rock samples collected during this dive will allow us to fill this glaring data gap. The dive plan was laid out to observe the style of volcanism in this intermediate depth range and to collect rock specimens for whole rock and glass analysis.

494 Dive Observed Geology

We landed at 11:10 at a water depth of 2541 meter in a pillow lava field with one meter diameter pillows covered by a fine dusting of sediments. The presence of abundant corals showed that this particular flow was over twenty years old. The pillows showed unusual structures in the form of squeeze outs from the pillows that produced short trunk like sprouts from the pillows. The ridge slope, sloping off to the east was observed to have aslope of 70˚.At a water depth of 2519 meters sheet flows and black sand was encountered on the eastern flank of the ridge. Pillows and tubes were observed to be protruding vertically out of the ridge axis. At a water depth of 2484 meters a vertical pillow wall was encountered striking across the rift axis. Tubes were observed protruding horizontally out of the wall. The top of the wall was reached at a water depth of 2466 meters. The wall turned out to be one side of a twenty-meter high pillow mound. Descending down the slope of the mound, a section of the wall had collapsed revealing a cross section of sequential hollowed out lava tubes that had fed lava to the section that had collapsed and slumped down slope. The continuing traverse up the rift axis continued along a path with pillow cones up to forty meters high. Crumpled sheet flows were observed to have accumulated at the base of the cones. Yellow hydrothermal deposits were frequently observed deposited around the base of individual pillows. Narrow ridges and fissures striking along the rift axis were observed to be exposed at 2345 meters. These appeared to be extensional features, burried further upslope by younger lava flows, and appeared to be the eruptive sources for the axial flows and cones observed in our traverse. Two to three meter high hornitos were also observed to have formed along the rift axis. At a water depth of 2275 meters the black sand which appeared to consist of glass flakes, shimmering in the submersible lights covered most of the flat ground between the pillows. By water depth of 2223 the black sand cover edge of the flat patches of the ocean floor had decreased considerably. After climbing a slope of tube, pillow and broken sheet flow lavas, the dive traverse terminated at the summit of a large pillow lava cone, located at a water depth of 2171 meters. This particular cone appeared to be the source of the extensive lava flows encountered during the past 500 meters of the length of the traverse. The eruptive source of the black sand, presumably younger in age than the underlying lava flows and located in the vicinity of the large rift axial cone, was not found. Rocks collected during this dive were generally glassy, but the glass did not have a fresh appearance and in most hand observed determinations appeared to be vitrified. Most of the specimens appeared to have been affected by hydrothermal activity with fresh deposits of red to yellow nontronite filling cracks and joints in the specimens.

Narrative Dive Log of Shinkai 494 Dive (Alexander MALAHOFF)

TIME			Depth (in meters)	Heading (in degrees)	Narrative
Hrs	Min	Sec			
11	07	00	2537		On bottom; pillow basalts in form of wall with protrusions. Relatively fresh, some fingers.
11	08	00	2534	338	Fresh pillows; some sediment dusting. No evidence of hydrothermal activity. Dense concentration of gold coral gorgonians. Vertical walls of pillows.
11	14	00	2548		On station at base of wall; pillows 1 to 2 meters in diameter. Medium glassy. Much benthic life. Many pillows evacuated. Sampling.
11	17	00	2545		Sample of pillow fragment taken. Orange staining on sample.
11	22	00	2544		Sample of gorgonian taken.
11	28	00	2544	316	Underway. Pillows formed *in situ* along ridges and in walls of fissures.
11	30	44	2537	300	Crossed pillow ridge, apparently built by volcanism along fissures.
11	32	37	2538		Sheet flows in between pillows with elephant trunk pillows protruding out of walls.
11	34	20	2530	301	Pillows with fingers, striated.

TIME			Depth (in meters)	Heading (in degrees)	Narrative
Hrs	Min	Sec			
11	35	36	2523	301	Evidence of black, glassy shard sands in pockets between pillows.
11	36	56	2515	300	Transverse fissure with pillows in walls.
11	38	09	2505	299	Some talus in between pillows. Vertical wall.
11	40	20	2495	301	Top of wall of ridge pillows, extruded from top of ridge in form of cones.
11	41	56	2495	300	Pillow trunks and tubes extruded downslope out of vertical wall.
11	43	23	2492	300	Ridge and fissure terrain. Walls covered with gorgonians. Talus and pillows mixed.
11	46	26			Wall of unbroken pillows and tubes. Many gorgonians.
11	58	44	2465		Driving along wall of massive pillows. Slight sediment dusting.
11	56	25	2467		Sample taken from sheet flow. Orange staining.
11	59	00	2466	328	Broken pillows, top of ridge, dense gorgonians.
12	02	00	2467	301	Passed narrow fissure. Field of flattened pillows with sediments and black sand in pockets.
12	05	28	2471	301	Crossed several narrow 1-2 m recently formed fissures.
12	14	28	2497	301	Flattened pillows, fissures, sheet flows mixed with pillows. Some sheet flows stacked.
12	21	30	2479	312	Driving across ridges and walls. Climbing up wall of unbroken solid pillows protruding out of wall.
12	24	38	2456	310	Top of wall. Flattened terrain.
12	29	28	2490	314	Another wall.
12	37	00	2496	322	Pillow cones, climbing slowly.
12	38	32	2495	321	Crossing many pillow cones, 1 to 2 meters high.
12	39	56	2493	330	Elephant trunk pillows sticking out of wall.
12	47	08	2491		Small pillows sticking out of wall. Sampling.
12	51	47	2492		Sample of small pillow taken. Floor covered by small pillows 20 cm to 1 meter in diameter.

TIME			Depth (in meters)	Heading (in degrees)	Narrative
Hrs	Min	Sec			
12	57	40	2473	342	Complete swirl of pillow tubes, trunks, no talus, patches of black sand.
13	04	13	2471	008	Unbroken pillow field. Mixed small and large pillows. Top of pillow cone. Small tubular lava sampled.
13	15	38	2470	008	Unbroken pillow field. Mixed small and large pillows. Top of pillow cone. Small tubular lava sampled.
13	18	32	2468	025	Climbing wall. Many small protrusions out of pillows. Some striations.
13	28	24	2422	359	Climbing slope with tubular and corkscrew lavas intermixed with small pillows. Vertical wall, no sediments.
13	32	16	2396		Pillows, tubes cones. Climbing slope. Tubes extend downslope.
13	36	38	2385	341	Top of ridge.
13	46	35	2358	349	Field of smooth pillows. Slight dusting of sediments. Dark underside of pillows. Relatively fresh.
13	57	29	2353	339	Smooth pillow field. Black sand in pockets.
13	59	46	2349		Smooth pillows.
14	03	24	2345	346	Top of ridge.
14	08	46	2330	339	Tope of another ridge. Large patches of glassy black sand. Fissures 3m wide, greater than 5m deep, striking along ridge axis.
14	16	06	2321	338	Broken sheet flows. Overturned and squeezed sheets. Black sand in crevices.
14	23	08	2324		Sample of sheet flow taken.
14	25	26	2322	341	Pillow field. Dense patches of black sand.
14	35	00	2302	338	Sheet flows. Contorted sheets, ridges of sheets, cones of sheets.
14	38	00	2295	341	Pillow field. Extensive patches of black sand.
14	44	00	2277	340	Fresh pillow surface. Density of black sand patches increased.

TIME			Depth	Heading	Narrative
Hrs	Min	Sec	(in meters)	(in degrees)	
15	09	14	2271		Sand scoop of dark sand taken with push cover.
15	19	51	2269		Sample of crust of evacuated pillow taken.
15	27	25	2256	341	Climbing slope of mixed sheet flows and tube lavas. Piles of sheet flows.
15	38	00	2246	000	Pillow cones, pillows, black sand. Tubular trunk lavas descend down from cones, several meters high. Intense black sand cover.
15	39	47	2238	000	Intense black sand patches.
15	46	24	2221	000	Intertwined tubular lavas about 50 cm thick. Small protrusions from lava, relatively fresh, no talus.
15	50	46	2197	341	Many elephant trunk tubes descending down slope, intermixed with small pillows.
15	55	53	2169	355	Long tubular lavas descending downslope. Reached top of large cone with tubes extruding out of summit. Sample taken. END OF DIVE.

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1A

DIVE No	495	DATE	1999/8/10

	NAME	AFFILIATION
Japanese	仲　二郎	Deep Sea Research Department Japan Marine Science and Technology Center
SPECIALTY	Marine Geology	
PURPOSE	Geological mapping and rock sampling of younger lava flows at the southeast base of Kilauea East rift	
AREA	Kilauea East Rift	
SITE	Kilauea East Rift Southeast base	

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	19°28.49’ N	154°21.41’W	12:07	5568 m
LEAVING	19°29.68’N	154°21.24’W	15:19	5566 m

DIVE DISTANCE:	2200 m	DEEPEST POINT:	5568m

DIVE SUMMARY	The dive #495 identified the high backscattering intensity field which detected by GRORIA survey at the southeast base of the Kilauea east rift. The nature was flat and wide spread aphyric basaltic lava flows. These lava flow was only slightly covered by thin fine grained sediments. Based on the SeaBeam side scan and sub bottom profile record and this dive results, this lava flow seems erupted recently. However, the vent area was not identified and the relationship between the Kilauea East Rift is not certain.
PAYLOAD	Two sample baskets, three push core samplers, one grab, one heat flow meter
VISUAL RECORDS	VTR1　VTR2　STILL CAMERA 400　ONBOARD CAMERA YES
SAMPLE	Organisms:　Rocks:7　Cores:2　Water: cc Sediments:1 (grab)　Others:　TOTAL:10
VIDEO HIGHLIGHTS	1）Edge of the lava flow　2）Pillow lava area　3）Flattened lava dome

KEY WORD	Base of Kilauea East Rift, Flat lava flow, High bacscattering intensity field

Abstract

The dive #495 identified the high backscattering intensity field which detected by GRORIA survey at the southeast base of the Kilauea east rift.　The nature was flat and wide spread aphyric basaltic lava flows. These lava flow was only slightly covered by thin fine grained sediments.　Based on the SeaBeam side scan and sub bottom profile record and this dive results, this lava flow seems erupted recently.　However, the vent area was not identified and the relationship between the Kilauea East Rift is not certain.

要旨

４９５潜航はキラウエア火山東リフトの南東基底部において GRORIA による調査で認められていた強い後方散乱強度をもつ平坦な部分の確認を行った。その実体は枕状溶岩等の新鮮なガラス質急冷縁を持つ、斑晶に乏しい玄武岩の広い溶岩流であった。この溶岩流はやや細粒の堆積物に被われているが、潜航直前に実施した、サブボトムプロフィラーにる記録でも堆積物は殆ど被われておらづ、比較的最近噴出したものと思われる。しかし、今回の潜航ではその噴火場所は特定できず、そのキラウエア火山の東リフトとの関係もまだ定かではない。

Video Highlights

1. 12:53:44 - 12:54:27 Edge of the lava flow
2. 13:59:50 - 14:00:20 Lobate and bulbous pillow lava and ropy surface
3. 14:07:30 - 14:08:00 Juggled surface flattened dome sharp lava
4. 14:55:15 - 14:55:30 Yellowish brown spot on the sediment.
5. 15:00:00 - 15:00:20 Closed up of the core sample site of the yellowish deposit.

Objective

The main objective of this dive are 1) to identify the nature of flat body which has very high back scattering intensity at the southeast base of the Kuala east rift (the water depth is about 5570 m) and 2) comparison of the material and structure of the basal part of Kilauea east rift and Hilina slump.

Around the basal part of the Kilauea East Rift, very flat large high backscattering intensity showing bodes identified by GRORIA long-range side scan sonar image (Holcomb et al., 1988) and these bodies seems voluminous lava flows.　The last year’s KAIREI cruise, we mapped these body using SeaBeam 2112 side scan sonar image.　The frequency of SeaBeam is much higher than GLORIA, so these body are seems almost sediment free.　Moreover, we carried out a 3.5kz subbottom profiling also using SeaBeam 2112, just before the diving and it shows sediment free record. Moreover, in this dive site alkali basalt was obtained by dredge previously. So, the one propose is this dive is to identified the this high backscattering intensity bottom material by direct observation and have a petrologic study using collected samples.

In the Leg 2A, we will have some diving expedition.　And during then, we may have a dive around the base of the Hilina Slump.　The other objective is to compare the nature of the basal part of

Hilina Slump and Kilauea East Rift.

Dive results

The touched down point was the southern outside of the expected lava field. The bottom materials around there was a mostly composed of fine grained pelagic clay. But it contained little bit amount of basaltic volcanic sand. We measured Heat Flow at the tacked down point. This fine grained sediment area was very flat and smooth. We run about 300m and after then we met the boundary of the lava flow and fine grained sediment.

The boundary between fine grained sediment and lavaflow area is not clear. The hight of the edge of the lava flow is less than 30 cm. In appearance, the thickness of the lava flow is not certain, because this lava flow probably, extruded into the soft fine grained sediment. After we entered the lava flow area we run about 1800m along the elongate direction of this lava flow. The entire topography of this lava flow area is very flat. Because, the depth change during this dive varied between only 5568 and 5564 meter and we didn't identified significant echo in the sonar image during the dive.

The dominant lava flow morphology were 1) lobate or bulbous pillow lava and 2) 10 to 20 meter wide flattened dome sharp lava flow. The lobate pillow showed mostly smooth surface and the size was varied from 2 to 5 meter in width and 0.5 to 2 meter in thickness. The size of bulbous pillows were mostly 1 to 2 meter in diameter, and some of them were decelerated by small size knobby pillows. 10 to 20 m width flattened dome like lava showed gentle overall sharp, but their surface showed juggled aa crinker like brecciated surface. In some place in these dome sharp lava, there were 2 to 10 meter width and 1 to 5 meter deep radius pits. Lobate pillow lava were observed in some of these it's bottom. The relationship between these lava is not clear, but lobate pillow may be the distal type of the dome sharp lava flow. During this dive we didn't identified the vent area, but it seemed that these lava flowed toward the edge side (toward south).

The most of the collected samples are almost no vesiculated fresh glassy chilled margins having aphyric basalt. The last one #7 showed amebifrom surface fresh glassy basalt. We didn't identified the rock type during the cruise yet. However, these rock is very different from the previous SHINKAI dive samples which collected deep portion of Kilauea East Rift (Dive # 491).

The thickness of the fine grained sediment cover on this lava flow seems not so thick (probably less than 5 meter in the maximum and no cover in the minimum). This observation is concordant the 3.5 subbottom profile record which we took just before the dive. These characters indicate this lava flow have not so old in age.

Around the final area, we observed few centimeter size yellowish spots on the fine grained sediments, and we took it by push core. It shows 5 cm thick yellowish (probably hydrothermal origin Fe-oxide baring sediment) were observed about 5 cm below the sea floor. It indicate that some kind of hydrothermal activity happened after this lava flow emplacement.

In addition we observed few animals like sea cucumber, squid and shrimp.

Sampling locations

Rock samples

6K495-01 12:59 19 ° 28.76'N, 154 ° 21.51'W D:5567

6K495-02 13:24 19 ° 28.82'N, 154 ° 21.49'W D:5566

6K495-03 13:27 19 ° 28.82'N, 154 ° 21.49'W D:5566

6K495-04 13:55 19 ° 28.97'N, 154 ° 21.39'W D:5567

6K495-05 14:22 19 ° 29.39'N, 154 ° 21.36'W D:5564

6K495-06 14:45 19 ° 29.56'N, 154 ° 21.26'W D:5567

6K495-07 15:05 19 ° 29.63'N, 154 ° 21.23'W D:5568

Core Samples

6K495 C-1 12:07 19 ° 28.49'N, 154 ° 21.41'W D:5568

6K495 C-2 13:27 19 ° 29.63'N, 154 ° 21.23'W D:5568

Grab Sample

6K495 G-1 12:07 19 ° 28.49'N, 154 ° 21.41'W D:5568

Heat Flow Station

12:07 19 ° 28.49'N, 154 ° 21.41'W D:5568

Dive Log (Number 2 Camera)

Time	Depth	Description
12:01	5510	Start recording
12:05	5567	Arrived at bottom. Flat and smooth sea floor covered with thick fine grained sediment.
12:15	5568	Started heat flow measurement.
12:20	5568	Collected grab sample.
12:22	5568	Finished heat flow measurement.
12:33	5568	Collected one push core sample.
12:37	5568	Started moving toward to the north. Almost no significant echo in the CTFM sonar.
12:39	5568	Flat and smooth sea floor covered with fine grained sediment. Few whit size materials scatted on it.
12:42:40	5566	Warm trace on the sediment.

12:45	5568	Flat and smooth sea floor covered with fine grained sediment.
12:46:45	5568	A sea cucumber
12:48	5568	Changed the course toward the weak sonar reflector.
12:50	5568	Flat and smooth sea floor covered with fine grained sediment.
12:52	5568	Flat and smooth sea floor covered with fine grained sediment.
12:53	5569	Arrived at the edge of the lava flow area. Mostly, lava composed of lobate pillow lava. The average size of the pillows are about 1m for horizontal axis.
12:58	5567	Collected one 20 cm size rock sample(#1). The sample seems very fragile.
13:00	5566	Jagged surface lava.
13:02	5566	Mostly lobate sharp pillow lava. The surface undulate gentle. The maximum height is about 5m.
13:06	5568	Slightly sediment covered mostly lobate sharp pillow lava. Attempt collect rock sample.
13:11	5568	Held a small pillow and break it, so it is very fragile.
13:13	5568	Close up of the collected sample, but soon after it break.
13:17	5568	Break small pillow.
13:19	5568	Abundant to collect sample.
13:20	5567	10m width and 2 to 3 meter high lava dome which had jagged surface. Tension crack was observed on the summit.
13:24	5568	Collected a sample #2. 20 to 30 cm size, put into the left side basket.
13:26	5567	Collected lava sample #3 from dome sharp lava. Put into the left side basket.
13:29	5566	Start to move the dredge site along course 30.
13:30	5566	slightly sediment covered mostly lobate sharp pillow lava.
13:33	5567	Slightly sediment covered juggled surface 10m size dome sharp lobate lava.
13:35	5567	Jagged surface, 10 to 20 width and 5 meter high size large lobete sharp lava dome.
13:36	5566	A 1 to 2 meter deep hole in the juggled surface lava.
13:38	5564	Mostly juggled surface lava field, and smooth surface lobate pillow lava field. Ropy surface was observed on the lobate lava's surface.
13:40	5567	Slightly sedimented lobate pillow. There was no significant echo in the sonar image.
13:44	5566	Lobate pillow lava field, roppy surface was observed on it.
13:54	5567	Collected 20 cm size rock sample #4. Put into left sample basket.
13:57	5566	Slightly sediment covered , lobate to bulbous pillow lava. Move toward to north.Upslope toward to left

14:00	5565	Flat lobate and sheet flow field.
14:02	5564	Bulbous and lobate sharp lava.
14:03:45	5562	Ropy surfaced sheet flow lava.
14:04	5563	Slightly sediment covered sheet flow and lobate pillow lava.
14:07	5563	Juggled surface 10 to 20 width few meter high flattened dome sharp lava. In some place 2 to 5 meter width and few meter deep pits. Bulbous pillow filled the some of these pits bottom.
14:09	5564	Lobate pillow field.
14:10	5564	Jagged surface flattened dome sharp lava.
14:12	5562	Jagged surface flattened dome sharp lava.
14:13	5564	Jagged surface flattened dome sharp lava. No significant echo in the sonar. Changed course to 45.
14:16	5564	A shrimp
14:19	5564	Collected small lava fragment. #5
14:20	5564	Collected two pices of fragments and put into the left side basket.
14:24	5561	Slightly sediment covered juggled surface up to 20m width size flattened lava dome or flow.
14:26	5563	Lobate pillow lava field
14:28	5564	Jagged surface flattened lava dome or lava flow.
14:29	5565	Lobate pillow and bulbous pillow
14:31	5565	Mostly bulbous pillow and there surface were attached by small knobby pillow.
14:33	5566	Overview of lobate pillow field
14:39	5566	Collected small piece of lava. #6
14:44	5566	Collected small piece of lava #6-2.
14:47	5566	Start moving toward 30 deg along the elongation of the lava flow.
14:49	5566	Slightly thick sediment covered lobate or bulbous pillow lava.
14:50	5562	Flat and smooth sea floor covered with comparatively thick sediment. Yellowish brown spots were scattered on it.
14:55	5568	Closed up of the yellowish brown spot.
14:58	5568	Collected push core sample #c-2 at the boundary between lava flow and sediment area.
15:00	5568	Closed up of the core sample point. Yellowish material is exposed by sampling.
15:02	5568	Collected 50 cm size lava sample and put it into behind the grab box. Yellowish materials were attached on its side.
15:06	5567	Started moving toward the slightly high sonar image. Slightly thick sediment covered lava flow.
15:09	5566	Lobate and bulbous pillow lava.

15:10	5566	Attempted last sampling at the bulbous pillow dominated area.
15:18	5566	Abundant sampling and started to ascend.

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1B

DIVE No	**496**	DATE	August 12, 1999

	NAME	AFFILIATION
Japanese	高橋　栄一	東京工業大学理学部地球惑星科学科 Earth and Planetary Sciences,

SPECIALTY	[illegible]
PURPOSE	Geological mapping and petrologic study
AREA	North of Oahu Island
SITE	Northern flank near the base of 2.5 Ma old Koolau volcano

	LATITUDE	LONGITUDE	TIME	DEPTH
	Ex). 24 ° 18.5’ N	127 ° 36.2’ E	13:35	6499 m
LANDING	N	W	11:38	3923 m
LEAVING	N	W	15:37	3239 m

DIVE DISTANCE:	2700 m	DEEPEST POINT:	3923 m

DIVE SUMMARY	In order to study growth history of 2.5 Ma old Koolau volcano in Hawaii, deep submarine portion of north Oahu Island was studied. Previous study conducted in this region (D-7 and K89 in 98-JAMSTEC cruise) revealed good exposure of pillow lavas in the depth range of 2800-2500m, but the dive site of 6K496 (depths of 3923-3239m) consists solely of volcaniclastic materials (hyaloclastite, volcanic breccias). The dive site 6K496 was characterized by the sporadic occurrence of relatively smaller outcrops (2 to 10 m size) in the lower part of the slope, and almost continuous steep walls in the upper part of the slope. The lower slope is covered by thin mud probably under laid by a few meter thick layer of young gravel deposit (mantle bedding). The hyaloclastite forms highly jointed rugged outcrops with abundant angular boulders in the talus. Bedding plane was observed in several localities dipping steeply
PAYLOAD	Push cores
VISUAL RECORDS	VTR1 VTR2 STILL CAMERA 170 ONBOARD CAMERA No

SAMPLE	Organisms:	Rocks: 14	Cores: 1	Water: cc
	Sediments:	Others:	TOTAL: 15	

VIDEO HIGHLIGHTS	1）hyaloclastite	2）volcanic breccias	3）

KEY WORD	Oahu Island, Koolau volcano, hyaloclastite, volcanic breccias

6K496 Dive Summary and Results

Abstract

In order to study growth history of Koolau volcano in Hawaii, deep submarine portion of north Oahu Island was studied. Previous study conducted in this region (D-7 and K89 in 98-JAMSTEC cruise) revealed good exposure of pillow lavas in the depth range of 2800-2500m, but the dive site of 6K496 (depths of 3923-3239m) consists solely of volcaniclastic materials (hyaloclastite).

The dive site 6K496 is characterized by the sporadic occurrence of relatively smaller outcrops (2 to 10 m size) in the lower part of the slope, and almost continuous steep walls in the upper part of the slope. The lower slope is covered by thin mud probably underlain by a few meter thick layer of young gravel deposit (mantle bedding).

The hyaloclastite forms highly jointed rugged outcrops with abundant angular boulders in the talus. Bedding plane was observed in several localities dipping steeply towards south. The volcanic breccias are massive and make steep walls in some localities. Field occurrence and lithology of the recovered rock specimens from the Dive-496 are very similar to those observed in the deep slope of the Hilina slide area (south of Hawaii Island) during the 98Kaiko-dives.

概要

約２５０万年以前に活動したハワイ楯状火山であるオアフ島のコーラウ火山の深部構造を解明し、ハワイ型楯状火山の成長史を明らかにする目的で、しんかい６５００の第４９６潜航をオアフ島北方の急斜面で行った。この海域では９８年のかいこう・かいれいを用いた調査により水深２８００－２５００mでは枕状溶岩の路頭が確認されていた。今回の潜航では水深３９００－３２００m で潜航調査を行い、岩石の採取と路頭の観察を行った結果、以下の事実が明らかになった。

（１）調査地域全体に渡り、ハイアロクラスタイト等の火山砕削物が路頭を構成している。

（２）火山砕削物の多くは斜面の内側(南)に向いて傾斜した層理面を持つ。

（３）北に向いて傾斜した斜面の表面を覆う厚さ数メートル以下の若い礫岩層が存在する。

（４）全体として第 496 潜航地点の地質学的特長は、98 年のかいこう・かいれいによる調査で明らかとなった、キラウエア火山ヒリナ地滑り帯の水深 3000m以上の地域に酷似している。

Video Highlights (Dive#496, 12 August 1999)

Rugged Outcrop of hyaloclastite
(start: 13:59 end 14:02 camera #1, #2)

This portion of video-recording shows highly jointed rugged outcrop of hyaloclastite dipping to south. The rock seems like compact lava in its appearance but is a well-consolidated hyaloclastite (glassy lapilli tuff with basaltic clasts of various lithology). In the down slope side of the outcrop, numerous angular boulders are seen suggesting that the outcrop is yielding abundant gravels to form talus deposit.

Massive wall of volcanic breccias
(start 15:26, end 15:30 camera #1)

In this part of the video, massive outcrops of volcanic breccias are seen. The breccias contains up to 0.5 m size boulders. There is no apparent bedding structure in the outcrop.

A platform on top of the steep walls
(start 15:33, end 15:35 camera #1)

In this part of video, top portion of the massive outcrop of volcanic breccias is seen. The top surface is a narrow platform (about 20m across) surrounded by steep walls in 360 degree direction. The submersible turned around at this point and ascended.

Dive results of 6K496 (Deep slope of Koolau)

Pilot: **S. Ogura**
Copilot: **A. Higuchi**
Dive observer: **E. Takahashi**

Purpose and Dive plans

Koolau volcano in Oahu island is unique in several aspects in geochemistry. The prime objective of the Dive-496 was to obtain geologic information of the deep slopes of the 2.5 Ma Koolau volcano. The diving site was chosen based on results of 98-JAMSTEC cruise. In the dredge site D-7 and ROV-Kaiko dive site K-89, sporadic to continuous outcrops of fresh pillow lavas were found at the depth of 2800 to 2500 m. We therefore selected deeper slopes in the adjacent area for the Dive-496.

Topography

The dive site is on the north slope of a topographically distinct semi-isolated mass. The topographically distinct mass might be a large slumped block in the old Koolau volcano. The time relation between the Nuuanu landslide and the detachment of the topographic mass is unclear. There is a mismatch in the direction of transportation; the detached block moved towards north, whereas Nuuanu landslide blocks were transported to NE. It is thus likely that the Dive-496 site represents a slope of Koolau volcano possibly transported slightly to north by small scale slumping but not disturbed by Nuuanu landslide.

The dive site was relatively gentle in the slope and covered with young soft sediments at greater than 3850m depths. Between 3850 and 3650m depths, the slope is a relatively steep and comprising sporadic outcrops. At shallower than 3650m, the slope consists mostly of steep walls of continuous outcrops. The Dive-496 was terminated when submersible reached a small platform on top of >40m high steep walls. The final point at 3239m is near the shoulder of the semi-detached block.

Geology and petrology

The Dive site 6K496 consists almost entirely of volcaniclastic materials (volcanic breccia and volcanic sandstone) undoubtedly of submarine origin. A few suspicious fragments of pillow lava were seen on the video image but none of them were recovered. Most of the volcanic breccias contain more than one lithologic type of clasts (aphyric to strongly olivine-phyric, strongly vesicular to vesicle free, glassy to highly oxidized). Matrix of volcanic breccias and volcanic sandstone consists of fine-grained glass that is partially paragonatized.

The dive site 6K496 is characterized by the sporadic occurrence of relatively smaller outcrops (2 to 10 m size) in the lower part of the slope, and almost continuous steep walls in the upper part of the slope. The lower slope is covered by thin mud probably underlain by a few meter thick layer of young gravel deposit (mantle bedding). It is possible that the small size outcrops in the lower slope represent blocks moved by secondary slumping from the steep wall. This interpretation is in accordance with the apparent change in dipping of the out crops (north dipping at depths >3800m but south dipping at shallower depths)

The hyaloclastite above 3800m depths forms highly jointed rugged outcrops with abundant angular boulders in the talus. Bedding plane was observed in several localities dipping steeply towards south. The volcanic breccias are massive and make steep walls in some localities. Field occurrence and lithology of the recovered rock specimens from the Dive-496 are very similar to those observed in the deep slope of the Hilina slide area (south of Hawaii Island) during the 98Kaiko-dives.

Preliminary observation of the rocks with hand lens and petrologic microscope indicates that glass and lithic fragments in hyaloclastite have oliv, oliv+cpx, and oliv+cpx+pl type phenocryst assemblages. These mineral assemblages are common in most Hawiian tholeiite shields but are different from those in subaerial Koolau volcano (Takeguchi and Takahashi, 1999) in that it contains cpx instead of opx. Because most pillow basalts in the K-89 and D-7 sites (shallower than Dive-496 but close in locality) contain opx but not cpx, it is expected that there is a significant change in bulk chemistry of the lavas between the Dive-496 and K-89 sites.

Summary of important results

(1) The lower part of Koolau volcano (at depths 3900 to 3200m) is found to consist dominantly of volcaniclastic materials (hyaloclastite).

(2) The bedding plane of hyaloclastite is towards south (inward dipping).

(3) The composition of the lavas in Dive-496 site (3900-3200m depth) may be different from those of the pillow lavas in the shallower part of the slope (2800-2500m depth).

(4) The geologic situation and the lithology of the rocks are very similar to those found in the south frank of Kilauea volcano (deep slope of the Hilina slump region) studied by JAMSTEC-98 cruise.

Rock samples

6K496-1 volcanic breccia; hyaloclastite (angular monolithologic clast)

6K496-2 volcanic breccia; reworked (polymictitic)

6K496-3 volcanic breccia, with a large clast of strongly olivine-phyric basalt

6K496-4 volcanic breccia; hyaloclastite

6K496-5 volcanic sandstone; hyaloclastite

6K496-6 volcanic breccia; hyaloclastite (polymictic but one type is dominating as clasts)

6K496-7 volcanic breccia; hyaloclastite (polymictic, some strongly vesicular clasts)

6K496-8 volcanic sandstone; hyaloclastite (massive sandstone with small clasts of aphyric to picritic olivine basalt clasts)

6K496-9 sample was lost during transportation

6K496-10 volcanic breccia; hyaloclastite

6K496-11 volcanic breccia; hyaloclastite (polymictic)

6K496-12 volcanic breccia; hyaloclastite (nearly monolithologic)

6K496-13 volcanic breccia; hyaloclastite (angular glass in fine matrix)

6K496-14 volcanic breccia; hyaloclastite (angular basalt fragments)

Video Log of 6K496

Time	Depth	Sub Heading	Descriptions
11:35	3923m	221°	on bottom, current Left to right 0.1, muddy surface
11:37			one push core sample in blue column
11:40	3922m	213°	start to move south
11:42		181°	a fish on bottom
11:45	3904	230°	move on muddy surface
11:48	3893	263°	move towards outcrop(?) on radar
11:51	3887	186°	move on muddy surface
11:54	3885	186°	large boulder on muddy surface
11:56	3856	212°	small gravels on muddy surface (sub hedding to sonar image)
11:58	3832	217°	first outcrop
12:01	3828	269°	another small outcrop
12:02	3826	271	outcrop of volcanic breccia with some angular blocks
12:07			attempting a sampling at the same outcrop
12:08			sample#1 (small, fragile, altered hyaloclastite)
12:10			sample#2 (volcanic surface)
12:12	3822	220	move to south
12:13	3821	226°	passing through a large outcrop with beddings to north
12:14	3811	184°	talus with huge boulders
12:15	3803	186°	steep slope covered with thick mud
12:18	3783	173°	slope covered with mud
12:19	3772	160°	hedding to next outcop by sonar
12:20	3757	157°	outcrop with some loose rocks
12:22			dust covered the sub, nothing is visible
12:25	3753	246°	outcrop bedding to north, jointed
12:29			volcanic breccia with various size of angular blocks
12:30			sample#3 (volcanic breccia with picrite clast)
12:33	3749	250°	distant view of the outcrop

12:35	3747	253°	start to move south (changed pilot)
12:36	3740	207°	shrimp on mud
12:38	3724	185°	mud covered slope
12:40	3705	157°	slope covered with mud
12:41	3699	132°	outcrop covered with thin mud and gravel
12:45	3697	187°	attempting a sampling at the same outcrop
12:51	3693	240°	abandoned the sampling
12:54	3684	180°	move to south
12:56	3683	180°	slope covered with mud
12:58	3673	156°	slope covered with mud
13:00	3671	144°	slope covered with mud
13:02	3665	143°	hedding to next outcop by sonar
13:04	3657	143°	slope covered with gravels and mud
13:06	3656	143°	many gravels on mud
13:09	3645	149°	approach to an outcrop
	3634	167°	massive outcrop with large joints
13:13	3633	188°	start sampling
13:17	3632	247°	outcrop bedding to south
13:20	3631	203°	talus close to outcrop covered with mud
13:22			sample#4 from the talus (volcanin breccia)
13:26			attempting a sampling from the same outcrop and dropped a specimen
13:30			a shrimp in front of outcrop
13:30			sample#5 from the outcrop (hyaloclastitewith lappili)
13:34	3625	115°	start to move south
13:36	3615	181°	mantle bedding sediment
13:37	3605	181	flat surface of mantle bedding surface
13:38	3595	187°	bedding sediment dipping to SE
	3590	219°	crevies on mantle bedding sediments
13:41	3581	264°	outcrop of massive volcanic breccia
13:44	3571	197°	proceed up along a valley
13:46	3571	193	sample#6 (large boulder in talus; volcanic breccia)
13:47			sample#7(taken with left arm; hyaloclastite)
13:49	3564	177°	start move to south
13:51	3552	231°	a narrow ditch from S to N formed on the mantle bedding
13:52	3547	204°	massive outcrop of volcanic breccia
13:53	3543	186°	slope coverd with mud
13:55	3534	152°	slope covered with mud, occasinal large boulder
13:58	3519	147°	talus with huge angular blocks of hyaloclastite
13:58	3514		a coral (Golgona?)

13:59	3511	144	outcrop of highly jointed hyaloclastite
14:03	3507	120°	sample# 8 (taken from gravel: hyaloclastite, lapilli tuff)
14:06	3505	131°	well bedded outcrop dipping to south
14:07	3504		sample#9 (this sample was lost while sub floated)
14:09	3502	134°	very good exposure of hyaloclastite
14:11	3504	119°	dust covered the sub, nothing is visible
14:14	3502	127°	start to move south
14:16	3493	138°	recognized that the still camera was not taking photos
14:17	3487	148°	start taking still photos from No.16
14:17	3481	155°	talus with large angular blocks
14:18	3472	171°	chaotic outcrop of volcanic breccias (continuous outcrops)
14:20	3459	181°	outcrop of volcanic breccia with huge gravels
14:23	3438	182°	end of the continuous outcrop
14:25	3431	179°	attempting sampling at outcrop of volcanic breccia
14:32			still attempting to take a rock
14:37	3420	296	out crop of very massive rock (impossible to take a sample)
14:38			changed pilot
14:39	3420	272°	gravels on top of outcrop
14:42	3421	229°	attempting sampling at outcrop of volcanic breccia
14:43	3422	196°	sample #10 (taken from gravel; an altered hyaloclastite)
14:45	3420	168°	sample #11 (taken from gravel; hyaloclastite)
14:47	3417	168°	start move to south
14:49	3408	205°	very good exposure of hyaloclastite, large crevice
14:51	3397	189°	slope covered with mud and small gravels
14:51	3391	193°	mantle bedding sediment with coarse angular gravels
14:56	3370	172°	attempting sampling from a small outcrop with weal bedding
15:00	3369	195°	a large outcrop of hyaloclastite
15:05	3368	114°	massive outcrop of hyaloclastite with coase joints
15:07			sample#12(taken out from outcrop, hyaloclastite)
15:10	3367	84°	start to move south
15:13	3362	180°	slope covered with thin mud and gravels
15:15	3346	185°	mantle bedding sediments with crevices
15:16	3326	185°	slope covered with mud
15:19	3303	184°	slope covered with mud
15:21	3279	225°	approach to an outcrop guided by sonar image
15:23	3272	270°	base of the last outcrop
15:23	3274		huge boulders of volcanic breccia
15:26	3253	162°	very steep wall with masive surface of volcanic breccia
15:27	3248	148	excellent outcrop of volcanic breccia

15:28	3243	132	very steep wall continue
15:30	3242	109	attempting sampling in a small terrace
15:32	3242	119	sample#13 (taken from talus, large piece of hyaloclastite)
			sample#14 (hyaloclstite with thick Mn coating)
15:33	3239	116	start to move south along a large wall of volcanic breccia
15:33	3237	117	arrived top of the large outcrop, a small platform
15:35			finished the videotape
15:37			Shinkai took off the bottom

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1B

DIVE No.	6K-497	DATE	99/8/13	
	NAME		AFFILIATION	
Japanese	Michael Garcia		Dept. of Geology and Geophysics, University of Hawaii, Honolulu	
SPECIALTY	Igneous Petrology, Volcanology, Marine Geology			
PURPOSE	To examine the internal structure of and collect samples from a proximal block of the Nuuanu slide			
AREA	Southern flank of the Nuuanu Landslide, Oahu Island, Hawaii			
SITE	Proximal Block			
	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	21^{o} 46.31’ N	157^{o} 29.85’ W	11:37	3648 m
LEAVING	21^{o} 43.34’ N	157^{o} 30.69’ W	16:12	2540 m
DIVE DISTANCE:	2.4 km	DEEPEST POINT:	3658 m	
DIVE SUMMARY	Dive track was designed to study the internal structure and sample from a steep section of a proximal block within the Nuuanu slide. The lower portion of the dive encountered mostly mud overlying a slope-mantling deposit of interbedded sandstone and pebbly conglomerate, which outcropped locally. The slope mantling deposit was at least 2 m thick. Excellent exposures of moderately dipping layers of hyaloclastite were found along the steeper, upper part of the block. These deposits contained coarse boulders of volcanic rocks, which were sampled. In two areas, depths of 2560 and 2640, smooth, steep (>70 ^{o}) slopes with slickensides (?) were observed, which may have been slip surfaces for a block within the Nuuanu slide.			
PAYLOAD				
VISUAL RECORDS	VTR1	VTR2	STILL CAMERA 400 Yes	ONBOARD CAMERA No
SAMPLE	Organisms: / Sediments:	Rocks: 9 / Others:	Push Cores: 1 / TOTAL: 10	Water: cc
VIDEO HIGHLIGHTS	1) 15:31- 15:33	2) 15:00- 15:05	3) 14:21- 14:24	

KEY WORDS	hyaloclastite, volcanic breccia, slickensides, slip surface, landslide block

Results of Shinkai 6500 Dive #497

Date: Aug. 13, 1999
Pilot: Kazuk Iijima **Co-pilot**: Tsuyoshi Yoshiume
Science Observer: Michael Garcia, University of Hawaii
Dive Location: Proximal Block of Nuuanu Slide, Oahu, Hawaii

Objectives

The dive track was designed to study the internal structure and sample from a steep section of a proximal block within the Nuuanu slide. The goal of this dive was to determine the rock types and orientations within the deep interior of the Koolau Volcano to evaluate models for the evolution of Hawaiian volcanoes and the mechanics of landslide movement.

Dive Summary

The lower portion of the dive encountered mostly mud overlying a slope-mantling deposit of interbedded sandstone and pebbly conglomerate, which outcropped locally. The slope mantling deposit was at least 2 m thick.

In the upper part of the dive, excellent exposures of moderately dipping layers of hyaloclastite were found in a giant wall. These deposits contained coarse boulders of volcanic rocks, which were sampled. In two areas, depths of 2560 and 2640 m, smooth, steep (>70^{o}) slopes with slickensides (?) were observed, which may have been slip surfaces for a block failure within the Nuuanu slide.

Nine rock samples were recovered: 8 are lava flow fragments including 3 picritic basalts; one is a hyaloclastite. The lavas were clasts from within coarse hyaloclastite deposits. A push core of mud was also taken near the beginning of the dive.

Dive Interpretations

The proximal block is thought to be a part of the outer core of Koolau Volcano. Our observations indicate that much of the interior of Koolau Volcano is comprised of hyaloclastite deposits (at least many 100's m thick). If the other Nuuanu slide blocks are composed of the same type of material (we already know that the Tuscaloosa block is), then the Moore and Chadwick (1994) model for a Hawaiian volcano must be the new working paradigm.

The hyaloclastite deposits within the proximal block is locally well bedded and these beds dip inward towards Koolau Volcano suggesting that the block has rotated at least 30^{o} back towards the volcano. The interpretation is consistent with a simple block failure model for the formation of the Nuuanu slide.

Hyaloclastite deposits that dip away from the volcano (and island) are more likely to be prone to failure along bedding planes that lava flows. However, the high angle slip surface observed on the proximal block cuts steeply across the bedding and the hyaloclastite deposits appear to be well indurated and not prone to slumping.

Fresh rocks can be obtained from the sedimentary deposits within the Nuuanu slump blocks. Many of the clasts from these deposits are relatively fresh lavas and are olivine-rich. The rocks we recovered from the proximal block are vesicular and some are stained red, indicating that they were subaerially erupted and then were eroded before being deposited in the apparently polymictitic hyaloclastite deposits.

The blocks may contain steep, smooth outer surfaces with slickensides, which may represent the detachment plane for blocks from within the Nuuanu slide.

It is essential to pick steep sections for dive targets if one hopes to sample the basement of a slide block. A slope-mantling deposit, which is at least 2 meters thick, forms a veneer on the block covering the basement in all but the steepest areas. Time should be reserved to take multiple samples and to photograph important features at such outcrops rather than to cover ground during a dive.

Table 1. Video Highlights (for a detailed summary see attached table)

Time	Depth (m)	Feature
11:26	3657	On bottom; mud covered surface
12:22	3583	Big wall of hyaloclastite; bedded sediments
12:33	3526	Slope mantling deposit
13:45	3176	Bedded hyaloclastite deposit
14:48	2924	Nicely bedded hyaloclastite
15:00	2848	Start of giant wall of hyaloclastite
15:31	2645	Steep wall with smooth surface and slickensides (?)
15:50	2548	Continuation of steep wall with slip-surface
16:12	2540	Leaving bottom

Table 2. Rock samples recovered during Shinkai 6500 Dive 6K497

Sample	depth	Rock type	in place	deposit (basement or slope mantling)
1	3658	basalt	no	probably locally derived; slope
2	3580	picritic basalt	no	probably locally derived; slope
3	3531	olivine basalt	yes	basement
4	3299	aphyric basalt	no	unknown
5	3172	hyaloclastite	yes	basement
6	3103	picritic basalt	yes	slope-mantling deposit

7	2999	olivine basalt	yes	slope-mantling deposit
8	2840	basalt	yes	basement
9	2641	picritic basalt	no	locally derived from basement (?)

Acknowledgments: Thanks to Drs. Yokose, Moore, Clague, Takaraka and Takahashi for help with the dive log and to the Shinkai navigation team for keeping good position of the sub at all times.

Videolog of 6K497

Time	Depth	Heading (°)	Description	Samples
11:27	3657	234	On bottom, hyaloclastite slighly covered with mud	
11:34	3657	264	Subangular block, ~20cm	rock #1
11:45	3657	226	Muddy bottom	Push core #1 Blue Front
11:50	3648	236	Mud with scattered rocks (volcanic breccia?)	
11:53	3639	245	talus slope of debris and muc	
11:57	3622	248	talus slope of debris and muc	
12:00	3602	221	mud	
12:03	3583	220	slope mantling deposit of med. grained hyaloclastite	rock #2
12:14	3517	226	massive hyaloclastite	
12:18	3550	218	mud with scattered pebbles	
12:22	3536	208	Big basement wall of hyaloclastite	rock #3
12:33	3526	231	slope-mantling deposit of med. grained hyaloclastite	
12:39	3500	231	mud with scattered pebbles	
12:40	3489	231	mud with scattered rocks	
12:47			mud with scattered rocks	
12:55	3392	230	mud with scattered rocks	
12:57	3387	226	mud with scattered rocks	
13:03	3377	232	failed sampling attempt	
13:11	3352	249	mud with boulders	
13:14	3346	234	boulders on mud	
13:18	3340	247	mud	
13:23	3307	261	talus slope of debris and muc	rock #4

13:34	3281	221	mud	
13:38	3224	221	mud with boulders	
13:40	3196	221	mud	
13:45	3176	206	layered hyaloclastite	rock #5
13:56	3167		star fish, mud and talus	
13:58	3168	210	mud	
14:00	3143	211	mud; course change to 215o	
14:02	3142	200	mud	
14:08	3107	206	massive volcaniclastic rocks	rock #6
14:17	3077	191	basement rocks showing layering	
14:19	3057	193	Into the most steepest slope	
14:22	3017	191	massive hyaloclastite wall	
14:24	3004	189	mud with scattered rocks	
14:25	2996	190	mud with scattered rocks	
14:28	2996	198	layered hyaloclastite	rock #7
14:40	2979	192	mud	
14:41	2969	205	fractured hyaloclastite	
14:45	2951	192	layered hyaloclastite	
14:48	2924	203	layered hyaloclastite	
14:51	2920	191	layered hyaloclastite	
14:53	2916	192	massive volcanic sandstone with many joints	
14:54	2906	193	massive hyaloclastite wall	
15:00	2848	192	massive hyaloclastite wall	
15:04	2840	210	massive hyaloclastite wall	rock #8
15:16	2777	217	massive hyaloclastite wall	
15:19	2750	236	massive hyaloclastite wall	
15:20	2727	236	massive hyaloclastite wall	
15:26	2703	206	brittle star; massive wall	
15:28	2670		rat tail fish; massive wall	
15:32	2640	222	ledge of massive wall	rock #9
15:42	2618	228	talus slope of debris and muc	
15:45	2588	234	layered hyaloclastite	
15:50	2568	280	gorgonia coral, massive unit	
15:53	2531	235	failed sampling attempt; brittle star	
16:12	2539	236	off bottom	

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1B

DIVE No.	6	August 14, 1999	
	NAME	AFFILIATION	
Japanese English	**James G. Moore**	U. S Geological Survey (retired)	
SPECIALTY	Volcanology		
PURPOSE	Geological observations and sampling of rock making up lower part of		
AREA	Nuuanu Landslide NE of Island of Oahu.		
SITE	**ESE corner of Tuscaloosa seamount**		

	LATITUDE N	LONGITUDE E	TIME	DEPTH m
LANDING	21° 58.82' N	157° 02.14' W	1200	4680
LEAVING	21° 59.73 N	157° 02.62' W	1546	3762

DIVE DISTANCE:	1800 m	DEEPEST POINT:	4680 m

DIVE SUMMARY	We landed at the base of the east corner of Tuscaloosa Seamount in the Nuuanu landslide at a water depth of 4680 m, and climbed up the seamount slope from its base for about 1000 m to 3762 m. The overall slope averaged about 25 degrees and most was covered by light-colored muddy sediment. A total of seven samples were taken from outcrops and loose blocks. The samples include both volclaniclastic breccia and chunks of basaltic lava, some of which are probably derived from breccia outcrops. Some of the breccias contain well-preserved glass. The limited outcrops seen were both rubbly and irregularly fractured, and no distinct layered structure was observed.
PAYLOAD	Two sample baskets, 4 push core samplers
VISUAL RECORDS	VTR1, VTR2, Still Camera

SAMPLE	Organisms:	Rocks: 7	Cores: 1	Water: cc
	Sediments:	Others:	TOTAL: 8	

VIDEO HIGHLIGHTS	Rocky walls widely separated by sediment-covered slopes at 1322, 1416, 1500, 1531
KEY WORD	Tuscaloosa Seamount, Nuuanu Landslide, hyaloclastite breccia

6K 498 Dive Results

Objective

The objectives of dive 498 was to determine with observations and samples the makeup of the layering in the southeast wall of Tuscaloosa Seamount. This seamount is the largest block in the Nuuanu Landslide with a length of 30 km and width of 20 km. The wall examined is believed to be a giant fracture surface where this block has broken away from adjacent blocks, (all originally making up the Koolau volcanic edifice) and moved downslope tens of kilometers to its present position. The data collected will be melded with that from two previous 1998 JAMSTEC sampling programs higher up on the same block wall: Dredge # 5, and Kaiko Dive # 90.

Geologic Observations

We landed at 1200 at 4680 m on a sloping plane of white sediment. The pushcore went into its full depth unimpeded. As The submersible move NNW upslope we encountered scattered gravel-sized rocks as well as scattered blocks and boulders, some up to several meters in size, that apparently originated from above and slid or rolled downslope. Sample #1 was from one of these collected from a depth of 4658 m.

Sample #2 (4554m) was taken from the vicinity of an apparent small outcrop protruding though the sediment. The first well-developed outcrop occurred at an elevation of 4383 m, 300 m above the start of the dive. The rock face was about 5 m high with a broken and fractured aspect producing sharp cornered rocks. Samples #3 and #4 were collected from this rocky area several meters apart. The outcrop is surrounded by the sediment-covered slope.

Sample #5 (4198m) was collected from a small ragged outcrop surrounted by sediment. Upward we attemped to collect from a massive jointed outcrop 6m high at 4085 m, but were unable to find and collect a rock in place. After again attempting to break loose a sample from a cliffy area at 3971 m, we collected sample #6, a detatched block apparentlly belonging to this outcrop. Sample 7 was collected from an outcrop of what may be a mantling, indurated sedment at 3884 m.

We continued upward, and at 3761 m attempted sampling from an outcrop with flat layering several decimeters in thickness. Time was up at 1546, depth 3762, and Shinkai left the bottom.

<u>Video Record, Camera # 2</u>

Time	Depth, m	Comments
1158	4680	At bottom, covered by white sediment
1204	4680	Collect pushcore

1208	4679	Underway heading 278° up sedimented slope
1229	4658	Collected rock sample #1. From a boulder that apparently originated from above and slid or rolled downslope [olivine basalt]
1242	4586	Large boulders in mud.
1247	4558	Loose rocky zone, then back to sediment.
1254	4554	Rounded outcrop or buried boulder with loose anglular blocks, collecting.
1302	4554	Rock sample #2 [volcaniclastic lapillistone with fresh glass]
1313	4460	Sediment with gravel and boulders.
1322	4388	Rather large wall with jagged fractures.
1329	4389	Collecting sample #3. [red altered olivine basalt]
1343	4372	Second sample from same outcrop several meters apart. Sample #4 [fresh, non-vesicular oliv. basalt]
1401	4238	Wall of rubble.
1404	4208	Muddy slope.
1407	4198	muddy slope with outcrops.
1408	4198	Stopping for sampling from wall.
1416	4199	Sample from ragged and fractured outcrop. Sample #5 [volcanic breccia].
1422	4149	Rocky wall with lots of mud; some blocky outcrop.
1426	4126	Sediment and rock outcrops.
1429	4086	Rubbly wsall; stopped to sample.
1443	4063	Abandoned sampling; could not hold position on cliff.
1452	4005	Attempting to sample on rock wall.
1500	3971	Finally picked up fragment from wall, Sample #6 [olivine basalt, 10% vesicles].
1506	3940	Ascending up wall, very rubbly.
1512	3890	Stopping to collect sample.
1519	3884	Sample # 7 [hyaloclastite with oliv. basalt frag.and glass]
1530	3801	Up muddy slope with some pebbles.
1531	3789	Small wall-like outcrop; apparent flat bedding.
1534	3774	Sediment-covered slope.
1537	3763	Stopping to collect sample
1547	3761	No sampling could be accomplished—leaving bottom

Sample List, dive 6K-498

Sample	**21°N**	**157° W**	**Depth**		**MnOx**
Core	58.82’	02.14’	4680m		<1mm
1	58.86	02.18	6558	Oliv. basalt, oxid. and vesicular	
	<O.5				
2	58.96	02.29	4554	Volcaniclastic lapillistone, oliv.	
3	59.12	02.35	4383	Oliv. basalt, altered	0.5-1
4	59.12	02.35	4383	Oliv basalt, fresh, non-vesicular	
	<0.3				
5	59.32	02.40	4198	Basalt breccia ?	
	0-2				
6	59.48	02.45	3971	Oliv basalt, 10% vesicles	
	2.5				
7	59.55	0246	3884	Hyaloclastite, oliv. bas. Glass-1-4	

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1B

DIVE No.		DATE	99/8/18	
	NAME		AFFILIATION	
Japanese	宝田　晋治		地質調査所北海道支所	
SPECIALTY	Volcanology			
PURPOSE	To investigate inner structure of the Nuuanu-Wailau debris avalanche deposit and to reveal source of the deposit (from Koolau, W-Molokai, or E-Molokai)			
AREA	Middle part of the Nuuanu-Wailau debris avalanche deposit (north of Tuscaloosa Seamount)			
SITE	Southwestern slope of unnamed hummock at 22°15’N, 156°55’W			
	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	22 ° 14.35’ N	157 ° 00.38’ W	11:52	4507 m
LEAVING	22 ° 15.24’ N	156 ° 59.68’ W	15:36	3610 m
DIVE DISTANCE:	2750 m	DEEPEST POINT:	4507 m	
DIVE SUMMARY	Dive track was on the southwestern part of unnamed hummock at 22°15’N, 156°55’W. North side of this hummock was dredged by Kairei at site D-6 last year. Fractured massive lava and flat-topped layered volcanic breccia were sometimes observed on the lower gentle slope. Highly fractured volcanic breccia and flat-topped layered volcanic breccia were seen on the middle and upper steep slope. The flat-topped layered volcanic breccia looks mantling on the slope. Open cracks (<1 m in width) filled with mud were seen in the layered volcanic breccia. This mantle-bedding layered volcanic breccia may have been formed during transportation of the debris avalanche. No obvious vertical variation of fracture intensity in the volcanic breccia was identified. The summit area of the diving point shows hummocky topography (>15 m in height). Weakly indurated mud clasts containing angular lapilli and breccia were collected. This mud may be the debris–avalanche matrix, which formed by mixture of source material and pelagic sediments during transportation. Most rock samples were volcanic breccia. Many jigsaw cracks were seen in the volcanic breccia.			
PAYLOAD	Sample baskets and push core (4)			
VISUAL RECORDS	VTR1 2	VTR2 2	STILL CAMERA 400	ONBOARD CAMERA No
SAMPLE	Organisms:	Rocks:17 total95.3kg	Push Cores: 3	Water: cc
	Sediments:	Others:	TOTAL: 20	
VIDEO HIGHLIGHTS	1）12:56 – 13:31	2）13:55 –14:37	3）15:03-15:36	

KEY WORD	Nuuanu, Wailau, debris avalanche, jigsaw cracks, fracture, volcanic breccia

Results of Dive #499

Date: Aug. 18, 1999

Place: southwestern slope of unnamed seamont at 22°15'N, 156°55'W, medial region of the Nuuanu-Wailau debris avalanche deposits.

Pilot: Satoshi OGURA　Co-pilot: Itaru KAWAMA

Observer: Shinji TAKARADA

Abstract

Dive track was on the southwestern part of unnamed hummock at 22°15'N, 156°55'W. North side of this hummock was dredged by Kairei at site D-6 last year. Fractured massive lava and flat-topped layered volcanic breccia were sometimes observed on the lower gentle slope. Highly fractured volcanic breccia and flat-topped layered volcanic breccia were seen on the middle and upper steep slope. The flat-topped layered volcanic breccia looks mantling on the slope. Open cracks (<1 m in width) filled with mud were seen in the layered volcanic breccia. This mantle-bedding layered volcanic breccia may have been formed during transportation of the debris avalanche. No obvious vertical variation of fracture intensity in the volcanic breccia was identified. The summit area of the diving point shows hummocky topography (>15 m in height). Weakly indurated mud clasts containing angular lapilli and breccia were collected. This mud may be the debris–avalanche matrix, which formed by mixture of source material and pelagic sediments during transportation. Most rock samples were volcanic breccia. Many jigsaw cracks were seen in the volcanic breccia.

要旨

「しんかい 6500」による 499 回目の潜航では，タスカロ−サ海山の北，北緯 22 度 15 分，西経 156 度 55 分にある流れ山の南西斜面の調査を行った．この流れ山の北斜面では，昨年「かいれい」によるドレッジ調査を行っている(D-6)．多数のクラックの入った溶岩流や層理の発達した角礫層が，斜面下部の緩斜面でしばしば観察できた．また，多数のクラックが入った火山性の角礫岩や層理の発達した角礫層が斜面の中部や上部の急傾斜部で観察できた．層理の発達した角礫層には，泥のつまった開口性の割れ目(幅 70cm 以下)が見られた．層理の発達した角礫層は，斜面の傾斜に平行に堆積していた．このことは，岩屑なだれの流走中に巻き上げられた泥，砂，角礫が，流れ山の斜面を覆うように堆積してこの角礫層が形成されたことを示唆している．角礫岩中のジグソ−クラックの顕著な上下方向の変化は観察できなかった．水深 3620m付近の流れ山の頂上付近では，比高 15m 以上のいくつかの小丘上の地形が観察できた．採取したサンプルの中には，角礫を含むやや硬化した泥質のかたまりがあった．これは，岩屑なだれの流走中に海洋底の泥と給源の物質が混合してできた岩屑なだれ基質である可能性がある．採取したサンプルの多くは火山性の角礫岩であった．これらの角礫岩には多くのジグソ−クラックが入っていた．

Video Highlights

11:50-12:01 Scattered angular rocks on muddy sediment. Sample #1

12:12-12:18 Camera 1&2: Fractured massive lava and flat-topped layered volcanic breccia.

12:51-12:55 Camera 1&2: Large angular talus blocks (<2 m) on muddy sediment. Pebbly grain flow deposits on surface.

12:56-12:59 Camera 1&2: Highly fractured volcanic breccia. Sample #3.

13:06-13:31 Camera 1&2: Fractured mantle-beddin layered volcanic breccia. Many open cracks (<70 cm in width) filled with mud. Sample #4.

13:37-13:38 Camera 1&2: Fractured volcanic breccia.

13:39-13:41 Camera 1&2: Fractured layered (flat surface) volcanic breccia.

13:55-14:13 Camera 1&2: Highly fractured volcanic breccia. Sample #5.

14:28-14:29 Camera 1&2: Fractured layered (flat surface) volcanic breccia.

14:30-14:37 Camera 1&2: Highly fractured volcanic breccia.

14:40-15:02 Camera 1&2: Scattered angular blocks on muddy sedment. Sample #7.

15:03-15:16 Camera 1&2: Fractured volcanic breccia. Sample #8.

15:18-15:20 Camera 1&2: Fractured layered (flat surface) volcanic breccia on top of the hill (3620 m).

15:23-15:36 Camera 1&2: Fractured massive lava? or volcanic breccia and flat-surface layered volcanic breccia. Many open cracks filled with mud in the layered volcanic breccia. Hummocky topography at the summit area. Small conical-shaped muddy mounds on the surface may be formed by bioturbation.

Purpose of Dive

To reveal transportation and depositional mechanism of giant submarine debris avalanche, in-situ observation of the avalanche deposit is very important. Pervasive jigsaw cracks in the debris avalanche deposit can be used to reveal transportation mechanism of the debris avalanche. (1) Crack numbers per meter, (2) vertical and lateral variation, (3) crack pattern (fractography), (4) Fractal dimension, and (5) anisotropy of crack distribution will be investigated using video image and collected rock samples.

Rock samples dredged from site D6 by Kairei last year were similar to the rocks at east Molokai. Petrochemical analysis of rocks samples taken from the southewestern slope of the hummock will provide information of source area of the debris avalanche deposit (identical to Koolau, west Molokai, or east Molokai volcano?).

Debris-avalanche blocks and debris-avalanche matrix are common in subaerial debris avalanche deposits. These debris-avalanche blocks and matrix may be observed also in the submarine debris avalanche deposit.

Dive Results

The 499 dive track was along the southwestern slope of unnamed hummock at 22^{o}15'N, 156^{o}55'W. The on-bottom point was 4507 m in depth and the off-bottom point was at the summit of the western part of the hummock, 3610 m in depth. We moved to N40^{o}E direction from the on-bottom point for 800 m in lateral distance. The moving direction was changed to N60^{o}E at a point 4300 m in depth and traversed relatively steep slope for 1.3 km in lateral distance. The moving direction was changed to north at a point 3900 m in depth. We climbed on steep slope (<50^{o}) for 300 m in lateral distance. Then we reached the top of the summit at the western part of the hummock. We moved to NW for 200 m in lateral distance and off bottom at 3610 m in depth.

Scattered angular rocks was seen on muddy sediment on the lower gentle slope. Also, fractured massive lava and flat-topped layered volcanic breccia were observed on the gentle slope. Highly fractured volcanic breccia and flat-topped, indurated, layered volcanic breccia were observed on the middle and upper steep slope. The flat-topped layered volcanic breccia seemed mantling on the slope surface (bedding is parallel to the slope angle). The thickness of the layered volcanic breccia was > 50 cm. Open cracks (< 1 m in width) filled with mud were seen in the layered volcanic breccia. This mantle-bedding, flat-topped, layered volcanic breccia may have been formed during transportation of the debris avalanche. The formation process of this layered volcanic breccia is still unsolved. The summit area shows hummcky topography (>15 m in height). The summit area is also covered by flat-topped indurated layered volcanic breccia.

Weakly indurated mud clast containing angular lapilli and breccia were collected. No calcareous components was seen in the mud clast, suggesting deep sea pelagic sediment origin. This weakly indurated mud may be the debris-avalanche matrix, which formed by mixture of source material (lava and volcanic breccia fragments) and pelagic sediment during transportation. It is assumed that the pelagic sediment was incorporated into debris avalanche due to shearing at the base of the rapidly moving submarine debris avalanche, and the debris-avalanche matrix was produced by mixing between source material and pelagic sediment at the basal part. The debris-avalanhe matrix filled spaces between disaggregated debris-avalanche blocks due to lateral spreading of the debris avalanche.

Many jigsaw cracks were observed in volcanic breccia and massive lava. No obvious vertical variation of jigsaw crack intensity was identified. More detail video image analysis and rock sample analysis will be needed. Most rock samples collected in this dive were volcanic breccia. Many jigsaw cracks were seen in the volcanic breccia. (1) Crack numbers per meter, (2) vertical and lateral variation, (3) crack pattern (fractography), (4) fractal dimension, (5) anisotoropy of crack distribution will be investigated using video image and collected rock samples. Fig. 1 shows an example of fractal dimension analysis using collected rock sample.

Videolog of Dive 499

Time	Depth	Heading (。)	Position (x)	Position (y)	Description
11:52	4506	71	-680	-810	On bottom, thick mud with scattered anguler rocks
11:54	4507				push coring (black), **push core sample (black)**
11:57	4507				scattered rocks (<15cm) on sediment (>15cm in thickness)
12:00	4506	69			sampling a small pebble-size rock, **sample # 1** (conglomerate)
12:06	4506	75			debris
12:08	4500	60			sediment with small scattered rocks
12:09	4491	61			sediment with small scattered rocks
12:12	4457		-600	-720	coherent massive lava
12:13	4435				flat-topped layered volcanic breccia covered with sediment
12:14	4436	62			mud with pebble
12:15	4416	61			fractured massive lava
12:17	4375	61			massive lava and talus
12:19	4367	61	-380	-470	talus
12:20	4350	80			change heading to north
12:22	4334	81			scattered rocks on sediment
12:24	4315	90	-280	-250	scattered rocks on sediment
12:27	4285	90	-300	-50	scattered rocks on sediment
12:29	4272	75	-310	20	talus composed of volcanic breccia (<30cm in diameter) on sediment
12:34	4238				talus composed of volcanic breccia (<70cm) on sediment
12:36	4222	76			talus composed of volcanic breccia (<70cm) on sediment
12:38	4209	75	-190	140	talus composed of volcanic breccia (<70cm) on sediment
12:40	4191	76			talus composed of angular volcanic breccia
12:44	4165	71	-180	210	talus composed of angular volcanic breccia, **Sample#2** (two pieces of

					lava fragment with white creature)taken from talus deposit
12:51	4148	76			talus composed of angular volcanic lapilli and breccia (<70cm)
12:56	4093	84			fractured volcanic breccia (outcrop)
12:59	4090	78	-140	350	sampling, **sample#3**(two pieces of lapilli stone)
13:06	4055	90			rocks seen on the bottom
13:08	4044	84	-160	420	fractured, mantle-bedding, flat-topped, layered volcanic breccia
13:10	4025	74			fractured layered volcanic breccia
13:11	4020	53			fractured layered volcanic breccia, open cracks, some cracks are parallel, layering is parallel to the slope (mantle bedding)
13:16	4017	81			layered volcanic breccia
13:24	4016	64			layered volcanic breccia, attempting sampling
13:27	4016	72	-120	460	sampling (football size), **sample#4**(two pieces)
13:32	4005	69			fractured volcanic breccia, eastern area is steep slope
13:36	3988	15	-70	500	talus, volcanic breccia (<boulder size), changes heading
13:38	3949	17			outcrop, fractured volcanic breccia (<boulder size)
13:39	3943	29			fractured layered hyaloclastite
13:47	3867	35	270	750	scattered pebbles on layered volcanic breccia partly coverd with mud
13:48	3852	36	270	750	pebbles and breccias on mud
13:52	3819	6			pebbles and breccias on mud, change direction to north, grain flow deposit of pebbles
13:53	3793	6			pebbly sediments, sometimes layered volcanic breccia
13:55	3766	6	510	810	outcrop, volcanic breccia
14:01	3747	66			highly fractured volcanic breccia
14:07	3740	74	550	810	sampling, **sample#5**(large two pieces)
14:12	3735	6			fractured volcanic breccia partly coverd with mud
14:14	3722	25	560	800	fractured volcanic breccia partly coverd with mud
14:25	3718	55	580	810	sampling(breccia), **sample#6**(two pieces)
14:29	3707	50			fractured volcanic breccia partly coverd with mud (open cracks)

14:32	3698	46			highly fractured volcanic breccia (steep slope)
14:37	3664	21			highly fractured volcanic breccia partly covered with mud (steep slope) block<1m, grain flow deposits on surface
14:45	3649	55			try to get samples, hyaloclastite
14:53	3645	28	690	830	sampling(volcanic breccia), **sample#7**(two pieces)
15:00	3613	327			pebble to boulder-size talus, partly covered by mud, steep slope on left side
15:11	3612	68			sampling from highly fractured boulder (volcanic breccia), **sample#8**(three pieces)
15:18	3613	329	740	780	sampling finish
15:18	3612	320			flat-topped volcanic breccia, summit
15:20	3611	290			move to northwestward, hummocky hills
15:23	3613	290			small sily mounds, 10-30 cm in diameter (formed by bioturbation?), fractured volcanic breccia or lava?
15:25	3608	290			open cracks in layered lapilli-size volcanic breccia, partly covered with small silty mounds
15:36	3610	91	800	600	two push core samples from open cracks in layered volcanic breccia, off bottom, **push core sample:** white (push two times), black

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1B

DIVE No	6K-500	DATE	99/8/19
	NAME	AFFILIATION	
Japanese		Dept. of Geology and Geophysics, University of Hawaii, Honolulu	
SPECIALTY	Igneous Petrology, Volcanology, Marine Geology		
PURPOSE	To examine the internal structure of and collect samples from the submarine flank of Koolau Volcano		
AREA	Just offshore of the Kahuku area of Oahu Island, Hawaii		
SITE	Kahuku Steps		

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	21° 51.47' N	157° 45.50' W	11:21	3037 m
LEAVING	21° 50.53' N	157° 46.16' W	16:10	2602 m

DIVE DISTANCE:	2.6 km	DEEPEST POINT:	3037 m

DIVE SUMMARY

The dive track was chosen to study the internal structure and sample from a steep section of a basement rocks from Koolau volcano in the area of Kaiko dive 89. After landing a push core was taken of the mud.

Two traverses were made up steep rock sections. In both sections, a moderately dipping (15-25o) fan of submarine lavas include hyaloclastite breccia, pillow lavas and a mixture of pillows and breccia. The younger and deeper section had breccia on top grading with depth into pillows; the older upper section has the opposite sequence. The pillow lavas from the two traverses may be from the same unit. Although loose samples were collected at some sites, they were probably derived locally.Fifteen rock samples were recovered from 9 sites: 12 are from lavas; 3 are volcanic breccias (hyaloclastites). The rocks range from picritic basalts (>20% olivine) to aphyric basalts. Under a thin to

PAYLOAD						
VISUAL RECORDS	VTR1	VTR2	STILL CAMERA	400 Yes	ONBOARD CAMERA	No

SAMPLE	Organisms:	Rocks: 15	Push Cores: 1	Water: cc
	Sediments:	Others:	TOTAL: 16	

VIDEO HIGHLIGHTS	1) 12:50- 12:51	2) 13:26- 13:36	3) 15:45- 15:51

KEY WORDS	pillow lavas, hyaloclastite, volcanic breccia, basement, vesicularity

Results of Shinkai 6500 Dive #500

Date: Aug. 19, 1999
Pilot: Kazuk Iijima Co-pilot: Haruhiko Higuchi
Science Observer: Michael Garcia, University of Hawaii

Dive Location: Kahuku Steps, northeast flank of Oahu Island, Hawaii

Objectives

The dive track was designed to study the internal structure and sample from a steep section into the basement of Koolau Volcano in the same area of the successful Kaiko dive #89. The goal of this Shinkai dive was to determine the rock type variations, rock orientations and to sample within the dissected flank of the Koolau Volcano to evaluate models for the evolution of Hawaiian volcanoes. A previous Shinkai dive (#496) in the same area found a landslide block and hyaloclastite debris rather than pillow lavas. The new dive site was selected to overlap with the area where we found pillow lavas during Kaiko dive 89 and to extend to lower and shallower depths. The dive was to consist of 3 sections, with the middle one overlapping with the Kaiko dive area.

Dive Summary

We overshoot our landing site and landed somewhat deeper and in a basin of mud. After taking a push core of the mud, we ascended the gentle slopes of the first section until the slopes steepened and we arrived at the base of volcanic breccia section. The breccia was clast supported and coarsened with depth. A loose block from the base of this deposit was sampled. and at the base of the two steep sections that were investigated. This mud appeared to be relatively thin (< 1 m) to overlie a slope-mantling volcanic breccia deposit.

Two traverses were made up steep rock sections. In both sections, a moderately dipping (15-25o) fan of submarine lavas include hyaloclastite breccia, pillow lavas and mixed pillows and breccia. The younger, deeper section (3037-2695 m), had breccia on top grading with depth into pillows; the older, upper section (2815-2602 m) was the opposite. The pillows lavas from the two traverses may be from the same unit sandwiched between different hyaloclastite units. Although loose samples were collected at some sites, they were probably derived locally.

Fifteen rock samples were recovered from 9 sites: 12 are from lavas; 3 are volcanic breccias (hyaloclastites). The rocks range from picritic basalts (>20% olivine) to aphyric basalts. Under a thin to moderately thick Mn coating, (<1-5 mm) the rocks are relatively fresh and some should be suitable for Ar-Ar dating. A push core of mud was also taken near the beginning of the dive.

Dive Interpretations

The northeast flank of Koolau is the only area we have been able to sample good outcrops of pillow lavas. We have made repeated attempts to sample other areas that are remnants of the Koolau Volcano and have found only fragmental debris. Thus, it would appear that the outer portion of the Koolau Volcano, and probably other Hawaiian volcanoes, are comprised of fragmental debris and proposed by Moore and Chadwick (1994). This interpretation has fundamental implications for the structure of all oceanic island volcanoes and indicates that a major portion of these volcanoes is composed of relatively low seismic velocity, poorly to moderately consolidated debris. This debris may be inherently unstable and be the explanation for why landslides are so common on oceanic island volcanoes.

Relatively fresh rocks were obtained from the volcanic breccias and pillow lava outcrops. Although these outcrops have Mn coatings, the underlying rocks have experienced limited alteration over the last few million years. The cold temperatures of the seawater (~1oC) where these were located may retard the alteration of the rocks. The low vesicularity of most of the collected rocks (1-5 volume %) indicates that these lavas were probably subaerially erupted and then flowed into the ocean. The mostly likely means for allowing these lavas to cross the seashore without fragmenting is in lava tubes. One small (~1 m wide, 0.3 m tall) lava tube was observed in the upper section of pillow lavas. The presence of this open lava tube may also indicate that these lavas were not deeply buried.

Cautionary note: It is essential to pick steep sections for dive targets if one hopes to observe and sample ‘in place’ rocks. Mud and talus obscures the basement rocks in areas with gentle to moderate slopes.

Table 1. Video Highlights for Shinkai dive 500
(for a detailed summary see attached table)

Time	Depth (m)	Feature
11:21	3037	On bottom; mud covered surface; push core taken
11:39	2980	First outcrop of volcanic breccia; rock sample #1
12:29	2994	Volcanic breccia with pillows; sample #3
13:04	2906	Pillow lavas mixed with breccia
13:26	2810	Volcanic breccia coarsing upsection
13:34	2754	Nice pillow lavas
15:08	2815	Pillow lavas from base of traverse two
15:42	2652	Pillow lavas grading upsection into breccia
15:45	2645	More pillows; sample #8 taken
16:02	2602	Pillow breccia; Sample #9; Leaving bottom

Table 2. Rock samples recovered during Shinkai 6500 Dive 500

Sample	Depth	Rock types	in place; probably source	Relative Age
Traverse One				
1	2980	picritic basalt	no; probably locally derived	7
2A	2986	picritic basalt	yes; ripped from outcrop	8
2B	2986	picritic basalt	yes; ripped from outcrop	8
3A	2994	olivine basalt	no; probably locally derived	9
3B	2993	volcanic breccia	no; probably locally derived	9
4A	2830	volcanic breccia	yes; ripped from basement	6
4B	2830	volcanic breccia	yes; ripped from basement	6
5A	2698	basalt with olivine	no; probably locally derived	5?
5B	2696	picritic basalt	yes; ripped from basement	5
Traverse Two				
6	2815	picritic basalt	no; probably locally derived	1 (oldest)
7	2743	weakly phyric basalt	no; probably locally derived	2
8	2646	olivine basalt	yes; ripped from outcrop	3
9A	2602	aphyric basalt	no; probably locally derived	4?
9B	2602	weakly phyric basalt	yes; ripped from basement	4

Acknowledgments: Thanks to Drs. Yokose, Moore, Clague, Takaraka and Takahashi and Mr. Shinozaki for their help with the dive log and rock descriptions, to the Shinkai navigation team for keeping good position of the sub at all times and to the pilots of the Shinkai sub for their good work picking up samples and making this dive so successful.

Video Log of Dive500

Time	Depth	Heading		Sample
	m	(°)		
11:21	3036	287	On bottom, thick mud	push core taken (black)
11:30	3021	185	started moving; thick mud with some rock talus	
11:35	2980	179	talus	

11:38	2980	185	volcanic breccia	Rock sample # 1
11:45	2985	109	volcanic breccia	
11:48	2986	152	volcanic breccia; A- orange size but broke into many pieces, 2986 m; B- grapefruit size, 2987 m	Samples #2 A and B
12:18	2994	188	rock sampling from base of massive breccia outcrop; two loose rocks taken	Samples # 3A and B
12:31	2985	185	mud	
12:33	2973	186	more mud with some talus	
12:35	2973	186	bedded hyaloclastite	
12:37	2951	186		
12:44	2930	186	mud with some pebbles	
12:45	2918	221	pillow lava; stopped to collect but lost outcrop in muddy water	
13:11	2871	221		
13:17	2830	187	hyaloclastite coarse breccia	Sample#4
13:34	2754	159	pillow lava; stopped to collect but unsuccessful	
14:02	2700	151	volcanic breccia	
14:24	2694	198	pillow lava breccia; A-loose rock; 2698; B- broken from outcrop, 2696	Sample #5 A and B
14:30	2670	231	moving toward WSW in mid-water	
14:34	2648	231	moving toward WSW in mid-water	
14:37	2640	231	moving toward WSW in mid-water	
14:38	2633	270	change the direction to W	
14:42	2629	285	change the direction NW	
14:45	2628	285	descending to bottom	
14:59	2818	181	on bottom, thick mud	
15:09	2815	151	pillow lava	Sample #6 from talus pile
15:18	2775	180	volcanic breccia	
15:33	2743	181	pillow breccia	Sample #7 from outcrop
15:41	2660	181	talus	
15:44	2643		volcanic breccia with some pillow fragments	
15:45	2646	92	pillow lavas	Sample #8 from outcrop
15:56	2627	180	pillow lavas	
15:59	2602	145	lobate pillow lavas; A- loose talus; B-	Sample #9; A and B

			broken off outcrop	
16:10	2602		Off the bottom	

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1B

<table>
<tr><td>DIVE No.</td><td>6K-501</td><td colspan="2">August 20, 1999</td><td></td></tr>
<tr><td></td><td colspan="2">NAME</td><td colspan="2">AFFILIATION</td></tr>
<tr><td>Japanese</td><td colspan="2">James G. Moore</td><td colspan="2">U. S Geological Survey
(retired)</td></tr>
<tr><td>SPECIALTY</td><td colspan="4">Volcanology</td></tr>
<tr><td>PURPOSE</td><td colspan="4">Geological observations and sampling of rock making up N slope of second</td></tr>
<tr><td>AREA</td><td colspan="4">Wailau Landslide N of Island of Oahu.</td></tr>
<tr><td>SITE</td><td colspan="4">N slope at W end of elongate blocky seamount</td></tr>
<tr><td></td><td>LATITUDE
N</td><td>LONGITUDE
E</td><td>TIME</td><td>DEPTH
m</td></tr>
<tr><td>LANDING</td><td>21° 43.31’ N</td><td>156° 58.68’W</td><td>1147</td><td>4469</td></tr>
<tr><td>LEAVING</td><td>21° 42.87’ N</td><td>157° 58.47’ W</td><td>1521</td><td>3898</td></tr>
<tr><td>DIVE DISTANCE:</td><td>1300 m</td><td colspan="2">DEEPEST POINT:</td><td>4469 m</td></tr>
<tr><td>DIVE SUMMARY</td><td colspan="4">We landed part way up the N slope of the large second elongate block of the Wailau landslide at a water depth of 4469 m, and climbed S up to near the highest point of the seamount slope for a rise of about 571 m to 3898 m. The overall slope averaged about 25 degrees Much of the lower 250 m was covered with light colored sediment, or an indurated scree composed of sediment mixed with angular gravel. This mantling scree was cut through in sediment-filled chutes, and could be seen to be 0.4-1 m thick.
Above the sedimented slope we passed into a region of many outcrops, some with deep chutes carved in them, and most with a massive aspect which made sampling difficult. Above 4075 m the rock became more intensively fractured, and some seemed to resemble pillow lava.</td></tr>
<tr><td></td><td colspan="4">Two sample baskets, 4 push core samplers</td></tr>
<tr><td>VISUAL RECORDS</td><td colspan="4">VTR1, VTR2, Still Camera</td></tr>
<tr><td>SAMPLE</td><td colspan="4">Organisms: Rocks: 8 Cores: 1 Water: cc
Sediments: Others: TOTAL: 9</td></tr>
<tr><td>VIDEO HIGHLIGHTS</td><td colspan="4">1334, 1335: massive outcrops cut by deep chutes.
1442, 1445, 1505: fractured, shattered outcrops = hyaloclastite</td></tr>
</table>

KEY WORD	Molokai landslide, Wailau landslide.

6K 501 Dive Results

Objective

The objectives of dive 501 was to determine with observations and samples the makeup of the large landslide block 37 km long and 7 km wide which is the second large block north from the headwall of the Wailau Landslide. The landslide extends an undertermined distance north from the north shore of East Molokai. The wall examined is believed to be a giant fracture surface where this block has broken away from adjacent blocks, (all originally making up the East Molokai volcanic edifice) and moved downslope tens of kilometers to its present position. Composition and structures of the collected lavas will be compared with those from the Molokai mainland in order to shed light on the prelandslide structure of the volcano. The data collected will be compared with that collected in Shinkai dives from the Nuuanu Landslide in order to understand the disputed age relationships between these two giant landslides.

Geologic Observations

We landed at 1145 at 4468 m on a sloping plane of white sediment. The pushcore was used to collect soft sediment. Scattered gravel-sized rocks as well as blocks and boulders that apparently originated from above and slid or rolled downslope.are scattered and one was collected nearby as Sample #1 at a depth of 4469 m.

Sample #2 (4366 m) was taken from an exposed ledge of a gravelly inderated scree deposit that no doubt contains material that had moved downslope.. These slope-mantling deposits are common; they are 0.5 to more than 1 m thick. Samples #3 (4316 m) was collected from apparent bedrock exposed in the margin of a sediment-filled chute conducting debris down the steep slope.

Upon ascending, at a depth of 4218 m, we encountered a terrain of massive sculpted outcrops producing smooth bluffs of solid rock. Sampling in this terrain was a challenge, and several attempts to sample were abandoned. At 4195 m Sample # 4 was collected, and at 4141, sample #5 was collected.

At about 4075 m the character of the mountain wall changed to a more irregular character, exposing jointed and fractured bedrock from which samples could by more easily collected. Sample #6 was collected at 4062 m, sample #7 at 4005 m, and sample #8 at 3890 m. Time ran out and Shinkai left the bottom at 1521, 3890m. The summit of the landslide block was not attained, but it was less than 100 m above the point at which the dive was terminated.

Preliminary inspection of the samples indicates that most are hyaloclastite breccia. The lesser amount of MnOx rims and the much glassier nature of the hyaloclastite samples (relative to samples from the Nuuanu landslide blocks) strongly suggests that the Wailau landslide is considerably younger than the Nuuanu landslide. However,k at least one more Wailau block should be sampled to support this notion.

Video Record, Camera # 2

Time	Depth, m	Comments
1141	4429	Sonar showing wall and outcrops to N
1145	4468	Reached bottom, covered by white sediment
1149	4468	Taking Core # 1. Position: .580,-290.
1155	4468	Scree deposit about 1 m thick exposed in chute wall
1159	4469	Sample #1. Large block of fine hyaloclastite mud.
1207	4465	Muddy bottom with pebbles and some loose blocks
1208	4461	Low ledge of mantle-bedded scree
1211	4461	Layered scree.
1211	4461	Attemped to sample consolidated scree, too soft.
1218	4458	Pebbly bottom, some blocks
1220	4454	Sandy, muddy bottom.
1222	4454	Attempting to collect from poorly consolidated ledge.
1229	4450	Underway, sediment bottom
1231	4441	Rubbly bottom, some sand.
1234	4418	Low ridge of hyaloclastite
1237	4412	Much larger hyaloclastite outcrop.
1240	4412	Attempting to sample, but following current concentrates muddy plume, making visibility difficult. Position- 440-300.
1244	4391	Pebbly sediment.
1249	4368	Pebbly sediment, a sloping mantling deposit.
1253	4366	Purple sea slug, and protruding float rock which will be collected as, Sample #2. Pos: 410, -240.
1302	4350	Sediment covered bottom
1303	4342	Linear steps in outcrop of hyaloclastite, looking down cliff in outcrop, down gully walls.
1305	4328	Layered outcrop as exposed in chute walls.
1308	4316	Sampling on chute walls, apparent hyaloclastite. Note overall uniformity of massive outcrop..
1319	4314	Sample #3. [hyaloclastite breccia]. Pos: 280, -200.
1324	4297	Sandy-muddy bottom. Bottom is scored by chutes,

		the walls of which expose mantling deposits of scree.
1331	4226	Position: -190, -140.
1334	4298	Sampling on big bluff of solid, massive outcrop, sampling was abandoned 10 minutes later.
1345	4191	Massive sculpted cliffs, with deep chutes.
1349	4195	Sampling again on coherent and somewhat fractured outcrop.
1405	4188	Sample #4. Position 110, 160.
1410	4161	Moving up steep outcrop.
1412	4146	Fractured outcrop.
1415	4142	Sample #5, 2 pieces. [hyaloclastic breccia] Position: 30, -100.
1418	4140	Underway.
1423	4119	Massive solid outcrop
1430	4080	Continuous hyaloclastic outcrop.
1431	4081	Layered outcrop; more breccia?
1436	4075	Position: -70, -70
1445	4068	Outcrop of coarse fractured breccia. Note what appear to be gently dipping layers with perpendicular joints. Sample #6, position: -100, -60.
1450	4055	More brecciated outcrops.
1452	4052	Layered jointed rock.
1455	4038	Fractured and brecciated outcrops.
1458	4020	Massive, coarse, blocky outcrop
1500	4005	Finer-grained clasts. Sample #7 [picritic hyaloclastite breccia]. Position: -100, -60.
1510	3916	Fractured wall outcrop.
1511	3899	Collecting fractured lava-like rock.
1519	3890	Sample #8. [hyaloclastite breccia]. Position: -340,-40.
1522	3890	Leaving bottom.

Sample List, dive 6K-501

Sample	21°N	156° W	Depth	MnOx

	m			
Core	43.31’	58.68’	4469	
1	43.31 <0.5	58.68	4469	Hyaloclastite breccia
2	43.22	58.64 thin	4366	Hyaloclastite breccia.
3	43.15 0.5	58.61	4314	Hyaloclastite breccia
4	43.06 1	58.58	4188	Oliv basalt, fresh
5	43.01 0.2	58.55	4142	Hyaloclastite breccia
6	42.95 thin	5852	4068	Hyaloclastite breccia
7	42.91 thin	58.52	4005	Hyaloclastite, oliv.
8	42.87 <1	58.47	3898	Hyaloclastite, oliv.

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1B

DIVE No.	502	DATE	Aug. 22, 1999

	NAME	AFFILIATION
Japanese	宇都浩三	地質調査所地殻化学部
SPECIALTY	[illegible]	
PURPOSE	Origin of the North Arch volcanic field	
AREA	North Arch volcanic field	
SITE	360 m high vent cone in the southern central area	

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	23 ° 35.4’ N	157 ° 43.5’ W	11:44	4403 m
LEAVING	23 ° 35.3’ N	157 ° 42.5’ W	15:20	4065 m

DIVE DISTANCE:	2000 m	DEEPEST POINT:	4403 m

DIVE SUMMARY	We dived one of the vent cone area of the North Arch volcanic field. We started the dive from the western foot of the cone, where we found the very prominent pressure ridge of a lava flow above the mud, and succeeded in collecting very dense twisted pahoehoe-like smooth lava fragment with glassy skin. On the western slope of the cone, we observed the alternation of pillow lava, slab pahoehoe-like vesiculated thin sheet lava flow, and hyaloclastite. They were inclining to the west with the slightly shallower dip angle than the cone slope. We collected a few viesicular pillow and slab lavas and one hyaloclastite fragment. After arriving to the top of the western crater rim of the cone and collecting a pillow lava, we moved to the crater floor, and started to climb the southern inner wall of the crater. We observed mainly the pillow lava talus with some outcrops of the pillow lobe, and saw sheet flows only a little. We collected two viesicular
PAYLOAD	Four push core sampler and sample basket
VISUAL RECORDS	VTR1 2 VTR2 2 STILL CAMERA 317 ONBOARD CAMERA YES
SAMPLE	Organisms: 0 Rocks: 11 Cores: 1 Water: 0 cc Sediments: a few g Others: TOTAL:
VIDEO HIGHLIGHTS	1）12:05-12:10 2）13:15-13:18 3）15:12-15:14

KEY WORD	North Arch volcanic field, alkali basalt, Hawaiian Arch, vent cone, pillow lava, sheet lava, hyaloclastite

DIVE SUMMARY AND RESULTS

Abstract

Dive #502 was conducted at the 360-m high vent cone in the southern central area of the North Arch volcanic field. We landed at the western foot of the cone, where we found the very prominent pressure ridge of a lava flow above the mud, and succeeded in collecting very dense twisted pahoehoe-like smooth lava fragment with glassy skin. On the western slope of the cone, we observed the alternation of pillow lava, slab pahoehoe-like vesiculated thin sheet lava flow, and hyaloclastite. They were inclining to the west with the slightly shallower dip angle than the cone slope. We collected a few viesicular pillow and slab lavas and one hyaloclastite fragment. After arriving to the top of the western crater rim of the cone and collecting a pillow lava, we moved to the crater floor, and started to climb the southern inner wall of the crater. We observed mainly the pillow lava talus with some outcrops of the pillow lobe, and saw sheet flows only a little. We collected two viesicular pillow lavas. On top of the southern crater rim, we observed many elongated pillow lava flows, and collected one pillow lava and one hyaloclastite. We collected 15 volcanic samples from 11 localities and one push core sample.

要旨

第 502 回潜航は，North Arch 火山地域の南部中央地域の比高 360m の噴火口丘において実施された．火口丘の西側山麓の平坦地に着底し泥の上に非常に明瞭なプレッシャーリッジを持つ溶岩流を観察し，ガラス質表皮を持ち緻密でなめらかな表面を持つねじれたパホエホエ的な溶岩の採取を行った．火口丘西側の外斜面では，枕状溶岩，スラブパホエホエ的で発泡した薄いシート状溶岩およびハイアロクラスタイトの互層を観察した．それらは，西側に向かい，斜面の傾斜より若干緩やかな角度で傾斜している．この斜面上でいくつかの発泡した枕状およびシート状溶岩とひとつのハイハロクラスタイトを採取した．火口丘西縁頂上に到着して枕状溶岩を採取したのち，火口底に移動し，火口南側の内側斜面を上昇した．そこでは，主に枕状溶岩の崖錐が発達していたが，いくつかの枕状溶岩ローブおよびシート状溶岩の露頭も認められた．二つの発泡した溶岩流を採取した．火口丘南縁頂部において，多数の伸長した枕状溶岩を観察し，枕状溶岩とハイアロクラスタイト試料を各１試料ずつ採取した．本潜航全体で，11 カ所において合計 15 試料の火山岩試料と１つのプッシュコア試料を採取した．

Purpose of the dive

The North Arch volcanic field is a widespread alkali basalt lava flow field, located 200-400 km north of Oahu Island on the Hawaiian Arch. Flat-lying sheet-like lava flows cover an area of about

25,000 km3. Small hills consisting of pillow lavas and hyaloclastites occur within the field, and some of them might have formed by explosive volcanism due to the high volatile contents, particularly CO_2 under the depth of 4,500 m below the sea level. Eruptive products are nephelinite and alkali olivine basalt, and their eruptive ages are estimated to be about 0.5 to 2 Ma. These lavas are contemporaneous with chemically similar Honolulu volcanics on Oahu Island, but more than 1000 times larger in eruptive volumes.

Despite the importance of the magmatism of the North Arch lavas, only a little is known for the occurrence and origin of the volcanism mainly due to the difficult access to the volcanic field. Main purpose of the dive is to investigate one of the vent areas to know the style and mode of eruption and emplacement of the highly vesiculated alkaline basalt with abundant volatiles under the deep-sea (4000 m). It is also important to collect samples of eruptives for the geochemistry and $^{40}Ar/^{39}Ar$ dating.

Dive results

We landed on the flat ocean floor, 4404 m below the sea level, about 400 m to the west of the foot of the vent cone about 360 m high. First we saw was thick mud and scattered rock fragments, but we quickly encountered lobate or flattened lava flows and sheet lava flows above the mud. Elongated pressure ridges are occasionally found on the surface of lava flows. The largest one is about 10 m long, 5-8 m high and 4-6 m wide. The samples collected from these lava flows are dense aphyric basalt with rare vesicles and olivine crystals. Thin (1-2 mm) glass layers are found in between dense crystalline inner part and thin (<1 mm) Mn coats attached along the surface. We started to climb along the western outer slope of the cone. In the lower part of the cone, we observed mainly pillow lavas and breccia. Samples collected from this part are moderately vesiculated olivine basalt. In the middle part of the slope, brecciated hyaloclastites became gradually dominant. They gradually became to form thin slab-shaped layers slightly more gentle to the cone slope. Lobate pillow lavas again become more dominant toward the upper slope of the cone, and they interlayered with sheeted hyaloclastite. 5-cm thick slab sample taken from the depth at 4224 m was a lapilli tuff made up of angular glassy fragments embedded among the brown soft mud matrix. Most glass fragments are quite vesicular and have palagonite rims ~0.2 mm thick. This texture indicates that this cone was made in some part by the explosive eruption of basalt magma under the very deep ocean floor at about 4400 m depth. Toward the top of the western rim of the crater, the alternation of rounded pillow lavas and slab-shaped hyaloclastite continued, but the elongated bulbous pillow lavas gradually became dominant. These pillow lavas are highly vesiculated containing 30-40 % bubbles. Most of them are confined bubbles but some of them are interconnected to form bigger vesicles. On top of the western crater rim, about 4040 m high, very large elongated bulbous pillow lavas and sheet lava flows are dominantly scattered and covered the surface. A layered lapilli tuff with angular scoriatious blocks attached is recovered from the top.

We left the western crater rim and proceeded into the crater, and landed again on the southern end of the crater floor at about 4220 m depth. We again started to gradually rise along the southern inner wall of the crater. There exposed are mostly talus of pillow breccias and some in-situ pillow lava flows.

Similar lithology continued nearly to the top of the crater, but elongated pillow lava lobes and slab-shaped hyaloclastite layers became dominant where the slope became gentle near the southern crater rim. We again collected one pillow lava block with abundant vesicles and one slab-shaped lapilli tuff block containing vesicular and angular glass fragments among the muddy matrix. On top of the southern crater (4065 m depth), abundant elongated pillow lavas with various shape were scattered and seemed to form a pillow mound. We left the bottom and started to rise to the sea surface from this point.

As a conclusion, we made following observation.

1. There are sheet and pillow lava flows existed at the western foot of the vent cone.
2. Western cone is made up of pillow lavas, breccia and layered hyaloclastite.
3. Southern cone is made up of mainly pillow lavas with occasional slab-shaped hyaloclastite.
4. Explosive eruption seems to have occurred to form at least a part of the cone.
5. Cone forming pillow lavas are highly vesiculated suggesting the vigorous vesiculation of volatiles during the effusion.
6. Lobate pillow flows and sheet flows on the western foot of the cone are dense and crystalline except for the thin glassy rim suggesting that most volatiles are escaped during the outflow of lavas.

Video Log DIVE #502, August 22, 1999, North Arch volcanic field, Camera #2

Time	Depth	Heading	Description
11:44	4404	115	Landed on bottom, thick mud with scattered rock fragments on mud
11:57	4403	162	mud(>50 cm thick) and scattered rock fragments, Push core-1, Sample#1(2)
12:02	4402	90	Started to move toward the east
12:03	4401	87	Lobate or flattened pillow and sheet lava flow
12:04	4401		Elongated pressure ridge of lava flow, ~5 m high
12:07	4401	133	Basket ball size lava taken from the smooth lava surface on the crest of the ridge, Sample #2
12:20	4400	82	Sheet lava flows and lobate pillow lava flows with/without thin mud cover
12:23	4399	68	Large bulbus and elongated lobate pillow lavas. Some pillows have twisted arm. Sample #3
12:34	4398	94	Very flat and drapery surface of lava flow with/without thin cover of mud
12:36	4399	94	Rock fragments rich, very flat surface
12:42	4382	68	Angluar blocks increased in size and volume. Some are pillow fragments.

12:48	4371	54	Collected a highly fragmented rock sample, Sample #4
12:54	4365	65	Steep wall made up of pillow lavas and/or breccia moderately covered by mud. Hyaloclastic materials fill between pillow and angluar blocks.
12:58	4330	70	elongated pillow lavas
12:58	4324	72	Finely fragmented hyaloclastite layer (~ 1 m thick)
13:02	4312	62	Rough layering of block rich hyaloclastite and pillow breccia, Sample #5
13:11	4281	65	Slab-shaped hyaloclastites start to appear
13:14	4237	65	sheeted hyaloclastite became dominant
13:18	4224	65	Slope became gentler, and slab-shaped hyaloclastite widely appeared on the surface subparallel to the slope, Saple #6
13:35	4212	81	Alternation of lobate pillow lavas and hyaloclastites
13:44	4194	56	Alternation of lobate pillow lavas and hyaloclastites, subparallel to the cone surface
13:48	4144	56	Large pillow lavas increased
13:52	4096	47	Pillow lavas and slab-pahoehoe like sheet lavas
13:58	4091	71	Stopped and collected pillow and sheet lavas (three blocks),sample #7
14:01	4083	67	Steps made of alternation of sheet and pillow lavas
14:05	4053	27	Arrived at the top of the western crater rim. Very large elongated bulbus pillow lavas and sheet lavas
14:25	4038	130	Flat top of the crater rim, collected a lava block, sample #8
14:36	4079	121	Started to move toward the crater floor
14:45	4221	115	Arrived at the southern end of the crater floor
14:47	4221	121	Leached the southern inner wall of the crater. Pillow breccia mostly talus but some in-situ lavas
14:51	4210	104	Collected a loose large lava block, and start rising along the moderately inclined crater wall ,mostly talus of large pillow lava blockssaple #9
15:06	4114	161	Near the top of the southern crater rim. Collected lava block,sample #10
15:10	4096	121	Hyaloclastite layer and overlying large pillow lava layer
15:16	4068	68	Leached on top of the southern crater rim. Elongated pillow lavas with various shapes
15:18	4065	83	Collected a lava block, Sample #11
15:20	4065		Pillow lava mound, off the bottom

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1B

DIVE No.	6K503	August 23		
	NAME		AFFILIATION	
Japanese	David A. Clague		MBARI	
SPECIALTY	Volcanology, Marine Geology			
PURPOSE	Geological observations and sampling of lavas exposed in the wall of a pit			
AREA	North Arch Volcanic Field, N of Island of Oahu.			
SITE	**South scarp in pit crater and along southwest rim of pit crater**			
	LATITUDE	LONGITUDE	TIME	DEPTH (m)
LANDING	23° 56.90’ N	157° 40.74’ W	1150	4655
LEAVING	23° 56.74’ N	157° 41.06’ W	1526	4330
DIVE DISTANCE:	600 m	DEEPEST POINT:	4684 m	
DIVE SUMMARY	We landed near the bottom of the roughly 1-km diameter pit crater in fine light sediment with many talus blocks, some as large as 2-3 m across. The lower south slope in the crater was mantled with talus and sediment from 4684 to 4462 m depth. Starting at 4462 and continuing to the rim of the crater at 4340 m, the wall is a near-vertical outcrop of truncated pillow lavas and interbedded massive flows, the thickest of which is more than 5 m thick. The total thickness of lava exposed in the pit crater wall is 122 m, and is a minimum thickness for the North Arch field in this area, since the section below the lava flows was covered by talus. The upper rim is sharp and the surface is covered with young-appearing folded sheet flows with only a thin discontinuous sediment cover. This surficial flow is only 1.5 to about 3 m thick in the uppermost wall of the pit crater. There are some open cracks that are concentric with the rim of the pit crater; these postdate the lava flows. Moving northwestward towards a low			
PAYLOAD	Two sample baskets, 7 push core samplers			
VISUAL RECORDS	VTR1, VTR2, Still Camera			
SAMPLE	Organisms: Sediments:	Rocks: 9 sites Others:	Cores: 2 TOTAL: 11	Water:
VIDEO HIGHLIGHTS	1235-large talus blocks on lower slopes, 1320-truncated pillow lavas in vertical wall, 1404-thick massive flow, 1422, 1435, 1442, 1459-excellent sheet flows, 1515-large pillow lavas			

KEY WORD	North Arch Lava Field, alkalic basalt, pit crater, pillow lava, sheet flow lava

Results of Dive #503

Date: August 24, 1999
Place: Pit Crater in North Arch Lava Field
Pilot: Satoshi OGURA, Co-pilot: Kazuki IIJIMA
Observer: David CLAGUE

Abstract

The dive track began at the base of a roughly 300-m-deep pit crater in the central part of the North Arch Volcanic Field. The pit crater is located just east of a low broad lava shield. This is the only pit crater in the North Arch flow field and the dive plan was to determine the thickness and chemical stratigraphy of lavas exposed in the wall of the pit and to examine the low shield adjacent to it. The inner ~30 degree slope of the pit is mantled with talus and moderately thick sediment from 4484 to 4462 m. The upper wall of the pit is a near-vertical outcrop of interbedded pillow lavas and massive lava flows. The rim at 4340 m is sharp and the folded sheetflows are truncated by the pit. The surface folded and striated sheetflows, lobate flows, and pillow flows have only thin sediment cover, suggesting they may be one of the younger lava flows in the North Arch Volcanic Field.

Purpose of Dive

The North Arch Volcanic Field covers some 25,000 km2, but its thickness and therefore, its volume are only poorly constrained. The great depth of the pit crater (from 270-330 m, depending on which rim you measure from) suggested that we could determine the thickness of the accumulated flows in this central region of the flow field and thereby constrain the total volume of the field. In addition, the individual sheetflow eruptions may be of long duration and we expected to be able to evaluate the sequence of lava compositions erupted during a prolonged eruption by sampling and analyzing a sequence of samples from the walls of the pit. We also wanted to observe the flow morphologies of near-vent lavas from a shield to determine the rheology and degassing history of the lava and perhaps estimate the magma supply rate for such eruptions.

Dive Results

The dive began near the deepest part of the pit crater and immediately determined that the floor of the crater at 4684 m was not flat, but instead consisted of coalesced talus slopes from all sides. The bottom had a fairly thick covering of sediment, and talus blocks were observed scattered in this sift sediment. Some large blocks of massive dense basalt as large as 5 meters across were observed, although most of the talus is smaller fragments less than a meter across. Some blocks have up to 10-15 cm of sediment perched on their flat tops. The talus slopes upwards towards the south rim at an angle of about

30 degrees. At 4462 m, the talus abruptly ends in a steep wall of pillow basalt that has a slope of perhaps 60 degrees. This first outcrop is perhaps 15 m tall, then there is a small shelf, now filled with sediment, before the wall rises as a nearly vertical outcrop of truncated pillow basalts and interbedded massive flows. The thickest massive flow is more than 5 m thick. The southern rim of the pit is at 4340 m. The surface flow consists of an elaborately folded (drapery folding) sheetflow that flowed towards, rather than away from the pit. Circumferential cracks parallel the rim of the pit and offset the sheetflow.

On a traverse towards the nearby lava shield, we crossed more folded sheetflows, flat striated sheetflows, lobate flows, and pillow flows. There is a lava channel, again directed downslope towards the pit, that has small levees and striated sheetflows within. An elongate tumulus is aligned along the center of the channel. The sediment cover on all the different flows on the rim of the pit is quite thin and discontinuous, suggesting that the flow is quite youthful compared to other flows in the North Arch, which were everywhere buried beneath at least 0.5 m of sediment.

The scientific findings on the dive include determining that the lava in this region is at least 122 m thick. This is far thicker than previously thought and requires that estimates of the flow field total volume be revised upwards significantly. We also determined that the pit crater is not an eruptive feature and does not surmount a lava shield, Instead, it is located adjacent to a lava shield and must postdate the eruption of most, if not all, the lavas from the shield (or the pit would have filled with lavas). These observations should allow us to develop models for the formation of pit craters in non- rift settings. We collected a sequence of lava flows from the wall of the pit that will allow us to determine the geochemical variations during long-sustained eruptions. Such changes may hold the key to understanding magma generation, accumulation, and transport in the mantle. We also determined that the areally extensive lava flows that make up the North Arch field are mainly sheetflows of extremely fluid lava that forms thin flows near the vents. The intricately folded flow tops will be useful in trying to quantify the rheologic properties and flow rates of these lavas. In addition, the lavas close to the vent are mostly highly vesicular, compared to the dense glassy flows sampled previously away from the vents. The loss of gas bubbles soon after eruption reflects the low viscosities of these lavas and serves to decrease the already low viscosities and enhance the ability of these flows to travel long distances on nearly horizontal surfaces.

Videolog of Dive503

Time	Depth	Heading	Position	Position	Description	Sample
		(。)	(x)	(y)		
11:40					sonar shows crater elongate N-S, but oval shaped	
11:53	4655	137	0	410	On bottom, many rock fragments in sediment	
11:56	4655	198			head to the point 1	
12:00	4674	333			Mud with basalt rubble	
12:03	4665	134	50	380	mud	
12:20	4684	21	50	370	Gravels scattered on mud; got large amount of mud in basket by accident	Core 1(Yellow+black), Sample #1(2 rocks)
12:23	4685	231			Big block	
12:27	4681	181			heading south	
12:36	4625	181			tabular angular blocks scattered in the mud	
12:38	4606		-100	320		
12:48	4586	154			steep slope, gently dipping semi-lithified volcanic rubble	Sample #2(2 friable rocks)
12:51	4578	163	-190	340	sampling succeeded	
12:55	4541	175			~30 degree slope, angular blocky talus above mud	
13:02	4460	172			first outcrop; steep wall of pillows, poor image (too distant)	
13:05	4444	143	-420	340	angular blocks and mud cover at base of second steep outcrop	Sample #3(2 moderately large blocks)
13:31	4420				moved up near vertical wall; pillows in cross section	
13:44	4435	173			steep wall, fractured pillow lava	
13:40	4421	173	-410	350	closely packed pillow lavas	Sample #4 (1)
13:55	4396	192			continuous exposure of pillow lava, thin mud under massive flow	Horizontal core #2(green)
14:00	4382	155	-440	340	continuous exposure of pillow lava	Sample #5(1)
14:04	4369				thick massive flow, then pillows, then another massive flow	
14:07	4347	211			elongated pillow lava	

14:13	4348	172	-430	330	hollow pillow lava with flat shelves	Sample #6(1)
14:17	4340	143			out of pit, sheet flow with folded drapery surface	
14:33	4342		-450	330		Sample #7(1)
14:55	4342	78	-450	330	jig-saw crack on the flat lava surface, also drapery surface	Sample #8(2)
14:57		250			go along the edge of pit	
15:02	4341	173			following pit rim, lobate pillow lava	
15:04	4346	291	-450	220	driving fast towards west-northwest	
15:08	4337	289	-430	180		
15:13	4328	319	-400	-50	pillow lava	
15:15	4330	277			pillow lava	Sample #9 (2) one broken
15:27	4328	240	-300	-100	off bottom	

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2A

DIVE No.	6K-504	DATE	99/09/03

	NAME	AFFILIATION
Japanese	宇井　忠英	北海道大学大学院理学研究科 Department of Earth and Planetary Sciences, Graduate School of Science, Hokkaido
SPECIALTY	Physical volcanology	
PURPOSE	To examine deep structure of the Hilina Slump and collect rock samples	
AREA	Middle bench of the Hilina Slump, Hawaii Island, Hawaii	
SITE	Northern part of the middle bench	

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	19 ° 15.0' N	154 ° 48.8' W	11:56	4123 m
LEAVING	19 ° 16.0' N	154 ° 50.1' W	15:36	3355 m

DIVE DISTANCE:	3200m	DEEPEST POINT:	4123m

DIVE SUMMARY	The dive track was chosen to confirm internal structure and sampling for the middle bench of the Hilina Slump. This site is east and below the dive K95 of 1998. The lower part of the dive track was covered by thin mud and black sand layers. Cluster of angular and dense rock fragments are exposed until the depth of ca. 3740 m below sea level. The first pillow lava outcrop was identified at 3735 m depth. Then, pillow lava formation without any deformation and jointing continued at least up to 3680 m depth. Sparse pillow fragments were identified until 3575 m depth. Then the slope becomes gentle and coverage of soft sediments increased slightly. Clusters of relatively large and angular dense rocks appeared ca. until 3510 m depth, then coverage of mud increased. Probable impact craters, several meters across were identified at several points near the end of the dive track. Cluster of angular to sub-angular fragments are identified at the
PAYLOAD	Two sample baskets, 4 push core samplers, 1 grab sampler

VISUAL RECORDS	VTR1 2	VTR2 2	STILL CAMERA 269	ONBOARD CAMERA 3
SAMPLE	Organisms:	Rocks:7	Cores:1	Water: cc
	Sediments:1	Others:	TOTAL:9	
VIDEO HIGHLIGHTS	1) 13:19-13:26	2) 14:02	3) 15:18-15:30	

KEY WORD	pillow lava, black sand, Hilina Slump

Result of dive #504

Date: September 3, 1999
Place: Middle bench of Hilina Slump
Pilot: Tsuyoshi Yoshiume, Co-pilot: Tetsuji Maki
Observer: Tadahide Ui

Abstract

At least, two lava flows are present along the dive track, and no sedimentary formations were found. Direct evidence of tectonic deformation is not identified along the dive track. Lower part of the dive track is mostly covered with thin mud without any clear and continuous outcrop. However, dense and angular rock fragments accumulated locally, suggesting the existence of pillow lava or pillow breccia and its talus beneath the mud. Excellent pillow lava is exposed at the upper part of the cliff, more than 100 meter in thickness. It preserves original morphology without any deformation and fracturing. Surface is partially eroded and covered with mud. Uppermost part of the cliff becomes gentle slope with increasing amount of mud coverage. Relatively large and dense rock fragments are exposed, forming mound-like morphology. Impact sag structures, ca. 2 m across, are found at the final part of the dive track. Large and dense rock fragments sit at the center of the structure. Less mud covers surfaces of the fragments. Sandy material is emplaced around the structure. These structures might be formed by a recent rock-fall avalanche event, probably associated with an earthquake.

要旨

この潜航では少なくとも２枚の溶岩流を確認した。堆積岩は見つからず、また構造的な変形の直接の証拠も見つからなかった。崖の下部は泥のかぶりが多くて明確な路頭はないが、緻密な角張った岩石の破片が所々に集っていて、枕状溶岩の本体ないしはその下の崖錘が少し見えている可能性がある。崖の上部には厚さ 100m 以上の見事な枕状溶岩の原形をとどめた露頭がある。変形、破砕の形跡はなく、表面が若干削られて、泥をかぶった程度である。更に上部は斜面がゆるくなって泥のかぶりが増し、産状ははっきりしないがマウンド状の高まりが点在し、そこに緻密で大きな岩塊が露出している。航程の最上部では火山弾が着地したのとそっくりの地形が点在する。泥層に円形の窪みが生じていて、その中央に緻密な岩塊が集っている。岩塊の表面には明らかに泥のかぶりが少ない。また周辺には放出された砂が見られる。現在の Hilina Slump の地形が出来てからずっと後に地震により岩塊が水中を転動して着底したイベントがあったのではないかと思われる。

Video Highlights

13:19-13:26, depth 3732-3680m

Excellent outcrop of pillow lava was found at this segment of the dive track. Each pillow shows globular or elongated shape having clear radial joints. Parts of external surfaces are also visible. Diameter of the pillow is several tens cm. The pillow interior is dense without any visible vesicles. The outcrop is partially covered with muddy material. No post-depositional deformation or fracturing is confirmed.

14:02, depth 3536m

Clusters of large and massive rock fragments are identified in muddy area. The diameter of the largest rock fragment is more than 1 m. This structure forms a slightly high mound. The rock is massive and dense.

15:18-15:30, depth 3373-3350m

A structure similar to impact sag is identified several points at this level. Diameter of crater rim is 1 to several meters. A cluster of dense and angular to sub-angular rock fragments is exposed at the center of the crater. The crater is slightly higher than surrounding area. The crater rim is made of mud and sand- to lapilli-size black particles. Sandy materials was sprayed around one of the craters. A flute cast-like depression was also found.

Objective

During the 1998 Kaiko K91 and 98 dives, we found volcaniclastic sediments at the upper and middle terrace of western part of the Hilina Slump. Also, we found pillow lava probably derived from Kilauea in K95 at the eastern upper terrace of the Hilina Slump. Major purpose of this dive is to confirm deposits of the middle-slope bench of eastern Hilina Slump, whether it is made of volcaniclastic sediments or pillow lava, and to collect rock samples for laboratory analysis to detect source volcano and eruption environment.

Dive results

At least, two layers of lava flows are found along the dive track, and none of sedimentary formation is found. Direct evidence of tectonic deformation is not identified along the dive track.

Starting point of the diving track was the bottom of the cliff covered with muddy material. A few rock fragments are scattered with mud cover. We sampled soft sediments at the depth of 4123 m using Ekman Barge Sampler. Several cm section exposed at the samplig site shows altenation of ca. 1 cm soft and pale-colored mud, 2 cm black sand, and underlying soft and pale-colored mud.

Lower part of the slope (4030-3740 m depth) is mostly covered with thin mud without any clear and continuous outcrop. However, dense and angular rock fragments accumulated locally, suggesting the existence of pillow lava or pillow breccia formation beneath mud. We sampled one angular rock fragment (sample #1, 2 pieces sampled simutaneously) at the depth of 3877 m. The rock is aphyric and dense basalt, containing a few tiny vesicles. The rim is slightly altered, with a thin manganese oxide coating.

Pillow lava crops out at the upper part of the cliff (3740-3570 m). Especially, excellent exposures at 3735-3650 m depth preserve original external morphology without any deformation and fracturing. Surfaces are partially eroded and covered with mud. Each pillow shows globular or elongated shapes having clear radial joints. Parts of external surfaces are also visible. Diameters of the pillows are several tens cm. The pillow interior is dense without any visible vesicles. The outcrops are partially covered with muddy material. No post-depositional deformation or fracturing is confirmed. We sampled pillow fragments at two levels, 3735 m (sample #2) and 3597 m (sample #3). Two fragments were sampled at each sites. The rock is olivine plagioclase-phyric basalt. Moderate amount of tiny vesicles, with diameters less than 0.5 mm, are present. The rim of each sample is slightly altered, with thin manganese oxide coating.

Uppermost part of the cliff (3570-3380 m) becomes a gentle slope, with increasing amount of mud. Relatively large and dense rock fragments form a mound-like morphology. Clusters of large and massive rock fragments were identified in muddy areas. The diameter of the largest rock fragment is more than 1 m. This structure forms slightly topographic high. The rock is massive and dense. We sampled at 3528 m depth (sample 4). The rock is dense aphyric basalt. The rim is slightly altered, with a thin manganese oxide coating. We tried to sample a push core at the depth of 3445 m, but could penetrate only a few cm. Black sand was identified beneath mud. All of the collected materials were lost.

Similar gentle slope continued until the final point of dive track, 3353 m depth. A structure similar to impact sag was identified several points between 3380-3353 m level. Diameter of crater rim is 1 to several meters. A cluster of dense and angular to sub-angular rock fragments is exposed at the center of the crater. Only a small amount of mud covers surfaces of the fragments. The crater is slightly higher than the surrounding area, which is covered with mud and sand to lapilli size black particles. Sandy materials was sprayed around one of the craters. A flute-cast-like depression was also found. This structure might have formed by a recent rock-fall avalanche event associated with an earthquake. We sampled one rock fragment from such crater structure at 3353 m depth. The rock is sparcely plagioclase-phyric basalt. Many cracks are developed. Degree of surface alteration is clearly less than the other samples collected during this dive.

Video log of dive 504 (camera 1 2)
and

Time	Depth	Position(x)	Position(y)	Description	Sample
1006	0			Shinkai 6500 landed on the sea	
1014	0			Start the diving	

1153				Start the still camera with 60 sec interval	
1156	4123	-700	1300	Landing target, mud on the seafloor	
1156				Start of sediments sampling using Eggman	Sediments
				sampler, mud/black sand/mud section	
1204				Sampling finished	
1209	4108			Towards 315 deg	
1211	4100			Mud	
1218	4024	-420	1080	Ascending gentle slope, increasing cluster	
				of and isolated rock fragments	
1222	3999			Towards 290 deg	
1225	3976			Cluster of angular fragments with cooling	
				cracks	
1229	3934			Cluster of angular fragments in mud	
1232	3897			Outcrop, preparation for sampling	
1243	3877	-220	720	Angular block on the slope	Sample 1
				Trouble on the left manupilator	
1245				Sampling finished	
1248	3867			Towards 270 deg	
1251	3845			Increasing cluster of rock fragments	
1257	3776	-230	540		
1302	3735			Pillow lava	
1304				Preparation for sampling	
1313	3732			Sample 2B from a surface of elongated	Sample 2
				pillow	(2 pieces)
1314	3733	-230	400	Leave sampling site	
1319	3732			Sampling finished	
1323	3703			Excellent pillow outcrop	
1326	3680			Continuing pillow lava outcrop	
1331	3629			Rock fragment scattered, pillow decreased	
1332	3622	-260	190		
1334	3610			Size of rock fragments become bigger	
1336				Stop for sampling from pillow mound?	
1337	3597			Sampled from a crest of flow lobe	Sample 3
1348	3596	-250	80	Sampling finished, trouble on the left arm	(2 pieces)
1351	3595			Towards 315 deg, gentle slope	
1352	3590			Mud	
1354	3582			Cluster of large angular fragments	
1356	3575			Pillow? in mud	
1358	3558	-140	0	Mud	

1402	3536			Cluster of massive and large angular	
				blocks in mud	
1403	3533			Turn around for sampling	
1412	3550				
1420	3529				
1425	3528			Abandon sample, too big	
1429	3528			Sampling of massive angular rock	Sample 4
1430	3526	30	-110		
1435	3525			Leave sampling site, towards 315 deg	
1436	3523			Mud	
1438	3513			Large massive blocks in muddy area	
1443	3490	230	-310	Thin mud cover, irregular surface, sand	
				and lapilli scattered	
1451	3445			Push core sampling start	Push core
1457	3444	430	-480	Sampling finished	
1500	3440			leave push core site, towards 315 deg	
1509	3400	610	-660	Muddy	
1514	3383			Muddy	
1515	3380			Impact sag structure?, rock fragments inside	
1515	3380			Flute cast? on mud surface (camera 1)	
1517	3376			Ripple mark	
1517	3374			Flute cast? on mud surface (camera 1)	
1518	3373			Another impact structure?	
1518	3372			Irregular surface (camera 1)	
1518	3371			Impact structure again, ca. 2m diameter	
				Spraid sandy particle around the hole	
1520	3368			Flute cast? on mud surface (camera 1)	
1523	3363			Muddy, scattered rock fragments	
1526	3358			Ripple mark	
1527	3355	1070	-1140		
1530	3350			Sampling rock fragment in mud, trace of	
				black sand layer partially covered with mud	
				at the upper slope of the rock.	
1536	3353	1120	-1160	Finish sampling, left bottom	Sample 5

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2A

DIVE No.	6K-505	DATE	99/9/04

	NAME	AFFILIATION
Japanese		Dept. Geology and Geophysics University of Hawaii

SPECIALTY	Marine Geology/Geophysics, Structural Geology
PURPOSE	To examine the internal structure and lithology of the base of Kilauea volcano flank
AREA	Outer slopes of low terraces at base of Kilauea's SE flank
SITE	

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	19 ° 03.7' N	154 ° 55.05' W	11:54	4705 m
LEAVING	19 ° 04.1' N	154 ° 55.98' W	15:21	4232 m

DIVE DISTANCE:	~1825 m	DEEPEST POINT:	4705 m

DIVE SUMMARY	The dive transected several of the deepest terraces that make up the outer slope of the midslope bench Kilauea's south flank. We landed on sand covered slope, with scattered talus blocks of basalt and soft, light colored sandstone. Upslope, ew encountered outcrops of highly fractured light sandstone. Almost all of the rocks from the lower section of the dive showed polished, sheared surfaces. The dive ascended to a major cliff, about 150 m high, composed predominantly of massive black, glassy volcaniclastic sandstone and breccia, with probable fining upward sequences. The outcrop was highly fractured and veined, creating resistant ledges. Where bedding orientations could be discerned, they tended to dip into the outcrop (to northeast) at 20-30°. The first terrace was covered by sand and talus. Outcrops and talus along the second slope consisted of volcaniclastic breccia. The findings of this dive confirm that the lower two terraces are
PAYLOAD	Sample boxes, 4 push cores
VISUAL RECORDS	VTR1 VTR2 STILL CAMERA 400 ONBOARD CAMERA YES
SAMPLE	Organisms: Rocks: 12 Cores: 2 Water: cc Sediments: Others: TOTAL:
VIDEO HIGHLIGHTS	1) 13:19-13:25 2) 13:35-13:55 3)14:48-15:03

KEY WORD	Volcaniclastic sandstone and breccia, shear surfaces, faulting, veining, hyaloclastite

Results of Shinkai 6500 Dive #505

Date: Sept. 4, 1999
Pilot: Yoshitaka Sasaki **Co-pilot:** Itaru Kawama
Science Observer: Julia Morgan, University of Hawaii

Location:
Outer slopes of two lowest terraces at base midslope bench along Kilauea's SE flank.

Objectives:
The dive track was designed to transect several of the deepest terraces that make up the outer slope of the midslope bench at the base of Kilauea's submarine flank. Results of Kaiko Dive #98 on the higher slopes of the bench revealed thick accumulations of volcaniclastic strata. This dive would determine if similar strata make up the deeper slopes as well. Moreover, multichannel seismic data collected by G. Moore and J. Morgan in 1998 across this slope reveal well-bedded folded strata beneath the terraces, so these low-relief structures are interpreted to be imbricated thrust sheets. This dive will look for evidence of deformation and bedding rotation, consistent with this structural interpretation.

Dive summary:
We landed on sand covered slope, with scattered talus blocks of two different lithologies: pillow basalt and soft, light colored sandstone with black flecks (salt-and pepper). The sand cover was relatively thin, so push-core sampling was not very successful. We ascended the slope, encountering large rounded boulders and scattered angular talus blocks. In places, white, fractured outcrops were exposed at the seafloor – these were not sampled. Occasional outcrops of highly fractured light sandstone were visible above the seafloor, and were sampled (sample 4). Almost all of the rocks recovered over the lower section of the dive revealed polished surfaces, and dark "veins" indicative of sheared surfaces. The dive continued upslope until scattered outcrop became a major cliff, about 150m high. We ascended the cliff, describing and sampling where possible.

The cliff was composed dominantly of black, glassy volcaniclastic sandstone and breccia. These were typically massive in outcrop, with little evidence for bedding. Apparent fining upward sequences were interpreted. The sandstone was highly fractured (e.g., sample 8), and veined; vein filling material was light colored, and resistant, defining ledges in the sandstone outcrop. Veins criss-crossed the outcrop, showing a range of orientations; some surfaces suggested slickensides, indicative of shearing; veined samples were recovered (samples 6-7). Several distinctive units in the cliff were not sampled: (1) a light gray, disaggregated lithology observed at the base of a steep sandstone outcrop – possibly fault gouge? (2) alternating light and dark layers that transected the sandstone outcrop, apparently bedded units.

Where orientations could be discerned, these layers tended to dip into the outcrop (to northeast) at 20-30°.

The top of the cliff marked the edge of the first terrace, which we crossed quickly. A push-core was attempted at the far side, before we climbed the second slope. The second slope was again sand covered with scattered talus blocks. We sampled a highly fractured outcrop of volcaniclastic breccia (sample 9). This was the only outcrop observed on this slope, but abundant talus indicated more exposure above. The dive was ended just upslope, after two pieces of talus float were sampled (sample 10).

More than 16 rock samples were recovered from 10 sites: most were volcaniclastic sandstones and breccias, although several were basalt fragments or glassy pillow basalts. Almost all of the clearly sedimentary samples from the lower slope showed evidence of shearing along external surfaces or fractures within the sample. All the samples from the upper slope were basalt fragments, probably derived from volcaniclastic breccia units upslope of the dive site.

Dive Results and Interpretations:

The results of this dive confirm that the lower two terraces along the outer slope of the midslope bench are composed of sediment, in particular volcaniclastic sandstones and breccias. The light colored (salt-and-pepper) sandstone found on the lower slope is enigmatic, because it appears to have a high proportion of silica, feldspar, and/or clay or micaceous(?) material. The abundance of polished, and slickensided surfaces on the samples, and apparent back-rotation and folding of layering in outcrop, indicates that the rocks on the lower slope have been highly deformed, consistent with interpretation that this terrace defines a thrust sheet at the base of the slope. Exposure at the base of the second slope was not as good, but this slope appears to contain fractured clastic sediments as well. The abundance of basalt in talus float indicates a ready source of talus upslope, probably volcaniclastic breccias as were observed on the lower slope. No in place basalt units were identified.

Dive# 505 - video log

time	depth	hdg	x-pos	y-pos	description	sample
11:54	4705	277			On bottom, rippled sand, talus float	
12:05			-590	1020		#1 push core; sample #1 (2 pc)
12:13	4703	291			large rounded boulder on sand	
12:16	4699	301			rippled sediment, gentle slope w/ talus	
12:18	4689	304			change heading to 270°	
12:25	4642	2	-530	840	position fix	
12:28					talus on slope	
12:30	4619	300			change heading to 300°	

12:37	4600	329	-440	780	talus on slope, large round boulder w/ white (C2)	sample #2 (2 pc) of float
12:39	4596	328			bright white, fractured boulder, low to slope - in place? (C2)	
12:47	4518	302			rough volcaniclastic breccia, in outcrop?	
12:50	4504	320			breccia boulders - white matrix; dark tabular base	
12:53	4504	15			light colored, rubbly breccia outcrop (C2)	sample #4 (dark pointed rock)
13:01	4501	313			massive, jointed outcrop (sandstone) w/ veins? (C2)	***note: samples 3 and 4 mislabeled. Inverted sample # to match rocks**
13:03			-360	590	evidence for folding?	sample #3 (long light rock)
13:10	4482	301			angular, fractured outcrop - breccia or sandstone. (C1, C2)	
13:11	4473	300			more outcrop - cliff (C1, C2)	
13:13	4465	304	-340	540	highly fractured outcrop (C1, C2)	sample #5 (2 pieces)
					black "rivulets" oozing out beneath outcrop and cliff (C2)	
13:19	4456	301			very rubbly, breccia or fractured ss cliff - light colored; bedding, shallow dips to west? (C1, C2)	
13:21	4446	320			thin layers of white rock - vein or bedding; highly contorted, folded (C1, C2)	
13:22	4441	324			base of cliff; gray, granular material at the base (gouge?), overlain by massive, fractured rock w/ yellow surface coating (vein filling) (C2)	asked to sample
13:25	4440	329	-330	510	slabby outcrop on cliff, yellow surface; slickensides on surfaces? (C1, C2)	samples #6 (2 pcs) and #7
13:32	4438	332			intermediate grain-size breccia, with bedding? (C2); massive sandstone (C1)	
13:33	4436	330			anastamosing, mineralized veins in weak sandstone outcrop (C1, C2)	
13:35	4422	330			alternating light and dark sediment layer in cliff; bedding is horizontal, or dips 20-30° into slope (NE) (C2)	
					massive, fractured rock overlies	
13:37	4413	330			mineralized fracture surface (C1)	
13:40	4413	296			alternating light and dark sediment layer in cliff (C1)	

13:44	4414	333	-300	480	veined, fining upward volcaniclastic unit: coarse breccia at base (C1, C2)	sample #8
13:53	4410	344			massive, poorly consolidated black sandstone, with resistant, light-colored veins or layers (C1, C2)	
13:55	4401	337			vertical wall, with steeply dipping fractures, shear surfaces, with possible normal offset? (C1, C2)	
					layering dips ~parallel to cliff (70-80° to SW)?	
13:57	4391	325			coarse breccia unit, fining upward, coarse layer in outcrop dips SE?	
13:57	4382	329			fine sandstone, sculpted, with resistant layers; bedding dips into slope ~30-40° (NE)	
13:58	4376	335			very coarse breccia - fining upward; layering dips slightly SE? (C1, C2)	
14:00	4364	344	-230	460	top of cliff - thick rippled sands w/ talus float	
14:00	4362	330			change heading to 270°	
14:09	4352	276	-200	200	position confirmed	
14:14	4355	277	-170	150	position confirmed	
14:21	4428	308	-180	280	sandy bottom	push core #2
14:39	4420	300			change heading to 300°	
14:46	4362	306	-160	-380	position confirmed	
14:47	4350	315			change heading to 315°; slope parallel layering (C1)	
14:48	4346	321	-110	-440	outcrop of fractured clastic rock (C1, C2); sandstone collected from outcrop - - may have distintegrated during transport; basalt fragments from talus	sample #9 (3 pcs; 1 from outcrop; 2 from ground)
14:58	4331	15			large rounded boulders in coarse breccia - clastic clasts? (C1, C2)	
15:03	4297	322	30	-540	top of outcrop, position confirmed	
15:12	4247	334			consolidated breccia (talus) outcrop (C1)	
15:13	4232	323	180	-690	talus on slope; basalt fragments collected	sample #10 (2 pcs)
15:21					leaving bottom	

Dive Log Sheet of SHINKAI 6500

HAWAII Leg ２A

DIVE No.	6K506	DATE	09-05-99

	NAME	AFFILIATION
Japanese		U.S. Geological Survey,

SPECIALTY	Volcanology, petrology, geologic structure and growth history of Hawaii Island
PURPOSE	Observe structures of a large lobate terrace along SE basal Puna Ridge, as it merges with Hilina benches; sample for petrologic study
AREA	Basal slope of Hawaii Island, transition zone between east margin of Hilina slump and south base of western submarine Puna Ridge
SITE	Steep south-facing slope of lowest lobate terrace

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	19º 21.2 ‘ N	154º 33.３ ‘ W		m
LEAVING	19º 21.７ ‘ N	154º 33.5 ‘ W		m

DIVE DISTANCE:	１７００ m	DEEPEST POINT:	５４４８m

DIVE SUMMARY	The dive S504 site is representative of an extensive lobate terrace area along the lower SE Puna Ridge, a terrane that had not been directly imaged or sampled previously. The results of Ｄive S506 provide strong evidence that: (1) the terraces are structural features related to protracted gravitational spreading and slumping of flanks of the rift zone rather than primary volcanic depositional features comparable to lava ponds along the crest of the Puna Ridge, and (2) this area of the lower ridge flank is relatively old, with infrequent recent eruptive activity and a lengthy history of sedimentation and deformation. Samples collected include 15 rocks (mainly pillow fragments) that will permit petrologic comparisons with pillow samples from dives K95 and S504, a grab sample, and 4 push-cores of sediments. The lobate terrace terrane should also serve as a small-scale model for early stages in development of the Hilina
PAYLOAD	Two sample baskets, 4 push-core samplers, 1 grab sampler
VISUAL RECORDS	VTR1 VTR2 STILL CAMERA 280 ONBOARD CAMERA No
SAMPLE	Organisms: Rocks: 15 Push cores: 4 Water: cc Sediments: 1 grab Others: TOTAL: 20
VIDEO HIGHLIGHTS	1: 12:19-:25 Young angular talus 2: 12:37-:41 Indurated clay, talus interbeds 3: 14:31 Outcrop, pillow cross-sections

KEY WORD	Hilina Slump, Puna Ridge, pillow lava, sheared muddy sediment, lobate slump terraces

Results of Dive #506

Date: Sept. 5, 1999

Place: Basal slope of Hawaii Island at 19º 21’ N, 154º 33’ E: transition zone between eastern benhes of Hilina slump and south base of western submarine Puna Ridge, steep south-facing slope of lowest lobate terrace

Pilot: Satoshi OGURA Co-pilot: Haruhiko HIGUCHI

Observer: Peter LIPMAN

Abstract

The dive S504 site is representative of the extensive lobate terrace terrane at the basal southeast flank of the Puna Ridge, a terrane that had not been directly imaged or sampled previously. Objectives of the dive were to: (1) interpret the origin (gravitational spreading/slumping vs. primary volcanic deposition) of the lobate terrace morphology that is transitional between the eastern Hilina benches beneath subaerial Kilauea and the southeast flank of the Puna Ridge; (2) evaluate the lobate terrace terrane as small-scale model for early stages in development of the Hilina benches; (3) obtain well located pillow-basalt samples to make petrologic comparisons with pillow fragments from dives K95 and S504, and with young Kilauea vs. Mauna Loa lavas; and (4) provide constraints on the age and frequency of eruptive activity along the lower flanks of the Puna Ridge. The results of dive S506 provide strong evidence that: (1) the terraces are structural features related to gravitational spreading and slumping of flanks of the rift zone rather than primary volcanic depositional features comparable to the lava ponds along the crest of Puna Ridge, and (2) this area of the lower ridge flank is relatively old, with infrequent recent eruptive activity and a lengthy history of sedimentation and deformation. Samples collected include 15 rocks, mainly pillow fragments, a grab sample of indurated mud, and 4 push-cores of sediments.

Video Highlights

12:19-12.25 Angular talus blocks, mantled by only light dusting of sediment, overlying muddy slope. Evidence for geologically young structural movement.

12:37-12:41: Ribs of indurated sediment on slope; interbedded layers or lenses of angular talus

13:32-13:34: Recently formed talus, without sediment cover, in contrast to widespread sediment on bench below

14:07-14:08: Cliff outcrops, showing pillows in cross section

14:09-14:12: Good exposure of contact between pillow breccia and overlying indurated muddy sediment cut by closely spaced steeply dipping fractures (shears?)

14:31: Steep wall, showing pillow cross sections

14:48 : Nice outcrop of pillow cross sections

Purpose of Dive

The target is the steep outer slope and ridge crest (5400-4800 m depth) of a large lobate terrace, at the SE base of the Puna Ridge (submarine E rift zone of Kilauea) as it merges with the Hilina benches. The dive area, and many other frontal ridges of lobate terraces in this area, bounds a closed basin within the terrace. Morphologically similar lobate terraces were imaged by low-resolution sonar near the bases of other Hawaiian rift zones and Cretaceous seamounts during the USGS GLORIA surveys, but none has been observed or sampled directly and their origin remains unknown. Possible alternatives include debris slides or slumpsg from higher along the rift zones, spreading along basal thrusts as the rift-zone ridges become larger, or lava-lake ponding behind pillowed deltas as has been observed at shallower depths along the crest of the Puna Ridge (time permitting, we would descend into the closed basin behind the bounding ridge crest of the terrace, to look for possible drain-back features. Even the age of these basal features of the Puna Ridge is currently unconstrained, whether geologically recent or representing an early stage in Kilauea's growth. The dive site may constitute a small-scale model for early stages in development of the Hilina benches which may originate, at least in part by some of the mechanisms listed above. The frontal scarps of the lobate terraces may also provide samples of early lavas erupted from the Puna Ridge, especially if they have been displaced outward in response to gravitational spreading. Such samples of early Kilauea lavas, hopefully less mantled by mud because of absence of a shoreline directly above them, would provide valuable material to compare with the old-appearing morphologically degraded pillow lavas of dives K95 and S504. Alternatively (but much less likely), these terraces could involve some previously unsuspected material, such as the alkalic flows that have been found surrounding the toe of the Puna Ridge, or even old volcaniclastic deposits related to a pre-Kilauea volcano.

Dive Results

The main objectives of dive S506 were to: (1) interpret the origin (gravitational spreading/slumping vs. primary volcanic deposition) of the lobate terrace morphology that is transitional between the eastern Hilina benches beneath subaerial Kilauea and the southeast flank of the Puna Ridge; (2) evaluate the lobate-terrace terrane as small all-scale model for early stages in development of the Hilina benches; (3) obtain well located pillow-basalt samples to make petrologic comparisons with pillow fragments from dives K95 and S504, and with young Kilauea vs. Mauna Loa lavas; and (4) provide constraints on the age and frequency of eruptive activity along the lower flanks of the Puna Ridge.

The dive site, selected for its steep slope, is believed representative of the extensive lobate terrace terrane (about 10-15 km wide and 50 km long) along the lower flank of the upper near-shore Puna Ridge. This terranes had not been directly imaged or sampled previously, and the origin of the lobate terraces has been unclear. The results of dive S506 provide strong evidence that: (1) the terraces are structural features related to gravitational spreading and slumping of flanks of the rift zone, rather than primary volcanic depositional features comparable to the lava ponds along upper crestal parts of Puna Ridge, and (2) this area of the lower ridge flank is relatively old, with infrequent recent eruptive activity and a lengthy history of deformation.

Dive summary:

The relatively deep touch-down point, at 5448 m was in talus (sample #1) at the very base of the lower terrace slope. The slope has two steps separated by a weak bench at about 5200 m. The lower part of the terrace slope consists mainly of angular talus (sample #2, and a few small apparent outcrops, varying from heavily sediment covered to very young appearing without any sediment. Weakly indurated clay well exposed at 5350 m (sample #3) appears to be interlayered with old talus deposits; it is intricately fractured, perhaps due to dewatering during diagnesis or to shearing. Pillow fragments collected from the lower step varied from phenocryst-poor to as much as 10% olivine; some are very dense, virtually lacking vesicles, and likely were subaerially erupted (samples #4B #5).

Lower parts of the upper step consist mainly of vast talus runs. Poorly exposed through young-appearing talus near the base of the upper step is phenocryst-poor pillow basalt (sample #5), immediately overlain by picrite (25-30% olivine) at about 5100 m (sample #6). These outcrops are strongly jointed and degraded by slope-failure events; no primary depositional outer surfaces of pillow deposits are preserved. Cliff-exposures, starting at about 5050 m, display beautiful pillow cross sections. Picrite pillow basalt of similar appearance was observed and sampled all the way to the crest of the outer terrace ridge crest (samples #7, 8). At 5030-5025 m depth, a second large horizon of indurated clay (grab sample) appears probably to be interleaved between picritic pillow lavas; this body is also tightly fractured or sheared. Another locality of indurated clay, apparently overlying the surface pillowed flow, was observed at 4900-4895 m. Near the top of the ridge, whole pillows and scattered good outcrops protrude through thin mud cover. volume. The dive was terminated at 4856 m.

Dive interpretations:

The widespread talus, strong fracturing, and structural disruption of all pillow lava outcrops indicates that the terrace slope is not a primary volcanic depositional feature comparable to the lava levees that bound subaerial and submarine lava ponds. The clear evidence for relatively old talus deposits embedded in, and deeply mantled by, consolidated mud demonstrates that the lobate terrace structures have been intermittently active over sizable time intervals. The intermingled presence of young-appearing talus indicates that deformation has continued to the present, or at least until relatively recently. The presence of nonsedimented recent talus along the base of the lower step, for which outcropping pillow lava seeminly is absent higher in this step, suggests that the sole of one active slump toe surfaces at this level. Similar recent talus along the base of the upper step suggests the emergent location of a second slump toe, although the steep cliffs of pillow lava higher along this step could provide sources for this talus without severe slumping and thrusting. The intersecting closely spaced fractures in the consolidated mud deposits also suggest influence by compression and shearing. Discontinuous patches of dark sand are probably derived from disintegrating glassy pillow rinds; such material is volumetrically much less conspicuous than in dives further to the west, where shoreline sand can be generated in large quantity. The microtopography is quite rugged, with cliffs exposing pillow interiors in cross section, even along relatively flat regions at the ridge crest. All these features indicate that the lobate terraces have formed by lateral spreading and or slumping, probably driven by dike injection along Kilauea's east rift zone (Puna Ridge).

The apparent absence of picrite, which is the dominant lithology of the upper step of the terrace slope, in the talus from the lower step suggests that the upper step may have overridden the lower step after accumulation of most of the talus exposed there. The presence of coherent pillowed outcrops along the upper step documents that the lobate terraces are not simple levees along debris-slide fronts, but rather were emplaced more coherently, probably at relatively slow rates over extend time intervals.

The several-meter-thick deposits of consolidated mud on lavas of both steps seemingly would have required considerable time to accumulate, especially as this area is largely beyond the influence of upslope shoreline sand-generating processes. Interpretation of the origin of the mud deposits will benefit from laboratory determination of the clay mineral assemblage, and evaluation of the proportional contribution from volcanogenic sources.

The pillow fragments do not appear to be geologically young; joint surfaces are heavily iron-stained and primary glass surfaces degraded. Still, they appear significantly younger, with better preserved glassy margins and less palagonite, than those sampled to the west in dives K95 and S504. At least some pillow fragments appear likely candidates to have degassed at low pressure, as evidenced by dense interiors, without abundant vesicles. In contrast, fragments from the uppermost picrite locality (sample #8) represent highly fluid gas-rich lava, as indicated by the hollow cores and settled olivine; these were likely submarine-erupted without prior degassing. As on Mauna Loa SW rift zone, picrite may be exceptionally well developed at deep bathymetric levels along the Puna Ridge.

The evidence for geologically recent deformation of relatively old rocks, as well as the slope and terrace morphology and presence of interlayered fine-grained sedimentary deposits is analogous in smaller scale to features of the Hilina slump. Development of steps and terraces in pillow basalts of the lobate-terrace terrane, apparently without substantial volumes of interlayered sediment, suggest that the thick sediments of the Hilina benches, while likely responsible for the large scale of this structure, are not an essential physical component. The relatively tight curvature and small area of many lobate terraces in plan view suggests that they are bounded by spoon-shaped detachments as gravitational slumps; a master detachment may be also present along the base of the lobate terraces area, comparable to the detachment documented for the Hilina slump by seismic, geodetic, and tsunami features of the 1975 Kalapana earthquake. Thus, this area may document on smaller scale the same processes as responsible for the Hilina structures, but without the complexities of the enormous quantities of shoreline-derived glass sand that mantle much of the lower Hilina region.

Sample list (see attached sheet for locations)

1. Talus block of sparsely porphyritic basalt (about 5% olivine), with heavily oxidized surface coatings; no glass.
2. Two basalt blocks from young-appearing talus
    A. Basalt pillow fragment, with preserved glass; olivine content about 10%; numerous small vesicles (submarine erupted?)
    B. Basalt with vuggy vesicles; about 10% olivine
3. Fragile weakly indurated tan clay, characterized by closely spaced intersecting fractures (shears, or diagenetic?). Collected with great skill, using hydraulic arm! Push-core samples #1, #2 are

from same locality

4. Two talus blocks of pillow basalt from near-outcrop area

   A. Dense fragment (5% olivine), with good glassy pillow surface, no vesicles (subaerially erupted?)

   B. Fragment with about 10% olivine, rounded vesicles, no glass

   Push-core #3 of sandy mud, adjacent to outcrop

5. Two pillow fragments from small outcrop, containing only sparse olivine (3%), <1% small vesicles (subaerially erupted?)

   A. Good glass on outer pillow surface

   B. No glassy surfaces

6. Two pillow fragments of picritic basalt (25-30% olivine; <1% vesicles), from outcrop

   A. Fragment containing no glass, only sparse small vesicles

   B. Contains glassy pillow margin, sparse vesicles

Grabber sample of indurated tan clay, characterized by closely spaced intersecting fractures (shears, or diagenetic?). Clay may be interlensed with pillow basalt

7. Two pillow fragments of picritic basalt (25-30% olivine; a few % vesicles), from pillow breccia adjacent to indurated clay sampled with grabber

   A. Fragment containing no glass, only sparse small vesicles

   B. Contains glassy pillow margin, sparse vesicles

8. Three pillow fragments of picritic basalt (25-30% olivine; 3-5% vesicles), from outcrop

   A. Slab from large hollow pillow or sheet flow, containing well-preserved outer glass and drip stone at interior surface. Olivine is much larger and more abundant downward, documenting settling after emplacement

   B. Fragment of similar rock type, but no glass

   C. A thick slab from a hollow pillow, displaying features similar to 8A

   Push-core #4 of sandy mud, adjacent to outcrop

Videolog of Dive 506

Time	Depth	Heading	Description	Sample
		(o)		
12:07	5448	295	on bottom, mud and sub-rnd boulders	sample #1
12:15	5448	45	change heading to 330	
12:17	5448	327	rounded outcrop?	
12:19	5433	331	angular talus blocks	
12:22	5406	339	blocks on slope; round pillow?	

12:25	5400	15	angular blocks	sample #2 (2 pcs)
12:32	5394	329	blocks on slope	
12:34	5375	336	mud covered slope, some blocks	
12:38	5347	337	lobes on slope, talus deposits	
12:38	5346	346	semi-consolidated slope;blocks	push core #1, #2 (black,blue)
12:50	5340	22	round, fractured outcrop - mud?	sample #3 (1 pc)
12:58	5331	340	change direction to 340	
13:03	5290	349	talus ridge?	
13:06	5259	347	confirm position	
13:07	5251	140	muddy outcrop, dark sand cover	sample #4 (3 pcs)
			possible pillow?	push core #3 (yellow)
13:25	5241	40	pillow breccia at surface	
13:28	5211	341	transit to depth 5100m	
13:32	5176	312	blocks on slope, volcanic breccia	
13:34	5154	314	white surface on block-hydrothermal	
13:36	5140	324	good pillow block	sample #5 (2 pc)
			change direction to 340	
13:44	5126	338	many pillow blocks, little cover	
13:46	5110	343	resistant wall, surrounded by blocks	
13:49	5100	357	stop to sample outcrop	
13:58	5096	19	yellow coating - hydrothermal	sample #6 (1 pc)
14:03	5094	39	more good pillow lavas	
			coherent outcrop of pillows	
14:07	5044	331	pillow breccia terrace	
14:09	5026	329	coarse clastic cliff, massive	
			rough surface, vertical fractures	smple #7 (2 pc), box 1
14:29	5018	334	coarse breccia, parallel fractures	
14:35	4947	344	check position	
14:36	4934	355	talus pile (pillows?)	
14:38	4911	356	tabular block	
14:40	4892	320	mud covered slope	
14:40	4888		talus	
14:43	4875	305	ascending slope to top	
14:45			more clastic outcrop	
14:48	4856	359	more clastic outcrop	
14:49	4861	310	check position	
14:51	4866	310	pillow deposit	sample #8 (2 pc)
14:56	4842	285	either pillow or clastic outcrop	push core #4
15:10			leave bottom	

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2A

DIVE No.	507	DATE	06 September 1999
	NAME	AFFILIATION	
Japanese	John R. Smith, Jr.	University of Hawaii School of Ocean & Earth Science & Technology (SOEST)	
SPECIALTY	Marine Geology & Geophysics		
PURPOSE	To study the geology and structure of step-and-bench features that are likely part of Mauna Loa and compare them with analagous features on		
AREA	Bathymetric bulge southwest of the Hilina slump and Loihi seamount.		
SITE	Base of previously proposed Punalu'u slump		

	LATITUDE N	LONGITUDE W	TIME HH:MM	DEPTH METERS
LANDING	18° 54.7568' N	155° 26.7458 W	11:38	3512 m
LEAVING	18° 55.8746' N	155° 27.5817 W	16:00	2720 m

DIVE DISTANCE:	~3500 m	DEEPEST POINT:	3512 m
DIVE SUMMARY	No previous dives or dredges had been carried out on this feature, so only speculation as to its composition and origin based on upslope subaerial observations and marine geophysical data were possible. The dive track was designed to study the steepest scarp face of the lower step of the proposed Punalu'u slump. Although the slope was steep (30° or >), it was covered by a consistent blanket of light colored pelagic sediment mixed with black sands, the latter of which was mostly below the surface and seen when the bottom was disturbed. Small, scattered angular talus was prevalent throughout the dive. The first two rock samples were loose talus on the open slope, and the remainder were collected from or near outcrops. Two types of outcrops were visited. One was a series of		
PAYLOAD	Ekman grab sampler, 4 push cores		
VISUAL RECORDS	VTR1 YES	VTR2	STILL 400 ONBOARD
SAMPLE	Organisms: Rocks: 12 Cores: 3 Water: cc Sediments: Others: TOTAL: 15		
VIDEO HIGHLIGHTS	1: 14:08 camera 2	2: 15:09 camera 2	3: 15:19 camera 2

KEY WORD	Punalu'u slump, Kilauea, Southwest Rift Zone, Hilina slump, South Flank, Hawaii, breccia, massive lava, basalt

Dive Report of 6K507

DATE: 06 September 1999
PILOT: S. SUZUKI Co-PILOT: T. MAKI
SCIENCE OBSERVER: John R. SMITH, Jr. (University Of Hawaii/SOEST)

LOCATION
Base of the proposed Punalu'u slump to the southwest of the Hilina slump and Loihi seamount.

MOTIVATION
HAWAII MR1 sidescan sonar collected by Smith in 1991 shows that three large domains of the southeast flank stand out as having high backscatter or bright tones in the MR1 imagery, indicative of volcanic terrain. These are: 1) Loihi Seamount, an active submarine volcano with two rift zones growing on the insular slope; 2) Kilauea's SWRZ extension/Punalu'u slump; and 3) Puna Ridge. The mottled "texture" from these volcanic features is primarily produced by fairly young pillow lavas, as confirmed by deep-tow camera, dredging, and submersible observations on both Loihi and Puna Ridge.

Various researchers have interpreted the area offshore the Kilauea SWRZ beginning near 19° 05'N, 155° 30'W as a landslide feature, either as part of the Hilina slump or a separate Punalu'u slide downslope from the subaerial Ninole Hills. It was initially identified as the offshore continuation of the Kilauea SWRZ based on a small unpublished SEA BEAM survey in 1987. A noticeable bulge appears in the contoured bathymetry and high backscatter is seen in the GLORIA and MR1 sidescan data at this location. A close inspection of the shaded relief image of bathymetry and the single-channel seismic reflection profiles acquired by Smith in 1991 show that this area is a series of at least three distinct steps or benches covered by lava flows having little or no sediment cover and downstepping to the southeast. These benches are located at approximately 1100, 1900, and 2200 m water depth.

The geophysical data do not show any debris avalanche type deposit (hummocky character). A *Pisces V* submersible investigation on the shallower section observed pillowed and lobate mounds and analyses of rock samples collected by the submersible indicate relatively fresh picritic lavas erupted along the base of the steps (A. Malahoff, pers. comm., 1995). This observation suggests lava leakage along fractures or fault slip planes.

Though subsurface slip planes are not evident in the seismic reflection data, the morphology and location of the benches on the feature offshore of the Kilauea SWRZ and the Ninole Hills area suggest the process of normal faulting as their origin. An alternative explanation is that the benches are strictly constructional lava mounds formed during subsidence and/or sea level rise events. The steepest parts of the bench faces yield slopes between 10-20° (maximum 23°) which is in the range of volcanic constructions on mid-ocean ridges and lower than the steeper gradients of >45° typically seen on mid-ocean ridge fault scarp faces. Subaerial Hawaiian volcanic slopes are, however, typically more subdued. For example, the steepest portions of the Hilina fault system are between 22.5° and 30°. Therefore, it is possible that the bench features observed here may indeed be down-dropped volcanic blocks composed of relatively intact lava flows. They do not appear to correspond to published descriptions of subsided slope breaks for the island of Hawaii.

Marine magnetic (both Smith's from 1991 and *Kairei* from 1998) and aeromagnetic anomaly data indicate in situ volcanic centers at depth, probably in the form of dike swarms. This is based on a high intensity bipole anomaly located over the morphologic expression of the rift zone. In addition, the presence of a Honuapo primary rift zone extend offshore abutting the southwest side of the Kilauea SWRZ submarine extension. Based on analysis of the geophysical data, I had proposed that at least the upper section of this feature is the offshore continuation of the Kilauea SWRZ which has nearly merged with the Honuapo rift zone. Below this upper portion, the interpretation becomes more complex because of the lack of continued magnetic anomalies coincident with the bathymetry. Overlayed on the magnetic anomalies, and continuing beyond them to 25 km offshore at a water depth of approximately 3500 m, are the bathymetric steps or benches. Finally, atop these benches appear to be numerous small volcanic cones distributed along the length of the feature.

OBJECTIVE

Since no previous sampling or observational work had been done on this feature, the driving force behind this dive was primarily exploration and sampling in addition to ground-truthing the remote geohysical data collected by Smith in 1991. A comparison in morphology, structure, and lithology with the lobate terraces at the base of Puna Ridge (Dive 506) and the outer scarp of the Hilina slump (all other dives in Leg 2A) is anticipated. Dives 506 and 507 serve to bracket the remainder of the dives on the Hilina slump proper, and will be used to determine if the Hilina slump outer scarp sandstones and breccias extend farther northeast and southwest than expected.

DIVE SUMMARY

The *Shinkai 6500* landed on a ~30° muddy slope that had black sand mixed in with small angular talus fragments scattered on top of the sediment. The first core sample attempt at this landing site was unsuccessful because of the thin sediment cover. This may be why the sidescan data reported highly reflective surfaces here. We proceeded directly upslope to the north but found the same type of material. However, core sampling was successful farther upslope, suggesting that we may have been near a recently covered outcrop near the landing point. Once it was evident that we were unlikely to see outcrop on the present course, we shifted to the west toward a small reentrant in the bathymetry were a steep slope was indicated. Along the way, we crossed a series of slope-parallel and stepped coarse breccia outcrop consisting of large basalt clasts. This outcrop was not evident in the *SeaBeam* bathymetric map. Heading toward the prime target, a bathymetric kink in the slope below a broad ridge or peninsula, we came across an increasingly dense talus field, the extent of which could be clearly viewed (and was recorded) on the submersible's sonar. The slope gradually increased to ~60° until we came to a near vertical wall of massive lava that had about 75 m relief. In place columnar jointing was observed and samples #4A, B were taken from the outcrop wall. We continued upslope to the northeast toward the summit of the ridge and came across additional steps in the outcrop, though they were not nearly as impressive. Sample #6 is a section taken from an old, in place lava flow lobe and has some manganese (Mn) coating on the exposed surface.

Twelve rock samples were recovered from six sites and all were basaltic in composition. Most rock samples were loose talus, though several were taken in place. Many of the rocks have thin Mn coatings. Two push cores were taken and show black sand and rock fragments mixed with pelagic ooze. The grab sample retained ~150 small rock fragments, but the sediment washed out.

DIVE RESULTS AND INTERPRETATIONS

This dive confirms the presence of slope mantling breccia deposits on the lower sections of this feature, and they are similar to those observed on the Hilina slump outer scarp. Preliminary visual interpretation of rock samples suggest at least some belong to Mauna Loa and are perhaps the oldest rocks collected from that volcano. The stepped, massive lava outcrops with associated talus fields are perhaps similar to the massive lava deposits found on the Hilina slump outer scarp and lobate terraces of Puna Ridge. In this case, the lavas appear to have ponded and cooled slowly, as the outcrop is too thick to have been a single flow. No obvious outside surfaces were apparent on the top or bottom. However, if this interpretation is correct, the retaining walls of the "pond" have fallen away long ago, since all that remains is a general ridge-like morphology and a steeply sloping relatively featureless muddy surface beyond the small outcrop that we studied. The talus field and massive lava section are strikingly similar to those located inside the West Pit crater on the Loihi seamount summit.

Both the Honuapo and Kilauea SW rift zones may have coalesced to produce this acoustically highly reflective and magnetically anomalous (upper section) feature. The rift zone region lies almost directly above the boundary between the southeast Mauna Loa and southeast Kilauea rigid, yet mobile blocks, proposed by others based on earthquake foci. This suggests a structural boundary that continues to some depth. Because the downslope section displays the same morphology and acoustic reflectivity as the upper part, but without the magnetic anomalies, the lower portion may represent lava flows and small eruptive pillow cone vents downslope from the rift zone proper. It is possible that the two rift zones developed and subsided with the island prior to block faulting caused by seaward movement of the

Kilauea and/or Mauna Loa flanks. Such faulting and seaward movement may have been stalled by the growing abutment of Loihi seamount. This explanation may satisfy both the submarine rift zone extension model presented here and the extended Hilina or Punalu'u slump models proposed by others.

VIDEO HIGHLIGHTS (camera 2)

11:43	Tried coring near landing point, but sediment cover was too thin
13:21	Sample site #1, core/grab and talus rocks
14:08	Megabreccia (?) outcrop. Ridges and scarp of large rocks in mud
14:49	Talus field as seen on sonar image. Broken "column"
15:09	Massive lava outcrop on vertical wall, ~25 m high section
15:19	Columnar jointing
15:27	Talus and core samples
15:51	Last rock sample from in place flow lobe

ROCK SAMPLE DESCRIPTIONS (See attached sheet for locations)

(Samples 1A-3B and 5A-C were loose talus pieces)

1A: Old pillow lava fagment with possible near-original surface. Contains pelletized glass.
1B: Olivine basalt. Massive lava with no vesicles.
2A: Very porphyritic olivine basalt with glass rind. Thin Mn coating.
2B: Olivine basalt with glass. Thin Mn coating.
3A: Olivine basalt with vesicles filled by zeolite. From near breccia outcrop. Thin Mn coating.
3B: Olivine basalt. From near breccia outcrop.
4A: Basalt with Ol & Cpx and holocrystalline groundmass. From massive lava outcrop. Thin Mn coating.
4B: Basalt with altered mafic phenocrysts. From massive lava outcrop. Thin Mn coating.
5A: Basalt with few very small vesicles.
5B: Massive picrite with rare Pl phenocrysts.
5C: Basalt with weak surface alteration.
6: Section of old pillow lava lobe with thin Mn coating. Taken in place.
7: About 150 small rock fragments (up to 4 cm) consisting of several types of basalt including fine-grained dense aphyric texture, olivine bearing (to ±10%), and basaltic glass. Probably collected by grab sampler (sediment washed out).

VIDEO LOG of D507

TIME hh:m	DEPTH meters	HDG (°)	CAM	DESCRIPTION

m				
11:26	3452	88	2	Start of tape; bluewater
11:31	3502	348	2	Bottom in site; light colored mud with scattered small dark color rocks
11:37	3511	98	2	Landed on bottom; Slopes 20-30° to north
11:43	3511	98	2	Tried blue push corer; but sediment only 2-3 cm thick
11:48	3511	91	2	Close-up view of attempted core site; Black sand mixed with mud
11:52	3505	0	2	Heading north up muddy slope; Small rocks, some black sand visible
11:56	3482	1	2	Concentration of small rocks increasing
12:01	3458	63	2	Set sub down on muddy slope to sample
12:06	3455	97	2	Attempted large rounded partly buried rock, but too big (saw it move)
12:07	3455	85	2	Rock sample #1A; loose talus piece
12:10	3455	93	2	Rock sample #1B; loose talus piece
12:11	3455	97	2	View of sample site; can see black sand disturbed
12:34	3273	355	2	Turned on automatic still camera timer to shoot every 60 seconds
12:45	3154	359	2	Concentration of rock fragments increasing
12:55	3056	359	2	Some larger pieces of talus than previously seen
12:57	3037	359	1	Thin layer or slab (~10 cm thick) protruding through sediment (<1 m long)
12:59	3019	359	2	Bioturbated trail shows black sand brought to the surface
13:03	2995	30	2	Set sub down on muddy slope to sample
13:11	2992	61	2	Push core #1 (blue) taken; fully penetrated into sandy sediment
13:21	2992	341	2	Ekman grab sample taken; possibly Rock sample #7 (sedimentwashed out)
13:27	2989	350	1, 2	End of tape #1
13:28	2985	354	1, 2	Start of tape #2
13:32	2987	336	2	Rock sample #2A, loose talus piece from slightly upslope of the grab
13:33	2986	336	2	Rock sample #2B, loose talus piece
13:36	2986	339	2	View of sample site; black sand and fragments exposed
13:43	2952	0	2	Continuing up the muddy slope to the north; black sand and talus
13:49	2887	356	1	Bioturbated trail of black sand cutting diagonally across view
13:50	2873	2	1	Slabby outcrop face (~10 cm thick) w/sediment in front and

				on top
13:52	2867	271	2	Change heading to west in order to reach small steep reentrant
13:58	2839	270	2	Camera 2 light interfering with pilot; move it to port side; no view
14:02	2847	276	2	Camera 2 back to seafloor; same muddy bottom with scarce talus
14:03	2842	276	2	Possible thin outcrop or exposed talus slab
14:04	2838	276	2	Concentration of talus and surficial black sand increasing
14:05	2832	276	1, 2	Two exposed faces (10-30 cm thick?) of possible breccia outcrop
14:06	2831	275	1	Outcrop of massive material (breccia?) or large isolated boulder protruding through sed; 40-50 cm in relief; 2 more 'outcrops' just upslope
14:06	2829	276	1	Another thin slabby outcrop similar to the one at 13:50; ~10 cm thick
14:06	2828	275	2	Looks like small (~30 cm thick) talus layer exposed
14:07	2827	274	1	More possible outcrop exposed through sediment cover
14:07	2825	276	1, 2	Thin layers exposed through sediment; possible breccia?
14:07	2822	274	1, 2	Outcrop of coarse breccia; lobe shape; > 1 m high
14:07	2822	276	1	Large area of breccia outcrop starts; sediment cover prevalent
14:08	2820	273	2	Breccia ridge(s); < 2 m high; saw two such ridges
14:08	2819	308	2	Possible rounded pillow surface protruding through outcrop surface
14:09	2819	317	1	Overhang with ~120° slope; looks more massive here(?)
14:09	2818	322	2	Good view of breccia outcrop wall; 2-3 m high; has sharp upper edge
14:10	2816	317	1	Outcrop wall looks ~vertical here, but difficult to determine
14:13	2812	354	1	Two rounded lobes protuding through sedimented outcrop; pillows?
14:16	2811	351	2	Moved to top of outcrop wall onto still steep slope to sample; View of sharp cliff edge to starboard side; Rock sample #3A; talus
14:20	2810	0	2	Rock sample #3B; talus from slightly upslope
14:27	2808	278	2	Underway to next site; view of 20-30 cm thick outcrop
14:28	2810	283	2	Another step in outcrop; similar thickness
14:30	2813	283	1	Large boulder; little sediment cover
14:30	2812	283	1	Another step in outcrop; likely breccia composed of talus; ~1m thick
14:30	2811	283	1	Curious line of small talus/black sand; seems too much for

				bioturb
14:31	2807	283	2	Muddy slope; camera 2 view into the blue
14:38	2791	305	2	Camera 2 view again; same muddy bottom with talus and black sand
14:39	2783	300	1	Edge of breccia outcrop aligned up/downslope; 20-30 cm thick; ~3 m in length; goes under sediment; continues upslope
14:39	2784	302	1, 2	Slope steepening over sedimented breccia outcrop (to 2780 m)
14:42	2782	300	2	Seeing some bigger talus pieces; camera 2 view not good
14:48	2837	46	1, 2	Camera 2 on bottom again; contact between sedimentslope and talus field; all sizes of talus mixed together or in close proximity to each other
14:49	2839	359	2	Looks like 2 or 3 overlapping breccia outcrops (1-2 m thick) composed of coarse and large talus facing downslope; steps ~5 m wide
14:49	2839	13	1	Possible pillow cross-section and other rounded pieces
14:50	2836	326	1	Wide angle view of large talus field; mixed assemblage of rock sizes
14:50	2835	311	1, 2	A wide sedimented section w/ talus; camera view not good; large rock
14:51	2836	310	2	Talus concentration and size increasing; light sedimentcover on all talus
14:51	2835	311	1	Possible step w/ ~1 m relief; breccia or talus front; but view not good
14:52	2840	294	1, 2	Numerous large talus boulders; rounded pieces in camera 1 view?
14:53	2841	288	1, 2	Edge of talus field; slope increasing to ~50°; sonar view of talus field
14:55	2847	304	1, 2	Total talus slope; large angular blocks (~ 1m or >); fresh edges, littlesedimentcover; some holdfast biota
14:56	2843	356	2	Now some smaller talus blocks mixed in w/ large ones
14:57	2838	357	2	Some sediment and less talus; must be crossing edge of talus field
14:57	2834	358	1, 2	Now mostly all talus in chute;sedimentto port side; large blocks; little sediment
14:59	2820	26	2	All talus now; large angular fresh-looking blocks; littlesedimentcover; course change to 50° up talus valley
14:59	2818	34	1	Broken columns; one ~1m long
15:00	2815	51	1	Broken columns; one ~1m long
15:01	2802	45	1, 2	Sed dusting even lighter now; 1-2 m long talus blocks; getting

				larger; white marks on talus surfaces (scars or zeolite?); columns in camera 1 view
15:02	2798	46	1	Slope now ~55°
15:03	2787	46	2	Can see sedimented area now; must be edge of talus field
15:04	2774	46	2	Back to only talus; slope steepening; possible broken column
15:04	2770	46	2	At base of near vertical massive outcrop w/ jointing; sediment at base, then grades to small talus and eventually large blocks farther downslope
15:05	2765	46	1, 2	Ascending the wall; white marks evident (scars or zeolite?); broken column; ~60° slope
15:07	2763	359	1	Face of freshly broken talus piece still in place
15:08	2764	326	2	Rock sample #4A; massive; in place
15:11	2762	310	1	Some rock faces appear to have a thin dark (Mn?) coating; ~60° slope
15:12	2758	296	1	Near vertical wall
15:15	2753	026	1	Close-up view of in place columnar jointing
15:16	2753	13	1, 2	Rock sample #4B after moving along wall; possibly pulled from edge of columnar jointed outcrop
15:17	2756	356	1, 2	View downslope on outcrop wall; white material (scars or zeolite?)
15:19	2751	45	2	View of wall straight-on; in place and tilted columnar jointing; fresh scars; brittle stars
15:19	2747	45	1	40-50 cm thick layer of massive rock, dipping ~10° to port
15:19	2746	45	1, 2	At top of outcrop wall; sedimented slope; still steep (as before wall)
15:20	2744	45	2	Outcrop of brownish massive-looking rock; possibly indurated sed; ~30 cm thick; jagged edges; layered?
15:20	2743	43	1, 2	Sedimented slope, then two more smaller outcrop ledges; some talus
15:21	2740	40	1, 2	Back to sedimented slope and scattered talus of various sizes; large boulder on camera 1
15:26	2740	18	2	Push core #2 (white) attempt; hard to penetrate sand; scooping it
15:29	2740	4	1, 2	End of tape #2
15:30	2739	3	1, 2	Start of tape #3; preparing to sample rock
15:33	2738	16	2	Rock sample #5A; loose piece of talus
15:37	2737	6	1, 2	Rock sample #5B; loose piece of talus; view of sample site on camera 1; black sand disturbed
15:42	2733	20	1, 2	Continue upslope; possible outcrop of old lava w/ light

				sediment cover; some black sand apparent; small scattered talus; ~60° slope?
15:43	2732	45	2	Outcrop ~30 cm thick; talus embedded in the slope above it
15:44	2725	46	1	Some large sedimented blocks outcropping; but view not good
15:47	2731	350	1, 2	Sedimented slope w/ talus few blocks; then poor camera view
15:48	2726	342	2	Possible talus front
15:49	2726	343	1, 2	Several steps w/ talus fronts continue upslope; angular talus blocks; concentration seems to be increasing; goes to bad camera view
15:50	2722	48	1, 2	Bottom in site; talus and sed; may be talus front; angular; black sand
15:51	2727	46	1, 2	View across slope, ~30°; talus and sediment
15:52	2722	9	1, 2	Outcrop, looks like breccia here; slope steeper
15:53	2721	13	1	Lateral edge of large lobate-shaped outcrop; appears well-jointed
15:54	2721	17	1, 2	Attempting sample from in place lobe, huge piece, dropped it
15:55	2722	22	1, 2	Can see sediment slope on upper edge of outcrop face, ~60°, 1-2 m thick; looks like in place massive lava like previous outcrop; jointing
15:55	2722	8	1	Lateral edge of outcrop again
15:55	2721	32	1, 2	Rock sample #6; in place, from top edge outcrop
15:56	2720	35	2	Sedimented slope; few small scattered talus pieces
15:57	2719	37	2	Leaving bottom; end of dive!

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2A

DIVE No.	**508**	DATE	1999/9/08
	NAME	AFFILIATION	
Japanese	仲　二郎	Deep Sea Research Department Japan Marine Science and Technology Center	
SPECIALTY	Marine Geology		
PURPOSE	Geological mapping and rock sampling along a steep slope of Hilina slump, south of Kilauea Volcano		
AREA	South flank of Kilauea volcano		
SITE	Hilina slump		
	LATITUDE / LONGITUDE / TIME / DEPTH		
LANDING	18°59.52' N / 155°02.74'W / 11:38 / 4058 m		
LEAVING	18°59.71'N / 155°03.55'W / 15:43 / 3229m		
DIVE DISTANCE:	1400m	DEEPEST POINT:	4058m
DIVE SUMMARY	We dove at the most continuous steep slope in the Hilina Slump area at the depth from about 4050 m to 3250m. This area is located about 5 km west of the last year's KAIKO 90 dive and deeper than it. The most dominate outcrop was well indulated massive volcaniclastic sandstone and breccia. Within these outcrop, we observed fractured area 3 or 4 times. It seem fault shear zone. The other area we mostly observed talus breccia which derived from these volcaniclastic rocks outcrops. However, we collected 3 rounded 20 to 30 cm size rounded rock fragments from a recent debris flow, and the origin is not certain.		
PAYLOAD	Two sample baskets, three push core samplers, one grab, one heat flow meter		
VISUAL RECORDS	VTR1 VTR2 STILL 350 ONBOARD YES		
SAMPLE	Organisms: Rocks:11 Cores:1 Water: Sediments:1 (grab) Others: TOTAL:10		
VIDEO HIGHLIGHTS	1) Gabbro point 2) Fractured outcrop 3) Massive		

KEY WORD	Hilina Slump, South flank of Kilauea, Volcaniclastic sandstone, Fault shear zone

Abstract

We dove at the most continuous steep slope in the Hilina Slump area at the depth from about 4050 m to 3250m.　This area is located about 5 km west of the last year's KAIKO 90 dive and deeper than it.　The most dominate outcrop was well indulated massive volcaniclastic sandstone and breccia.　Within these outcrop, we observed fractured area 3 or 4 times.　It seem fault shear zone.　The other area we mostly observed talus breccia which derived from these volcaniclastic rocks outcrops.　However, we collected 3 rounded 20 to 30 cm size rounded rock fragments from a recent debris flow, and the origin is not certain.

要旨

508潜航ではヒリナ地辷りのでは最も落差の大きい急傾斜の水深約４０５０mから３２５０mにかけて潜航を行った。この場所は昨年の「かいこう」の第９８潜航の西約５km に位置し、それより下位の部分に当たる。観察された露頭で最も優勢だったものは、よく固結し摂理の発達した、塊状の火山岩起原の砂岩や礫岩であった。その中では３－４個所かなり破砕された部分があり、癖開や裂かがかなり密に認められた。これらの露頭以外は崖錐性の角礫で多くは、露頭から由来したものと思われる。しかし水深約３９５０m 付近にあった土石流に含まれている礫は採集した３個すべてがハンレイ岩であり、その起原は良く分からない。

Video Highlights

1. 11:59:45-12:00:30 Gabbro bearing recent debris flow body.
2. 12:37:45-12:38:40 Fractured volcaniclastic sandstone or breccia outcrop and light coloered bedded layer.
3. 14:12:20-14:13:10 Massive jointed volcaniclastic sandstone or breccia outcrop.

1. Objective

This Based on the Seabeam map, we chosen the most continuous and steep slope in the Hilina slump area. This dive site is located about 5 km west of the KAIKO dive No. 98 in last year.　During the KAIKO dive we observed volcaniclastic sandstone or breccia sequence but this dive started not form the base of this steep slope.　We expected the most continuous exposure along this steep slope to get the stratigraphic sequence from the base of the steep slope.

Dive results

We started the dive at the western base of the concave sharp steep slope depth of 4058m.　At the start point we observed slightly sediment covered cobble to boulder size talus deposit.　The talus breccia mostly include dark colored materials but also include minor amount light colored ones.　Judging from the collected samples, the dark colored one are not altered volcaniclastic sandstone or breccia and light colored one are altered volcaniclastic sandstone or siltstone.　At the depth of 3954m, we saw less indulated newly formed debris flow deposit outcrop.　However, the all (three) collected samples were gabbro, and one of them was mica bearing gabbro.　From the occurrence, it is difficult to know the origin of these gabbro.

At the depth of 3887m the first well indulated volcaniclastic breccia and/or breccia outcrop appeared. This outcrop continued to the depth of about 3820m. This outcrop showed massive and jointed surface. Around the depth of 3850m, the volcaniclastic rocks became much dark colored and fractured and seemed like fault shear zone. The interstice of the fracture, white or yellowish colored materials (zeolite?) were observed.

The second appearance of the well indurated volcaniclastic rock was the depth of 3743m. However, the lower portion of this outcrop (3743m to 3448m) was much course grained boulder size gravel bearing volcaniclastic breccia or conglomerate. At this breccia out crop, we observed some open cracks. This volcaniclastic breccia became fining upward and became pebbly volcaniclastic sandstone around the depth of 3737m. This volcaniclastic sandstone outcrop continued to the depth of 3730m Between 3730m and 3658m the seafloor covered with talus breccia.

The third appearance of the well indurated volcaniclastic rocks was at the depth of 3658m. This outcrop continued to the depth of about 3520m. Around the depth of 3565m we observed fractured volcaniclastic sandstone or breccia again.

The fourth appearance of the well indurated volcaniclastic sandstone or breccia was at the depth of 3466m and this outcrop continued to 3270m, and this was the last outcrop. We observed mostly massive jointed volcaniclastic sandstone or breccia but around the depth of 3310m we observed bedded volcaniclastic sandstone. Within this outcrop, we observed slightly fractured volcaniclastic sandstone or breccia around the depth of 3275 m.

We arrive the comparatively flat and smooth seafloor around the depth above 3270m. This part was covered by thin clay size probably pelagic sediment and black colored volcanic sand.

The dominant lithology which observed as the outcrop was well indurated massive jointed volcaniclastic sandstone or pebbly breccia. We also observed much course grained breccia which was composed of boulder size rock fragments, but it didn’t showed joined feature. We observed three or four fractured or fault shear zone in the volcaniclastic sandstone and/or breccia. In some case, the interstice of the fracture or joints were filled by white or yellowish minerals and they became veins.

The most dominant size of the talus breccia was boulder size, but toward the base of the each fractured or sheared volcaniclastic sandstone or breccia, the size of talus breccia became small.

Sampling locations

Rock samples

6K508-01 11:48 18 ° 59.52’N, 155 ° 02.75’W D:4037
6K508-02 12:06 18 ° 59.53’N, 155 ° 02.82’W D:3954
6K508-03 12:30 18 ° 59.55’N, 155 ° 02.89’W D:3879
6K508-04 13:12 18 ° 59.59’N, 155 ° 03.02’W D:3749
6K508-05 13:26 18 ° 59.60’N, 155 ° 03.04’W D:3730
6K508-06 14:30 18 ° 59.72’N, 155 ° 03.32’W D:3452

Dive 508 Dive Log (Number 2 Camera)

Time	Depth	Heading	Position(y,x)	Description
11:34	4044	233		Bottom in view.
11:38	4058	205	-500, 1150	Arrived on the bottom. Slightly sediment covered cobble to boulder size angular talus deposit on the slope
11:42	4054	280		Mostly 10 to 20 cm sixe angular talus breccia covered of the steep slope. Maximum size of the breccia attained up to 1m.
11:45	4038	296	-520, 1150	Stopped to collect rock samples. Talus breccia were mostly dark colored surface but about 5% of them showed light colored surface. At here we collected both. Sp 01-A and B
11:51	4033	281		Talus breccia. The population of the light colored breccia became high. Bedding or lamination were observed 1n the light colored breccia.
11:54	4007	281		Talus breccia on the steep slope.
11:57	3974	281		Debris flow body which is composed of boulder size breccia slightly covered by fine sediment.
11:59	3960	283		Poor indulated volcaniclastic breccia or conglomerate outcrop.
12:00	3954	282	-500, 1010	Stopped to collect rock samples at the poor indulated breccia or conglomerate. We collected three rounded boulders, and all these are fine to medium grained gabbro. Sp 02A, B and C
12:07	3951	290		Change course to 290. Passing above the poor indulated debris flow body.
12:09	3938	294		Boulder size angular blocks on the poor indurated debris flow body.
12:11	3927	285		Cross cut outcrop of poor indulated debris flow. It showed boundary between lower dark colored part and upper light colored part.
12:13	3917	290		Boulder size talus angular breccia on the steep slope.
12:16	3900	291		Angular talus deposit on the steep slope. Light colored fragments became abundant (20%).
12:18	3887	291		First appearance of the basement rock outcrop. Well indurated jointed massive volcanicalstic coarse sandstone or breccia croped out on the steep cliff.
12:28	3882	343	-430,860	Collected one rock sample and put into left bottom box (Sp 03).
12:32	3880	291		Massive jointed volcanic sandstone or breccia. Yellowish white materials attached on the jointed plane.

12:35	3863	292		Fractured massive volcaniclastic sandstone.
12:37	3855	290		Fractured massive volcaniclasitc sandstone or breccia.
12:38:00	3851	295		White colored materials (zeolite?) filled the fracture (vein).
12:38:30	3851	304		Lens sharp bedded light colored volcanic sand layer between much dark colored jointed layers. Possibly, this light colored layer is much fine grained compared with dark layers.
12:41	3844	292		Much thick (up to meter) jointed light colored volcaniclastic sandstone layer.
12:43	3838	290		Talus breccia or recent debris flow deposits.
12:45	3827	290	-450,830	Talus breccia or recent debris flow.
12:46	3820	288		Massive jointed volcaniclastic sandstone or breccia outcrop.
12:47	3816	290		Talus breccia on slightly gentle slope. The dominant size is boulder.
12:50	3812	290		Slightly thick sediment covered talus boulder size breccia.
12:54	3786	290		Slightly thick sediment covered talus boulder size breccia on comparatively gentle slope.
12:58	3761	291		Slightly thick sediment covered boulder size talus breccia.
12:59	3753	292		Well indulated volcaniclastic breccia or conglomerate outcrop..
13:03	3745	280		Open crack on the well indurated volcaniclastic breccia.
13:05	3746	286		Attempted rock sample collection, but failed.
13:09	3748	297	-390, 660	Collected one boulder size sub rounded rock fragment from the indulated breccia. Sp04
13:12	3749	290		Move toward to Co. 290.
13:17	3737	291		Slightly sediment covered well indurated jointed massive massive volcaniclastic pebbly sandstone or breccia outcrop.
13:23	3730	307	-370, 640	Collected one rock sample from jointed massive sandstone outcrop. Sp 05
13:27	3722	290		Slightly thick sediment covered boulder size talus breccia.
13:31	3697	290		Slightly thick sediment covered boulder size talus breccia.
13:35	3663	291		Size of talus breccia became small. Dominant size was 10 to 20 cm.
13:36	3658	292		Outcrop of massive jointed volcaniclastic pebbly sandstone or breccia. On the foot of the outcrop, there were cobble to pebble size talus breccia.
13:39	3636	291		Massive jointed volcaniclastic pebbly sandstone or breccia outcrop
13:40	3627	291		Massive jointed volcaniclastic breccia outcrop.
13:42	3613	291		Slightly thick sediment covered boulder size talus deposit.

13:45	3596	291	-280, 390	Comparatively thick sediment covered talus breccia.
13:48	3577	291		Fractured massive volcaniclastic sandstone or pebbly breccia outcrop.
13:49	3571	292		Jointed massive volcaniclastic sandstone or pebbly breccia.
13:50	3565	298		Fractured volcaniclastic sandstone or breccia. White colored minerals filled veins.
13:54	3548	302		Pebble to cobble size dominated talus breccia.
13:55	3541	302		Fractured volcaniclastic sandstone or breecis. Most sheared part showed dark color (fault shear zone?).
13:59	3532	316		Fractured volcaniclastic sandstone.
14:00	3520	301		Massive volcaniclastic sandstone or breccia outcrop observed in some place on the comparatively gentle slope.
14:03	3500	300		Slightly thick sediment covered talus breccia on steep slope.
14:07	3478	300	-200, 180	Cobble to pebble size talus breccia.
14:09	3466	311		Fractured or jointed massive volcaniclastic sandstone or breccia. White colored minerals filled veins.
14:12	3459	321		Massive jointed volcaniclastic sandstone or breccia outcrop.
14:20	3452	299	-150, 130	Attempting rock sampling from massive sandstone outcrop.
14:22	3452	285		Collected one rock sample. Sp06-1 (May be floated rock)
14:29	3452	302		Collected one rock sample. Sp06-2
14:37	3449	290		Move toward Co290
14:38	3436	291		Massive jointed volcaniclastic sandstone or breccia outcrop.
14:40	3422	293		Massive jointed or fractured volcaniclastic sandstone outcrop.
14:43	3409	294		Massive jointed volcaniclastic pebbly breccia outcrop.
14:44	3404	295	-130,60	Slightly sediment covered talus breccia.
14:45	3393	290		Massive jointed volcaniclastic sandstone or breccia outcrop.
14:48	3380	291		Massive jointed volcaniclastic breccia outcrop.
14:50	3366	291		Slightly sediment covered jointed volcaniclastic sandstone outcrop.
14:51	3358	290		Thickness of sediment become thick.
14:54	3346	305		Stop at a outcrop of massive jointed volcaniclastic sandstone or breccia. Attempted to collected grab sample but failed.
14:57	3345	309		Attempted push core sample but failed.
15:00	3337	290		Massive jointed volcaniclastic sandstone or breccia outcrop.
15:01	3327	291		Suspended particles became rich.
15:03	3317	315		Mostly massive but in some place bedding like features were observed volcaniclastic sandstone or breccia. Slightly fractured.
15:07	3307	295		Bedded or massive jointed volcaniclastic sandstone outcrop.

15:10	3307	331	-90, -70	Collected one rock sample (Sp07) from massive volcaniclastic sandstone outcrop.
15:15	3315	285		Massive jointed bedded volcaniclastic breccia or sandstone outcrop.
15:17	3300	305		Slightly sediment covered jointed volcaniclastic sandstone or breccia outcrop.
15:20	3258	291		Massive jointed volcaniclastic breccia outcrop. Edge of the outcrop became rounded.
15:22	3278	291	-80, -70	Sediment covered jointed outcrop.
15:23	3275	290		Fractured massive volcaniclastic sandstone or breccia outcrop.
15:25	3270	290		The slope become gentle. Meter size angular blocks scattered on the floor. Water became foggy.
15:30	3266	278	-80, -130	After condition of push core sampling. Black colored volcanic sand papered the surface. Core yellow.
15:32	3263	291		Flat and smooth floor covered by fine sediments.
15:34	3251	258		Weakly rippled fine sediments on flat floor.
15:36	3233	235		Arrive the edge of few meter high sand rubble mound. Probably recent debris flow body.
15:40	3228	308		Attempting push core sampling. Black colored volcanic sand exist few centimeter below the sea floor. Corer Black
15:42	3228	310	-160, -270	Leave floor.

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2 A

DIVE No.	509	DATE	09-09-99

	NAME	AFFILIATION
Japanese		U.S. Geological Survey,
SPECIALTY	Volcanology, petrology, geologic structure and growth history of Hawaii Island	
PURPOSE	Observe stratigraphic sequence and structures of outer lower scarp at eastern end of main Hilina bench; sample for petrologic study	
AREA	South flank, Hawaii Island	
SITE	East end, outer slope of Hilina bench	

	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	19º 11.2 ' N	154º 50.8 ' W	11:46	4550 m
LEAVING	19º 12.2 ' N	154º 52.2 ' W	15:42	3522 m

DIVE DISTANCE:	2500 m	DEEPEST POINT:	4550 m

DIVE SUMMARY

The dive target is the steep lower slope at the eastern end of the main Hilina bench (4800-3200 m depth), intermediate in positions between dives S504 (all pillow basalt) and S505 (all basaltic sandstone and breccia) The main purposes of this dive were: to determine the lithology, stratigraphic sequence, and structure at the easternmost steeply exposed slope section, in comparison to the divergent features seen in previous dives; to constrain the map distribution of different rock types; and provide samples for laboratory structural and petrologic studies. The lowest part of the section (about 4540-4435 m) consisted of massive indurated basaltic breccia, cut by many fractures, some seemingly involving shear motions. Local discontinuous bedding, marked by sandy lenses, dips gently northward, toward Hawaii Island. Above a largely covered interval of sand and talus (4435-4165 m) were massive cliffs of dark gray distinctive vuggy (diktytaxitic) basalt (4165-3950 m), becoming increasingly fractured and brecciated upward. The upper third of the dive track (3950-3520 m) encountered only local small outcrops of bedded basaltic breccia, between large areas of ripple-marked muddy sediment; these breccias locally displayed slope-paralle bedding, and they appeared notably less indurated, less structurally complex, and younger than exposures lower along the dive track. Twelve rock samples and two push cores were recovered.

PAYLOAD	Two sample baskets, 4 push-core samplers, 1 grab sampler
VISUAL RECORDS	VTR1 VTR2 STILL CAMERA 300 ONBOARD CAMERA No
SAMPLE	Organisms: Rocks: 12 Push cores: 2 Water: c Sediments: Others:Loose pebbles, in TOTAL: 20
VIDEO HIGHLIGHTS	1: 11:57-1230: Massive breccia 2: 13:22-12:33: Massive brecciated gray vuggy basalt 3: 14:38-15:00: Slope-parallel breccia

KEY WORD	Hilina Slump, basaltic breccia, diktytaxitic basalt, slope-parallel breccia

Results of Dive #509

Date: Sept. 9, 1999

Place: Basal slope of Hawaii Island at 19º 11_e N, 154º 50_f E:
Eastern end of main lower scarp of Hilina slump, steep southeast-facing slope

Pilot: Yoshitaka SASAKI

Co-pilot: Haruhiko HIGUCHI

Observer: Peter LIPMAN

Abstract

The dive target is the steep lower slope at the eastern end of the main Hilina bench (4800-3200 m depth), intermediate in positions between dives S504 (all pillow basalt) and S505 (all basaltic sandstone and breccia) The main purposes of this dive were: to determine the lithology, stratigraphic sequence, and structure at the easternmost steeply exposed slope section, in comparison to the divergent features seen in previous dives; to constrain the map distribution of different rock types; and provide samples for laboratory structural and petrologic studies. The lowest part of the section (about 4540-4435 m) consisted of massive indurated basaltic breccia (sample site #1), cut by many fractures, some seemingly involving shear motions. Local discontinuous bedding, marked by sandy lenses, dips gently northward toward Hawaii Island. Above a largely covered interval of sand and talus (4435-4165 m) were massive cliffs of dark gray distinctive vuggy (diktytaxitic) basalt (4165-3950 m), becoming increasingly fractured and brecciated upward. The upper third of the dive track (3950-3520 m) encountered only local small outcrops of bedded basaltic breccia, between large areas of ripple-marked muddy sediment; these breccias locally displayed slope-parallel bedding, and they appeared notably less indurated, less structurally complex, and younger than exposures lower along the dive track. Twelve rock samples and two push cores were recovered.

Video Highlights

11:57-12:30: Massive basaltic breccia, with local discontinuous bedding features, patchy surface coating by white zeolite, and closely spaced steep fractures (shears?)

13:22-13:33: Massive brecciated gray vuggy basalt. Probably an exceptionally thick lava flow which unusual textures, but possibly a sill invasive into sedimentary section

14:38-15:00: Small outcrops of weakly indurated slope-parallel bedded breccias, containing mainly clasts of dense basalt

Purpose of Dive

The dive target is the steep lower slope at the eastern end of the main Hilina bench (4800-3200 m depth), intermediate in positions between dives S504 (all pillow basalt) and S505 (all basaltic sandstone and breccia) The main purposes of this dive are: to determine the lithology, stratigraphic sequence, and structure at the easternmost steeply exposed slope section, in comparison to the divergent features seen in previous dives; to constrain the map distribution of different rock types; and provide samples for laboratory structural and petrologic studies.

Dive Results

Dive #509 was designed to constrain the distribution of volcaniclastic sedimentary units relative to the two previous dives higher in the same area that encountered only pillow lavas. No pillow lavas were found during dive #509, but a textural distinctive finely vuggy (diktytaxitic) thick basalt unit, unlike any rocks previously encountered on the submarine or subaerial south flank of Hawaii Island, was observed, sandwiched between underlying and overlying basaltic breccias.

Dive summary:

The dive track was chosen to provide maximum vertical exposure of the stratigraphic and structural features along the outer slope below the east end of the main Hilina bench.

The lowest part of the section(about 4540-4435 m) consisted of massive indurated basaltic breccia (sample site #1), cut by many fractures, some seemingly involving shear motions. Local discontinuous bedding, marked by sandy lenses, dips gently northward, toward Hawaii Island.

Above a largely covered interval of sand and talus (4435-4165 m) were massive cliffs of dark gray rock (4165-3950 m), becoming increasingly fractured and brecciated upward. Fractures in the lower cliffs are between blocks that fit together and do not appear rotated, but higher in these steep slopes the rocks increasingly appear to be framework-supported breccia in which clasts have been rotated. In several places, apparent bedding planes between massive breccia units dip 10-15° into the slope (toward Hawaii Island). The thick gray massive unit was inferred to be variably brecciated sandstone during the dive, but all samples (sites #2, 3) are a distinctive porous aphyric basalt lacking large vesicles, but containing abundant small vuggy cavities between groundmass crystals (diktytaxitic texture) that was thought by the scientific team on the Yokosuka to be rare in Hawaii. This rock is virtually aphyric, but the groundmass is coarsely crystallized, and small plagioclase laths are readily visible with a hand lens. No pillow-like forms were observed, nor was any glass present in the recovered samples. Possibly, this unit may be a sheeted sill complex, invasive into the sedimentary section, but no diagnostic contacts were exposed along the dive track.

The upper third of the dive track (3950-3520 m) displayed only local small outcrops of bedded basaltic breccia (sites #4-6), between large areas of ripple-marked muddy sediment; these breccias locally displayed slope-parallel bedding, and they appeared notably less indurated, less structurally complex, and younger than exposures lower along the dive track. Several recovered basalt fragments have glassy surfaces (samples #4A, 4B, 6B); these may be submarine erupted pillow fragments, perhaps derived from the outcrops higher on this slope such as encountered during dive K95, or they may be fragments of subaerially degassed lava, depending on the retained volatile contents in the glassy rinds.

Dive interpretations:

The massive lower breccia unit seems fairly similar to basaltic breccias observed interlayered with finer-grained basalt-glass sandstones further west along the Hilina lower scarp The presence of closely spaced steep fractures, some occupied by fine-grained sandy material, suggests possible shearing along the fractures. Such an interpretation is also consistent with evidence for more intense compressional deformation low in the Hilina scarp observed during several previous Kaiko and Shinkai dives.

The origin of the distinctive diktytaxitic basalt, that was the most unusual aspect of dive #509, cannot be constrained solely from the submersible observations; petrologic data will be needed to evaluate whether these textures have developed within ordinary tholeiitic composition magma, or whether some unusual composition is involved. Texturally similar rocks in the western USA are characteristically high in alumina and modal plagioclase. Because of the thickness of this unit, an intrusive origin as a sill should be considered, but alternatively it may just be a thickly ponded lava flow, as suggested by well developed round vesicles in addition to the vuggy groundmass texture in sample #2B. The apparent presence of sedimentary interbeds between massive breccia zones involving rocks that appear to be the upper part of this unit also suggests a surface rather than intrusive origin.

The basaltic breccias along the upper third of the dive track appear to have been deposited on slopes much like the present-day surfaces, as indicated by slow-parallel bedding. These breccias are better sorted and bedded than the lower massive breccia sequence, which appears to have been back tilted toward Hawaii Island. Thus, the geometry here is much like that described for the much older slide block of the Nuuanu debris avalanche, in which the interiors of slides blocks are mantled by slope-parallel sedimentary deposits.

Several structural-stratigraphic alternatives remain possible to account for the rock distributions observed during multiple dives in this area. Probably the volcaniclastic sediments have been both (1) deposited against primary volcanic deposits of pillow lava and hyaloclastite, and (2) compressed and deformed, involving at least some thrust imbrication as suggested by recent Univ. Hawaii seismic studies. More detailed submarine mapping would be required to determine he relative roles of primary deposition as an alluvial wedge vs. gravitational spreading and tectonic shortening in accounting for the distribution of rock types as now known from the JAMSTEC research

Sample list (see attached sheet for locations)

1. Two clast samples and matrix sample from indurated massive breccia outcrop
    A. Clast of aphyric basalt, with small vesicles
    B. Three small clasts of basalt (collected at the same time), varying from aphyric and dense to sparsely porphyritic (olivine) and vesicular
    Push-core #1 (matrix sample)--Basaltic sand and gravel, from matrix of coarse breccia

2. Two samples from massive gray cliffs of diktytaxitic basalt (outcrop)
    A. Large fragment of nonvesicular gray aphanitic diktytaxitic basalt
    B. Fragment of vesicular gray aphanitic diktytaxitic basalt

3. Two clasts from breccia outcrop
    A. Large fragment of nonvesicular gray aphanitic diktytaxitic basalt
    B. Fragment of basaltic-glass lapilli breccia

4. Two clasts from breccia outcrop
    A. Fragment of aphyric basalt (pillow?), glassy margin preserved
    B. Fragment of aphyric basalt (pillow?), glassy margin preserved

5. Clast from bedded, slope-parallel breccia outcrop: fragment of olivine-phyric vesicular gray basalt

6. Clasts and matrix sample from breccia outcrop
    A. Angular fragment of olivine-phyric gray basalt
    B. Fragment of aphyric nonvesicular lava-flow rind (pillow?), glassy margin preserved
    C. Rounded boulder of vesicular basalt
    Push-core #2 (matrix sample)--Basaltic sand and gravel, from matrix of coarse breccia

7. Gravel-size basalt fragments from right-side sample basket: mostly angular fragments of non- to sparsely porphyritic dark gray basalt. Probably obtained mainly near beginning of dive (12:20, 4519m), when Shinkai triggered a small debris slide, as seen on camera #1, and pebbles can be heard landing on the sub.

Videolog of D509

Time	Depth	Heading	Description	Sample
	m	(。)		
11:43	4480		Arrived at the bottom.	
11:50	4550	307	Sediment and small rocks	

11:53	4550	313	Position confirmation; hdg to 315	
11:56	4543	271	Light color rocks; rough surface; hdg to 270	
11:58	4528	260	Steep wall of massive outcrop	
11:59	4524	223	Stop for sampling	
12:02	4524	229		Rock sample #1; in place
12:03	4524	223		Core sample #1; black
12:07	4524	222	Planar structure; no sample?	Attempt sample #2?; in place; slab
12:13	4524	299	This is probably sample #2	Rock sample #2; small piece
12:16	4524	302	Position confirmation; 2 rocks, 1 core taken; hdg to 270	
12:22	4512	223	Start moving west again; same outcrop continues	
12:27	4462	269	Position confirmation; sharp outcrop edges	
12:33	4422	270	Hdg to 320; volcaniclastic seds?	
12:38	4403	321	subangluar rock fragments; mega-breccia?	
12:40	4361	321	Sedimented slope; scattered rocks; some striping or ripples?	
12:42	4344	321	Position confirmaton	
12:45	4322	321	Strange striping or scalloped structures; young?; flowage?	
12:53	4270	321	Position confirmation; large boulders	
12:54	4262	321	Impressive view of terraces/striping features	
12:57	4244	321	"Flight of stairs" view of terraces	
13;00	4227	321	Position confimed; hdg back to brecciated part	
13:01	4216	322	Breccia	
13:06	4164	325	Possible pillow fragment; much talus; small and large	
13:09	4142	321	Featureless surface; bad camera view	
13:13	4132	324	Attempt sampling	
13:21	4127	321	2 rock samples taken; not seen; Hdg to 270	Rock samples #3 and 4

13:25	4108	321	Outcrop of consolidated volcaniclastic material?	
13:27	4095		white vein in clastic breccia	
13:32	4070	321	Position confirmaton	
13:34	4045	317	intermediate - coarse breccia outcrop	
13:32	4049	353	stopped to sample at breccia outcrop	sample #5 (1 pc)
13:42	4038	309	change direction to 320	
13:48	3982	321	irregular outcrops in talus slope	
13:50	3959		finer grained rock, fractured	
13:53	3922	323	slope with pebble-cobble talus	
13:54	3919	321	Position confirmaton	
14:00	3851	322	muddy slope - ripples	
14:04	3807	322	Position confirmaton	
14:08	3764	321	gentle muddy slope w/ loose rocks	
14:10	3740	322	Position confirmaton	
14:14	3715	322	rubbly outcrop, stopped	
14:22	3713	282		Rock sample #6A
14:29	3713	228	Heterogeneous exposure surface; pillow or fragment?	Rock sample #6B; 3 pcs?
14:00	3712	284	Sub reports 4 samples taken; not see all	pillows?
14:35	3702	286	Isolated frgment on slope; pillow?; transmitted image stalled	
14:36	3689	286	Transmitted image has returned	
14:38	3672	285	Pillow? fragment on sed slope	
14:39	3660	310	Hdg to 310; sedimented slope	
14:45	3649	331	Stop for sampling	
14:50	3641	318	Position confirmed; hdg to 270	
14:52	3630	269	Outcrop wall w/ sed cover; protruding rock fragments; rounded	
14:58	3595	358	Large outcrop wall	

15:00	3585	?	Large talus blocks on rippled sed; black sand; Hdg 302	
15:03	3570	270	Hdg to 270	
15:10	3527	271	Position confirmed; Hdg to 225	
15:15	3519	227	Sedimented slope; featureless	
15:24	3522	322	Stopped for last sampling attempt; breccia outcrop?	
15:37	3522	321		Rock sample #7; not seen
15:39	3523	341		Push core #2; blue
15:42	3522	308	Leaving bottom	2 rock samples reported; no mention of core

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2A

DIVE No.	510	DATE	1999/9/11		
	NAME		AFFILIATION		
Japanese			Deep Sea Research Department Japan Marine Science and Technology Center		
SPECIALTY	Marine Geology				
PURPOSE	Observation of structure in the detached landslide block in north of Molokai Is. and collect samples and magnetic data from the north slope				
AREA	Wailau Landslide, north of Molokai Is.				
SITE	North slope at the detached large landslide block i				
	LATITUDE	LONGITUDE	TIME	DEPTH	
	Ex). 124 ° 18.5’ N	127 ° 36.2’ E	13:35	6499	m
LANDING	21˚38.06’ N	156˚53.78’W	10:00	4469	m
LEAVING	21˚37.24’N	156˚54.85’W	15:42	3615	m
DIVE DISTANCE:	2450 m	DEEPEST POINT:	4469m		
DIVE SUMMARY	Dive # 510 was carried out in the north steep cliff of the detached landslide block in the in north of Molokai Is., which locates in the proximal area of Wailau Landslide. We landed and recovered volcanic breccias in the lower slope (4460 -4300) and the steep slope (4300-3700). In the lower slope, most outcrops are scattered in the muddy sea floor. It is supposed that volcanic breccia are covered with thick mud. On the other side, blocks of volcanic breccia were observed in the steep, which are separated by valley, which width are 50cm to several m. Stratified layers are well developed in the blocks and most are parallel to the slope (north dip with 20 degree). Gorges are filled with thick mud with no talus materials. In the upper slope (3700-),				
PAYLOAD	Two sample baskets, four push core samplers, one grabn				
VISUAL RECORDS	VTR1	VTR2	STILL CAMERA 400	ONBOARD CAMERA YES	
SAMPLE	Organisms: Sediments:1 (grab)	Rocks:6 Others:	Cores:3 TOTAL:10	Water: cc	
VIDEO HIGHLIGHTS	1) Block of vol. breccia	2) Pillow lava area	3)		

KEY WORD	Wailau landslide, Segmented block of volcanic breccia , pillow lava, magnetic diapole

Abstract

Dive # 510 was carried out in the north steep cliff of the detached landslide block in the in north of Molokai Is., which locates in the proximal area of Wailau Landslide. We landed and recovered volcanic breccias in the lower slope (4460 –4300 m) and the steep slope (4300-3700 m). In the lower slope, most outcrops are scattered in the muddy sea floor. It is supposed that volcanic breccia are covered with thick mud. On the other side, blocks of volcanic breccia were observed in the steep, which are separated by valley, which width are 50cm to several m. Stratified layers are well developed in the blocks and most are parallel to the slope (north dip with 20 degree). Gorges are filled with thick mud with no talus materials. In the upper slope (3700 m-), we encountered outcrops of pillow lava.

Objective

The dive point of # 510 is located in the north flank of the large detached block of Wailau Land Slide. The result onboard magnetic survey during KR98-08 shows magnetic anomalies with a dipole feature on the top flat of the block, which suggest that massive volcanic bodies exist in the block. Detail magnetic survey were performed using a three components magnetometer installed in SHINKAI 6500 to understand the origin of the magnetic distinction. Rock samples were collected to know source of the magnetic anomaly, which were expected to be exposed in the vertical section of the block.

Geological and visual information of the proximal area of Wailau Land Slide has been few except dredge KR98-08-# 9 in the series of surveys. Material and structure of the large detached block is a clue to understand not only the Wailau Land Slide, but entire land slides in the north of Oahu Is.. Because the distinction of the element of Wailau Land Slide is important to understand the emplacement history of land slides in the north of Oahu Is.

Results.

From geological and topographic features in the surveyed surface during dive # 510, slopes are divided into three sections. 1; lower slope area (4460 –4300 m) Most surface are covered with mud and scattered with pebbles. outcrop of volcanic breccia were observed. Polymictic volcanic breccias (# 1 and 2) were collected from there. 2; steep slope area (4300-3700 m) Valleys separate blocks of volcanic breccia. The widths of valleys range from 50cm to several m. Most strike to the direction of east west. Probably these structures were formed to cracking and sliding to the dip direction of slopes of volcanic breccia formations. Stratified layers are well developed in the section of blocks and most are parallel to the slope (north dipping to the north about 20 degree). Generally valleys are filled with thick mud and no talus. Polymictic volcanic breccias (# 3and 4) were collected from there. Volcanic breccia of sample 6K510-4B contains vesiculated, oxidized bassalt pebble. At sampling site 6K510-5, light brown silt stone were collected. They show laminated structure in several cm interval (probably ripple structure). 3; upper slope (3700 m-). Massive out-crop of pillow lava are exposed in the upper slope, several large block (probably breccia) were observed on the outcrop of the pillow lava. Pillow basalt were collected at site 6K510-6.

Video High light

12:26:00-12:29:00 outcrop (volcanic breccia) coverd with mud

12:41:00-12:46:00 stratified sub-consolideted mud.
13:05:40-13:06:00 bedding of volcanic breccia dipping to north
13:13:40-13:14:10 outcrop of volcanic breccia
13:24:13-13:24:20 fractured outcrop (pillow lava ?)
13:42:45-13:43:15 overhung massive outcrop
13:43:45-13:44:27 stratified layers of volcanic breccia
13:52:20-13:52:57 stratified layers of volcanic breccia dipping to north-west
14:11:45-14:11:56 valley filled with mud between blocks of volcanic breccia
14:14:17-14:16:30 vertical cross section of a blocks of volcanic breccia
14:16:55-14:17:15 large talus blocks
15:02:23-15:05:00 outcrop of pillow lava
15:05:50-15:07:00 pillow lava and block
15:07:05-15:09:00 outcrop of pillow lava

Sampling locations

Rock samples

6K510-01 12:20 (n=2) no record
6K510-02 12:20 (n=2) 21 ° 38.02'N, 156 ° 53.80'W D:4443 m
6K510-03 12:32 (n=2) 21 ° 37.98'N, 156 ° 53.86'W D:4396 m
6K510-04 13:01 (n=2) 21 ° 37.92'N, 156 ° 53.93'W D:4332 m
6K510-05 13:31 (n=2) 21 ° 37.64'N, 156 ° 54.24'W D:4121 m
6K495-06 15:42 (n=3) 21 ° 37.24'N, 156 ° 54.85'W D:3615 m
*Most rock samples collected during dive # 510 covered with thin Mn-coating (<0.5 mm)

Core Samples

6K510 C-1 11:54 21 ° 38.06'N, 156 ° 53.78'W D:4469 m
6K510 C-2 14:37 21 ° 37.64'N, 156 ° 54.52'W D:3887 m
6K510 C-3 15:42 (n=3) 21 ° 37.24'N, 156 ° 54.85'W D:3615 m

Grab Sample

6K510 G-1 15:42 (n=3) 21 ° 37.24'N, 156 ° 54.85'W D:3615 m

Video Log

Time	Depth m	Position (x)m	Position (y)m	Description
11:52	4469			Arrived at the bottom.
11:54	4469	1400	1250	"very muddy seafloor, small pebbles"(push core #1 (yellow))
12:03	4448	1330	1200	"low relief outcrop, breccia or pillow"(sample #1 (2 pc))

12:24	4425	1250	1100	continuing low outcrop – breccia(sample #2 (2 pc))
12:35	4385			"very rounded, knobby outcrop - breccia"
12:37	4380			"vert. fracture, irregular bedding"
12:42	4333	1150	990	stop at low outcrop (sample #3 (2 pc))
13:07	4306			"more low outcrop, and mud"
13:13	4240			move along slope covered with mud
13:13	4215			outcrop of breccia
13:19	4180			outcrop of breccia
13:21	4171	760	640	moving on mud coveed slope
13:24	4136			outcrop of stuccked pillow lava?
13:26	4120			stopped for sampling
13:31	4121	660	490	sampled from low outcrop (sample#4(2pc))
13:34	4118			outcrop of steep cliff
13:42	4051			massive outcrop
13:48	4023			small outcrop of mantle bedding sedim.
13:49	4012	460	250	moving on the slope
13:51	3999			mantle bedds
13:55	3975			slope covered with mud and gravel
13:56	3972			stopped for sampling from outcrop
13:57				outcrop of massive volcanic breccia
14:15	3976			still smpling from massie breccia
14:07	3970	400	140	abondoned ampling
14:12	3933			moving abov slope covered with mud
14:13	3920	330	40	moving above slope
14:14				contact of steep outcrop and slope
14:15	3914			bedding sediments of massive breccia
14:19	3898			sampling at a massive breccia
14:18	3886			still sampling from the same outcrop
14:35				making dust out of outcrop
14:38	3890	340	-20	finished sampling (sample#5(1pc), Push Core)
14:40	3866			moving along a slope covered with mud
14:45	3825	270	-130	moving along a slope
14:47	3812			outcrop of mantle bed
14:51	3776			masive outcrop of breccia
14:57	3707	40	-370	moving along a slope
15:02	3673			massive breccia outcrop
15:03	3659			many animals
15:06	3639			outcrops and talus of lava like rocks
15:09	3623	-100	-570	pillow lava fragments
15:10	3616			stopped for sampling

15;15	3616			sampling from a pillow lava
15:27				wait for dust to settle down
15:32	3615	-110	-610	finished sampling of rocks(sample#6(3pc))
15:34	3616			push core
15:36				grab core was used
15:41				left bottom

Dive Log Sheet of SHINKAI 6500

HAWAII Leg　２A

DIVE No.	6K-511	DATE	99/09/12	
	NAME		AFFILIATION	
Japanese	宇井　忠英		北海道大学大学院理学研究科 Department of Earth and Planetary Sciences, Graduate School of Science,	
SPECIALTY	Physical Volcanology			
PURPOSE	Geological observation and sampling of rocks at middle to upper part of Tuscaloosa Seamount in Nuuanu Landslide			
AREA	Nuuanu Landslide, NE of Island of Oahu			
SITE	West side of the seamount			
	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	22 ° 07.8' N	157 ° 14.8'　W	11:42	3960　m
LEAVING	22 ° 07.1' N	157 ° 13.5'　W	15:39	2923　m
DIVE DISTANCE:	3200 m	DEEPEST POINT:	3960 m	
DIVE SUMMARY	This dive was designed for inspection of the upper and western part of Tuscaloosa Seamount. Major interests are try to seek any evidence of subaerial or submarine environment prior to the landslide event and to find evidences related to debris avalanche origin. Number of outcrops found during the dive was limited. But, all of the outcrops show characteristic structure of debris avalanche origin, i.e. fractures and heterolithology. The exposures are covered with relatively thick manganese oxide coating. Mud covers occasionally at the top plateau of the seamount. Cut surface of eleven collected rock samples show a character of volcaniclastic formation of submarine environment. Most of the clasts included within the fragment are dense basalts of various petrographic			
PAYLOAD	Two sample baskets, 4 push core samplers, 1 grab sampler			
VISUAL RECORDS	VTR1　2	VTR2　2	STILL CAMERA　360	ONBOARD CAMERA　No
SAMPLE	Organisms: Sediments: 1	Rocks: 11 Others:	Cores: TOTAL: 12	Water:　cc
VIDEO HIGHLIGHTS	1）13:07-13:32	2）13:47-13:58	3）14:35-14:44	

KEY WORD	landslide, seamount, volcaniclastic

Result of dive #511

Date: September 12, 1999
Place: West corner of Tuscaloosa Seamount
Pilot: S.Suzuki, **Co-pilot:** I.Kawama
Observer: Tadahide Ui

Abstract

One of the important questions not yet solved for Nuuanu and Wailau Landslide Deposit is whether the source of the landslide is entirely submarine part of a volcanic edifice or it includes subaerial part of a volcanic edifice.

We surveyed middle to uppermost slope of the western side of Tuscaloosa Seamount. Breccia layers of various grain size distribution, partially filled with sand and mud layer, crop out on the surface of an undulated seafloor. Breccias are covered with thick manganese coating. Fragments of pillows are scarcely identified at the lowermost part of the dive track. Alternation of massive layers and breccia layers crops out at the uppermost steep cliff. Evidences obtained from these outcrops suggest that Tuscaloosa Seamont was derived from submarine volcaniclastic formation part of volcanic edifice. Mud covers scarcely at the top plateau of the seamount.

Cut surface of eleven collected rock samples show a character of secondary-derived volcaniclastic formation of submarine environment. Most of the clasts in the fragments are dense basalt. A conglomerate of subaerial origin is also included within the volcaniclastic rock. Mudstone and autobrecciated lava are also recovered as clast.

要旨

ヌアヌ及びワイラウ地すべり体の給源火山体は全て水中にあったのかそれとも陸上部分もあったのかは未解決の重要な課題の一つである。

このダイブでは Tuscaloosa Seamount 西端の崖の中部から最上部までを調査した。崖には大小様々の礫を含む火山性の堆積物が認められ、礫の周りを薄く砂層が覆っていた。海底面は細かく不規則な起伏に富む。礫は厚くマンガン酸化物に覆われている。枕状溶岩の破片と思われるものは潜航区間の最下部にわずかに認められるのみである。急崖の最上部にはマッシブな岩体と礫層との互層が認められた。明らかに陸成と判る火山噴出物は確認できなかった。頂上の平坦面も泥の堆積は少ない。

採取した 11 個の岩石試料を切断して肉眼観察した結果、火山性の二次堆積物が大部分であり、その構成物は殆ど水中噴火の多様な玄武岩と判断された。少数の円礫は陸成溶岩起源の可能性がある。このほか泥岩と水冷破砕溶岩片が確認された。

これらの証拠から Tuscaloosa Seamount は給源火山体の海底部分にあったと思われる。

Video Highlights

13:07-13:32, depth 3766-3741m

Outcrop of highly fragmented volcaniclastic formation. Grain size distribution is heterogeneous. Abrupt and local change of grain size suggests similarity with debris abvalanche block and debris avalanche matrix of subaerial debris avalanche deposit.

13:47-13:58, depth 3622-3523m
Outcrop of highly fractured volcaniclastic sediment. The outcrop is partially covered with muddy material.

14:35-14:44, depth 3309-3178m
Outcrop of single debris avalanche block. Alternation of volcaniclastic formation and unidentified massive formation is visible. Normal grading and bedding is observed.

Objective
During the 1998 Kaiko Cruise and 1999 Leg 1B of Shinkai 6500, we have dived, dredged and cored on the Nuuanu-Wailau Landslide (Debris Avalanche) Deposit. We have tentatively concluded in the last year that at least part of the source volcano was subaerial origin because of the existense of well-vesiculated basaltic pebbles. During Leg 1B, however, we could not confirmed any direct evidence of subaerial volcanic formation. Major objective of this dive is try to seek any evidence of subaerial or submarine volcanism at the upper western part of Tuscaloosa Seamount, which is the largest seamount (hummocky hill) within the Nuuanu-Wailau Landslide deposit.

Dive results
Any exact outcrop of subaerial volcanic edifice was not found throughout this dive. Fractures, which is characteristic on debris avalanche deposits, were developed at some outcrops. Most of the samples we have collected, were fragments of volcaniclastic formation of various grain size. The dive track started at the middle slope, 3960 m below sea level, of Tuscaloosa Seamount and drove towards east-southeast ward. The dive was finished at the top of the seamount, 2923 m below the sea level.
Many angular to subangular fragments were identified at the first segment (3960-3870 m depth) of the dive track. The slope is covered with thin and ill-sorted sandy deposit. A rock sample #1, collected at this site, is subrounded clast with thick manganese coating. Petrographically, this clast is polymictic poorly-sorted volcaniclastic breccia. An angular fragment, which characterised with quenched rim pattern was identified at this site. This clust is likely to be a pillow breccia. Any outcrop, which size exceeds 1 m is not identified in this segment. Two samples (#2) were collected from fractured and bedded outcrop at the upper part (3835 m) of the first segment. One of them (#2A) was dense and altered basalt fragment with volcaniclastic matrix material, and the other (#2B) is mudstone.
Exposures of debris avalanche deposit are found along the second segment (3870-3400 m depth) of the dive track. The lowest part of this segment is mostly covered with blocky talus deposits with and without manganese oxide coating. The seafloor is undurated and covered with sandy material. Area of

real outcrop of debris avalanche origin gradually increases towards the middle part of this segment and finally outcrop of moderate size appears at the middle slope (3766-3741 m). An outcrop of heterogeneous grain size distribution with relatively sharp contact suggests debris avalanche block and debris avalanche matrix origin. Fracture, which may appear typically on debris avalanche, is few in this outcrop probably because of volcaniclastic lithology. Occationally, pale brownish-colored pebbles are identified among of young talus deposit. Another highly fractured outcrop of debris avalanche origin crop out at 3622-3523 m depth. The uppermost part of this segment is covered with talus deposits. Two angular fragments and a pebble were sampled at 3741 m depth (sample #3). A rounded pebble (#3A) is fine-grained sandstone with thin manganese coating. One of the angular fragment (#3B) is volcanic breccia including some rounded clasts and polymictic paragonitized matrix. The other angular fragment (#3C) is well-sorted fine-grained volcaniclastic breccia. Both 3B and 3C are coated with moderate amount of manganese oxide.

The third segment of the dive track (3400-3155m depth) is made of an excellent outcrop having structures of debris avalanche origin and also talus deposit probably emplaced immediately after the landslide event. Alternation of volcaniclastic formation and massive formation of unidentified origin exposes during 3309-3178 m depth. Relatively broad-spaced fracture system developes on the massive formation. The pattern is different from that of cooling joint. Highly irregular joint system is found on the volcaniclastic formation at this segment. Steep (up to vertical) slope prevent us to make sampling from the outcrop of debris avalanche lithology. Two pieces of samples (#4) were collected at the depth of 3328 m. Sample 4A is altered fine-grained volcaniclastic breccia with manganese oxide coating. Some fractures are developed. Sample 4B is poorly sorted coarse-grained volcaniclastic sandstone. We have sampled volcaniclastic breccia (#5) at the top of the steep slope, 3156 m depth.

Outcrop is limited along the final segment of the dive track (3155-2923 m). A sheeted clastic sediments with open cracks, which is mantle over the seafloor, develop at the lower part of this segment (3155-3100 m depth). A small outcrop with fractured pattern crops out at the depth around 2952 m. The summit area of the dive track is covered with sandy clastic materials and locally covered with muddy material. Two pieces of angular fragments are sampled at 2965 m depth. One (#6A) is coarse-grained polymictic volcanic breccia and the other (#6B) is fine-grainedvolcaniclastic breccia. Soft sediments were sampled using Erkman Barge Sampler at the summit, 2923 m depth.

Video log of dive 511 (camera 2)

Time	Depth	Position (x)	Position (y)	Description	Sample
950	0			Shinkai 6500 landed on the sea	
957	0			Start the diving	
1137	3944			Start the still camera with 60 sec interval	
1139	3959			One pillow fragment, among of breccias	
1142	3960			On the bottom, breccia-rich floor with some mud	
1143	3960	730	-870	Stop for sampling	
1148	3960			Talus-like deposit with thick Mn coating	
1154	3959			Small outcrop of volcaniclastic formation	
1155	3959			Sampled subangular fragment	Sample #1
1203	3959			Drive 135 deg	
1205	3947			Angular to subangular fragments with mud and sand	
1206	3941			A lot of fragments with rough surface	
1211	3888			Angular to subangular fragments, wide variety	
				of grain size	
1213	3860	660	-720		
1215	3847			Drive 160 deg	
1215	3841			Fractured outcrop	
1216	3836			Stop for sampling	
1218	3835			Sampled from fractured outcrop	Sample #2A
1221	3835			Many fractures, bedding	
1222	3836			Sampled from bedded and fractured sediment	Sample #2B
				fragile sample	
1226	3832			Sand and mud fill local depression	
1227	3831	610	-680	Drive to 160 deg	
1228	3832			Mud, sand and lapilli, no boulder	
1229	3832			Drive to 180 deg	
1231	3832			Fractured outcrop, probably brecciated formation	
1232	3829			Mud, sand and lappili	
1234	3824			Angular to subangular fragments with mud and sand	
1235		380	-650		
1235	3823			Bedding with southward dip, rough ground surface	
1240	3849			Angular to subangular fragments with mud and sand	
1241	3854	230	-630		
1243	3877			Descending	

1244	3881			A pillow breccia?	
1244	3880			Increasing angular breccia	
1246	3870			Drive over small ridge, then local depression	
1247	3871			Younger talus deposit without Mn coating	
1248		-30	-660	Drive 150 deg and ascending again	
1249	3864			Increasing larger breccia	
1250	3858			Sand and mud predominant	
1251				Drive 135 deg, breccia and sand	
1253	3840			Small outcrop made of breccia, lapilli and sand	
1254	3836			An outcrop of volcaniclastic breccia	
1256	3823	-170	-550	Volcaniclastic breccia covered with secondary sand	
				and mud	
1258	3814			Volcaniclastic rock fragments scatter on sandy floor	
1301	3799			Finely undurated topography, breccia various size	
1302	3794			Small amount of pebble mixed with breccia	
				A volcaniclastic fragment with bedding	
1304	3784			An outcrop of volcaniclastic formation	
1305	3782			Talus?	
1306	3774	-270	-430		
1307	3766			Undurated topography. Seems to be continuous	
				outcrop of highly fragmented volcaniclastic formation	
1310	3754			Heterogeneous grain size distribution suggesting	
				debris avalanche block and debris avalanche matrix	
1314	3742			Stop for sampling, a few fractures on an outcrop	
1321	3741			Sampled soft pebble, mudstone?	Sample #3A
1329	3740			Sampled	Sample #3B
1330	3741			Sampled	Sample #3C
1332	3741	-280	-350		
1336				Drive 135 deg	
1338	3718			Locally increse mud cover	
1342	3676			A fracture across the display image	
1343	3662	-430	-240	Bottom mostly rock fragments, bedding?	
1344	3650			Mostly breccia, rugged topography	
1347	3622			Begin outcrop, volcanogenic sediments, fractures	
1352	3569	-510	-160	Continuing the same outcrop with partial mud cover	
1354	3540			Turn to 105 deg	
1355	3525			Turn to 90 deg	
1356	3523			Fractured outcrop of volcaniclastic formation	
1401	3483	-530	-50	Temporary stop	

1403	3476			Turn to 90 deg	
1405	3454			Aapproach steep slope, made of fractured	
				volcaniclastics	
1410	3428			Fishing net or rope? on the sea floor	
1413	3426			Steep and fractured cliff made of volcaniclastics	
1414	3417			Bedding?	
1414	3413	-550	-120		
1417	3399			Photo interval every 30 sec., highly fractured bed	
1418	3389			Towards 130 deg, begin steep slope	
1421	3357			Breccia with sand	
1425	3329	-560	160	Stop for sampling	
1429	3329			Sampled from local talus	Sample #4A
1431	3329			Another sample from the same local talus	Sample #4B
1433	3329			Sampling finished	
1434	3327	-560	170		
1435	3309			Continuous outcrop, fractured volcaniclastics	
1437	3280			Bedding?	
1438	3267			Alternation of brecciated and massive volcanics	
1439	3248			Massive body with fractures	
1440	3228			Back to volcaniclastics	
1441	3209			End of continous outcrop	
1442	3197			Again massive outcrop with fractures	
1444	3178	-620	240	Top of cliff	
1447	3159			Gentle slope, breccia with mud	
1453	3156			Sampling, cauliflower-shaped fragment	Sample #5
1454	3154	-640	280	Towards 90 deg	
				Rock fragments filled with mud	
1456	3145			Sheeted sed with open crack	
1459	3113			Sheeted sed with open crack	
1503	3094	-600	500	Temporary leave bottom, drive towards 90 deg	
1510	3094			On bottom again, sand and mud, flute cast?	
1511	3087	-620	970		
1513	3051			Fragments, sand and mud, no outcrop	
1517	2997			Outcrop of volcaniclastics, fractures	
1520	2971			Start sampling from outcrop of volcaniclastics	
1523	2971			Sampled from loose outcrop	Sample #6A
1525	2971			Another sample from the same outcrop	Sample #6B
1527	2965			Drive 90 deg	

1528	2958	-640	1180		
1528	2952			Small fractured outcrop, volcaniclastic	
1530	2927			Sheeted sediment with open crack	
1532	2923			Erkman Berge sampling at muddy bottom	Erkman
1538	2923	-640	1350	Sampling finished	
1529	2923			Leave bottom	
1650				Arrived sea level	

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2B

DIVE No	512	DATE	1999.9.14

	NAME	AFFILIATION
Japanese	石塚　治	地質調査所地殻化学部 Department of Geochemistry

SPECIALTY	Geochemistry, Economic geology
PURPOSE	Geolological and geochemical study of Loihi hydrothermal system
AREA	Loihi Seamount
SITE	South rift zone

	LATITUDE	LONGITUDE	TIME	DEPTH
	Ex). 24 ° 18.5' N	127 ° 36.2' E	13:35	6499 m
LANDING	18 ° 50.0215'N	155 ° 12.8468'W	11:12	2643
LEAVING	18 ° 50.9763'N	155 ° 14.0364'W	16:09	2116

DIVE DISTANCE:	3500m	DEEPEST POINT:	2676m

DIVE SUMMARY	The dive was conducted on the eastern slope of the South rift of the Loihi Seamount at water depth ranging from 2650 to 2100m. Main target of this dive was to discover hydrothermal vents or hydrothermal deposits. The survey track of thisdive was decided based on the results of Towyo survey conducted by R/V KOK of University of Hawaii. The dive course included areas at water depths where anomalies of temperature and/or particle density were recognized. Unfortunately, no signs of hydrothermal activity were recognized during this dive except for orange-colored material observed on the lava surface. The slope was almost completely composed of basaltic lavas. Pillow lava and pillow breccia were dominant as a lava morphorogy. Other morphology of lava flows including Pahoehoe and sheet flow (2380m-) and tumulus feature were also observed in some places. Topography along the dive course was very complicated, and ridges and
PAYLOAD	Grab sampler, 4 push cores, pH meter, Eh meter

VISUAL RECORDS	VTR1	3	VTR2	3	STILL CAMERA	376	ONBOARD CAMERA	No

SAMPLE	Organisms:	Rocks:2	Cores:	Water:	cc
	Sediments:	Others:	TOTAL:2		

VIDEO HIGHLIGHTS	1) 11:11-11:22	2) 12:51-13:09	3) 13:39-13:49

KEY WORD	Loihi Seamount, South rift, no hydrothermal activity, pillow lava, sheet flow

Shinkai 6500　Dive No.512 (September 14, 1999)

Investigation of hydrothermal vent area on the South Rift of the Loihi submarine volcano

Chief pilot: Tsuyoshi Yoshiume

Co-pilot: Tetsuji Maki

Observer: Osamu Ishizuka

(Geological Survey of Japan)

1. Objective of the Dives

The main objectives of this survey are geological and geochemical investigation of Loihi hydrothermal system. The investigation is mainly stressed on the following points:

1) Obtain size, distribution, structure, precipitation (growth) rate of hydrothermal deposits
2) Identify the hydrothermal precipitates and know their chemical characteristics
3) Estimate the physicochemical condition of hydrothermal activity
4) Investigate the evidence of microbial activity and estimate the contribution for selective concentration and precipitation of elements (e.g. Fe).
5) Collect altered host rocks for hydrothermal system and investigate the addition and dissolution of elements by hydrothermal solution.

Through this survey, we understand the characteristics of deep portion of the Loihi hydrothermal system. Combined with the information on the hydrothermal activity in the summit area, we obtain comprehensive image of submarine hot spot hydrothermal system and understand flux of various elements at this hydrothermal system. We will estimate the importance of this hydrothermal system on selective concentration of some elements and input of elements to the seawater.

Another objective is to understand the depth control on characteristics of hydrothermal deposits. Water depth is supposed to have significant effect on volatile and other element concentration and capability of transportation of metals. We will focus on the investigation of mode of occurrence, chemical composition and mineral assemblage of hydrothermal deposits.

Finally, we will do comparative study between the arc-back arc hydrothermal system and hotspot hydrothermal system. We will make clear the differences between the two systems and understand what cause the differences (e.g. host rock chemistry, magamtic input, etc.).

2. Dive results

The dive was conducted on the eastern slope of the South rift of the Loihi Seamount at water depth ranging from 2650 to 2100m. Main target of this dive was to discover hydrothermal vents or hydrothermal deposits. The survey track of this dive was decided based on the results of Towyo survey conducted by R/V KOK of University of Hawaii. The dive course included areas at water depths where anomalies of temperature and/or particle density were recognized during Towyo. Unfortunately, no signs of hydrothermal activity were recognized during this dive except for orange-colored material observed on the lava surface. The slope was almost completely composed of basaltic lavas. Pillow lava and pillow breccia were dominant as a lava morphorogy. Other morphology of lava flows including Pahoehoe and sheet flow and Tumulus feature were also observed in some places. Sheet flows were often observed at water depth ranging from 2435m to 2200m. The sheet flows usually have ribbon-like glass-rich margin, which is often contact with pillow lavas. The Tumulus feature is tower-like pile of pillows of several meters high which is prodruded by tubial lava at the top. This feature was only observed in the area where both sheet flow and intact pillow lava occur, probably where the flow rate (or supply rate) of lava was large. Topography along the dive course was very complicated, and ridges and troughs bounded by steep wall were often observed. Steep slopes were often composed of thick piles of pillows, and appear to be end of lava flow. Thus frequent change of seafloor depth along the dive course was due to passing over the lava flows by Shinkai. Intact pillow lava flows were observed near the rift axis (i.e., on the ridge). On the other hand, on the flank of the rift zone, collapstion of walls makes piles of blocky lava and intact lava flow is rare.

On the steep slope just below the crest of the ridge where inside the lava flow (cross section) is outcropped, reddish-yellow precipitates are observed among the surface of the each lava block. This suggests that vey small scale and short-lived circulation of hydrothermal solution occurred in hot lava flow.

Since sediment cover on the lava flows was very thin, recent volcanic activity is supposed to have occurred on the rift axis. However, no hydrothermal activity seems to have occurred.

3.Sample

Two rock samples were collected during this dive.

#512 R1 (ol basalt with glassy rind): This sample was collected near the landing point at a water depth of 2643m, which is located on the eastern flank of the South Rift. This sample is a crust of a pillow lava.

#512 R2 (reddish brown-colored precipitate on ol basalt): This sample was collected from the steep slope on the eastern flank of the South Rift, where angular lava blocks collapsed from the upper part of the slope are accumulated. This sample is an angular block of olivine basalt covered with reddish-brown-colored hydrothermal precipitates. The thickness of precipitates is less than 1mm. This precipitates show spherical shape (probably aggregates of very fine-grained crystal or amorphous material) and appear to be iron-rich clay (nontronite) or iron hydroxides.

Dive 512 99/14/9

TIME	DEPTH (m)	BEARING	COMMENT
11:11:34	2640	263	Pillow basalt flow; well-formed, elongate pillows. Black sand fills the interstices among pillows.
11:13:04	2643	263	ditto
11:16:45	2642	253	Pillow basalt flow; fairly flat flow surface, well-formed, elongate pillows
11:17:55	2642	245	**Sample #1; Crust of pillow/ lobe toe;**
11:20:35	2640	321	Smoother pahoehoe surface, elongate pillows less defined, more rounded, bulbous surface
11:22:15	2646	330	Pillow basalt appears very fresh-looking flow with elongate, intact, pillows
11:24:45	2653	328	Higher above same pillow, pahoehoe flow
11:26:55	2663	295	No change
11:28:25	2676	270	Closer to fresh lobate pahoehoe/pillow surface flow
11:30:15	2674	276	Flow surface incline, up to left; elongated pillow (tubial)
11:31:00	2671	268	Fresher(=blacker) looking pahoehoe surface, smaller more rounded pillow/ flow lobes
11:32:00	2663		Steep slope composed of collapsed pillow breccia, which partly bear yellowish material on their surface.
11:33:00	2660		Closer to fresh lobate pahoehoe/pillow surface flow surface; broken lobe with pillow rind(?); looks very similar to first flow encountered at 11:11
11:38:16			Steep slope.
11:38:16	2643	258	Flow edge encountered, probably fissure?
11:41:28	2632	249	Broken pillows, pillow rubble. Collapsed angular lava blocks
11:42:59	2624	248	Elongate pillows, lobate pillows
11:44:00			Slope composed of pillows on righthandside.
11:45:50	2616	250	Lost the view of sea floor
11:46:00			Pillows on lefthand side.
11:47:46	2616	249	Intact pillow lava
11:50:10			Steep wall
11:51:10	2599	250	Came across edge of lava flows
11:53:17	2596	251	Elongate pillows, some are broken.
11:54:57	2588	250	Lobate pillows

11:57:27	2577	253	Angular blocks of collapsed lavas. Pillow rubble, flat surface of fragmented, broken pillows
11:59:00	2565	260	Higher above same broken-pillow/ angular fragmented surface
12:01:07	2555	252	Encountered overlying Pillow lobe/ pahoehoe flow -- edge to right side
12:03:07	2549	251	Flow is similar in appearance to first flow encountered with some elongate and some bulbous pillow lobes on a gently sloping surface; down slope is toward camera
12:08:48	2530	253	Higher above same flow surface, no significant changes in lobate, pillow flow surface.
12:10:00	2521		Collapsed slope composed of broken pillows.
12:11:28	2514	245	Steeper slope , flow edge or channel?; x-section is pillow breccia-like
12:12:28	2509	250	Pillow flow surface, similar to above
12:13:00	2501	245	Steeper slope to right
12:15:00	2500		(changing heading to 350 deg)
12:15:00			Pillow flow surface, similar to above
12:16:48	2495	312	More fragmented, broken angular to rubbly flat surface
12:17:00			Intact pillow lava
12:19:58	2513	359	Pillow flow/ pahoehoe surface; relatively steep sloping (Down to front and left of view); move toward near vertical surface with bulbous pillow breccia appearance
12:24:00	2515	345	Collapsed wall. Pillow lobes on steeply dipping surface; dip toward camera and left side of view.
12:26:19	2504	349	After traversing higher above surface of uncertain texture, a new pahoehoe/lobate pillow flow is encountered to right side of view.
12:28:59	2536	352	Some Pillow lobes distincly broken; In general surface is represented by more fragmented broken pillow lobes, this view is fairly flat. Black sand fills the interstices amoung pillows.
12:32:00	2530	347	Some Pillow lobes distincly broken; In general surface is represented by more fragmented broken pillow lobes, this view is fairly flat. Black sand fills the interstices amoung pillows.
12:33:00	2542		Steep wall of angular pillow breccia.
12:36:00	2536	336	Getiing closer to right dipping fragmented pillow flow surface.

12:37:00	2532		Thick pile of angular lava block.
12:40:00	2552	298	Smooth and flat, pahoehoe (?) surface overhanging to left, surface is NOT lobeate, but flat (possibly eroded pillow breccia surface); looks more like framented pillow surface as traverse continues
12:45:00	2557	291	Blocky, fragmented pillow breccia surface
12:47:00	2551	289	Pillow breccia is very tightly packed
12:48:00	2539	270	Moved to top of small knoll; comprised of same angular, fractured/broken pillow breccia
12:51:00	2520	268	Clearly appears to be deposit of broken pillows; slope is toward camera
12:53:00	2510	271	No change
12:55:00	2494	271	Same talus-like deposit of closely-packed, angular pillow fragments Can see pillow selvage in broken fragments of rounded block.
12:59:31	2488	284	**Sample #2 fragmented pillow breccia sample.**
13:05:00	2478	270	No change
13:06:00	2480		Debris of angular block of lava.
13:07:00	2462	269	More sandy area with blocky pillow fragments, slope is shallow toward camera.
13:09:00	2446		Top of the slope composed of debris.
13:13:12	2454	272	Smooth pillow lava field. Some are elongated and tubial. Sediment became thick.
13:14:32	2443	272	Same as above
13:16:00	2438		Slope of pillow lava ended. Steep slope ahead.
13:16:52	2437	272	Younger-looking lava flow; blacker, fresher pillow lobes overlying previous deposit.
13:18:00			Typical pillows and tubial pillows.
13:19:12	2426	289	Flow surface comprising fresh, elongate and interwoven pillow lobes = pahoehoe toes
13:21:12	2406		Go over the pillow ridge.
13:25:00	2436		Pillow with almost no sediment dusting. Partly cracked.
13:26:00	2435	291	Flat, lobeate pillows, flow surface is inclined away from camera. Flow direction implied from lobe alignment is from upper left to lower left of screen.
13:26:20	2435		End of pillow flow.
13:27:00	2436		Sheet flow begins to appear. Platy surface cracked and marginal part is ribbon-like crust.

13:30:00	2429	289	Lobeate pillow flow surface, elongate lobes, rounded toes, occational bulbous, inflated pillow toes.
13:31:00	2416		**Same flow. Notable "pillow-buds" or small pillow lobes protruded from larger pillow lobe.**
13:33:00	2416		Split pahoehoe lobes/pillows = elongate splitting during inflation
13:33:46	2422		Sheet flow again appeared.
13:34:35			Pillow and tubial pillow.
13:35:00			Tumulous feature. Top portion seems to be lava which protruded from pillow piles.
13:37:00	2397	289	More angular pillow breccia on steeper slope
13:39:00	2386	291	Lobate pillows (on-slope deposit- not breccia) covered with thick sediment.
13:45:00	2372	288	**Distinct hornito-like or tall, steep sided pillow mound. Same flow unit as above**
13:48:00	2378		Small tumulus.
13:49:00	2374	286	Small flow front (?) steep area comprising leading edge of overlying flow of pillow -pahoehoe flow
13:51:00	2358		Pillow lava.
13:53:00	2354	287	Flat monotonous elongate pillow/ pahoehoe flow lobes of surface flow.
13:59:00	2370	324	No change
14:01:00	2363	321	No change
14:03:00	2372	319	**Tumulus-like feature, flat sided conical protrusion from flow**
14:04:00	2369	320	**Flat planar, platy surface = several lines of sheet flow**
14:07:00	2367	322	Pahoehoe lobe on top of ropey pahoehoe flow
14:10:00	2362	321	Lobeate flow grades into fractured sheet flow with ropey protrusions
14:13:00	2353	319	Pahoehoe sheet flow, occational lobes and "ribbons" extended perpendicular to flow direction along front of small breakout
14:15:05	2356		Sheet flow.(direction ca.80^{o}) to pillow lobe.
14:16:00	2353	320	Broad, flat lobes grading toward more pillow-like flow lobes
14:19:00	2345	320	More angular (pillow breccia?) grading to more slabby-looking pahoehoe
14:20:00	2342		Back to lobeate pahoehoe sheet

14:23:00	2331	320	Pillow flow. Black sand fill the interstices among pillows.
14:25:00	2332	321	Sheet flow with ribbon edges (Almost slabby)
14:27:00			Sheet flow in valley.
14:28:00	2336	321	Sheet flow (slabby-looking in places)
14:30:00	2335	301	**Sheet flow contact with steep sloped pillow breccia, many intact and unbroken lobes indicate insitu and flow on near slope.**
14:32:00			Steep slope of accumulated pillow basalts (until 14:35).
14:35:00	2313	336	Top of the 20m high steep slope of accumulated pillow lavas
14:36:00	2308	331	Relatively flat plane with black sand layers in depressions around inflated fllow lobes and pillows
14:40:00	2310	301	Lobate sheet flow= flattened and interwoven pahoehoe flow lobes
14:43:00	2310	313	Black sand fill the interpillow space. Pillow lobes.
14:44:00	2289	305	Steep escarpment/slope (down to lower right?) Pillow breccia on slope,
14:45:00	2296		Pillow breccia slope.
14:46:00	2285	308	Flat sheet flow, slabby (to ribbonny?) in places and grading to area of same flow with predominant lobeate pillows and small flattened lobes
14:48:00			Pillow or lobate flow. Interpillow space is filled with black sand.
14:50:00			Pillow.
14:53:00	2281	332	Pillow breccia on steeper slope; most pillow lobes are intact, so probably deposited insitu as flow rock. Lower part of the slope appears to be massive lava, and upper part consists of pillows.
14:56:00	2277		Pillow robes.
14:58:00	2271		Pillow basalt
14:59:00			Pillow lava burried with black sand.
15:02:00	2264	331	Sheet flow, appears to be upturned or broken slabs?
15:03:00	2263	332	Rounded and slightly elongated pillows
15:05:39	2258		Slope composed of accumulated pillow.
15:06:39	2255	326	The sea floor out of view
15:09:20	2245	336	Edge of lava flows, open fissure.(322^{o} direction)
15:10:49	2211	342	Clear striations on the surface of pillows
15:11:09	2240	343	Lobate sheet flows

15:13:49	2232	345	Pillow lava with fingers
15:17:49	2215	339	Lobate pillow lava
15:18:20	2216	338	Flat, smooth sea floor, lobate sheet??
15:20:00	2226	339	Collapsed pit formed from inflation feature
15:23:00	2229	350	Lobate pillow lava
15:24:10	2227	20	same as above
15:26:20	2224	343	Pillow breccia; most pillow lobes are intact
15:28:52	2213		Pillow basalt.
15:29:00	2211	355	Intact pillow lava
15:31:10	2213	350	Elongated pillows aligned subparallel to each other
15:32:30	2206	353	Intact pillow lava; some are elongated
15:34:30	2199	351	Pillow lavas with various sizes
15:36:00	2194	353	Pillow breccias probably formed in situ
15:37:21	2190	350	Pillow lava; some are broken
15:38:00	2183	350	same as above
15:39:31	2175	353	Yellowish white circular stain on the lava flow surface.
15:40:41	2170	355	Fragmented pillow lava
15:41:00	2167		Pillow lava ended. Debris of lava blocks.
15:42:31	2164	351	Large block of pillow lava; broken blocks
15:44:11	2152	352	Talus deposit, fragment size changes gradually, surface appears less "fresh"
15:48:00	2124		No discernable surface in 5 minute interval
15:49:00	2123	27	Steep escarpment/slope encountered to right (down to lower left?)(ca. 304^{o}) Pillow breccia on slope,
15:51:00	2120	14	Steep slope vertical to overhung. On right. Bulbous pillows intact and insitu
15:52:32	2118	343	Vertical to overhang wall (320^{o} direction) end. Broken ledge, slabby pahoehoe
15:54:00	2120	351	Lobeate pillow flow surface, elongate lobes, rounded toes, occational bulbous, inflated pillow toes.
15:56:00	2116	350	Sand deposit on surfaces of lobes and low areas of lobe intersections
15:57:00	2115	351	Yellowish white circular stain on the lava flow surface.
15:59:00	2115	349	same lobeate pillow/pahoehoe flow, no change
16:00:00	2114	349	Edge of flow (almost N-S direction), defined by steep escarpment; moving into void on right
16:01:00	2111	349	Bottom not clearly visible
16:02:00	2115	351	Bulbous-pilllowy flow, fresh looking sloping to right
16:04:00	2111	42	Bottom not clearly visible

16:06:00	2113	290	Steep escarpment of round pillows; slope and flow left to right; some broken fragments on steep slope but most insitu.
16:08:00	2109	15	Leaving the Bottom

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2b

DIVE No.	6K513	DATE	September 15, 1999	
	NAME		AFFILIATION	
Japanese	Brian Midson		University of Hawaii, SOEST	
SPECIALTY	[illegible]			
PURPOSE	Location and characteristics of deep (>2000m) Loihi hydrothermal systems			
AREA	Loihi submarine volcano			
SITE	Lower southeast rift zone			
	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	18 ° 45.5’ N	155 ° 10.6’ W	11:49	4225 m
LEAVING	18 ° 46.3’ N	155 ° 10.9’ W	15:32	3936 m
DIVE DISTANCE:	2200 m	DEEPEST POINT:	4425 m	
DIVE SUMMARY	Shinkai 6500 landed in 4425 meters of water on the lower southeast rift zone of Loihi to prospect for hydrothermal systems. The dive plan was to survey up the slope from 4425 meters to a local topographic high at 3920 meters. The heading for the upslope transect was 330 ° . Along this line the lava morphology was almost exclusively lobate pillow flows. The sediment cover varied from medium to light and was principally gray pelagic detritus. No hydrothermal vents or deposits were seen during the traverse. Near the top of the local high some blocky talus was directly below a near vertical wall of truncated pillows. The more gently sloping areas above 4000 meters exhibited pahoehoe-like sheet flow morphology and several collapsed lava channels. No hydrothermal vents were found, however, several of the larger pillows were crusted along their lower faces with a reddish deposit. This			
PAYLOAD	Grab sampler, eH sensor, pH sensor, Water Sampler, Temperature probe, 4 Push Cores, Transponder			
VISUAL RECORDS	VTR1 VTR2 STILL CAMERA 400 ONBOARD CAMERA YES			
SAMPLE	Organisms: Rocks: 9 Cores: Water: cc Sediments: Others: TOTAL: 9			
VIDEO HIGHLIGHTS	1) cam 2 Burst Pillow lobe12:17:25 2. cam. 2 dunite bearing lobe 13:58:10 3) collapse feature			

KEY WORD	Loihi, Hydrothermal vents, Pillow basalt, Xenolith,

Shinkai 6500 Dive No.513 (September 15, 1999)

Loihi submarine volcano of hydrothermal vent exploration on the southeast rift of the

Chief pilot: _____ Sasaki

Co-pilot: _____ Higuchi

Observer: Brian Midson

UH (SOEST)

1. Objectives of the Dive

The goals of this dive were:

1. To locate and sample active deep water hydrothermal vents in order to compare the flow rates, temperatures, pH/Total alkalinity/CO_2, and Fe:Mn ratios with Loihi shallow water systems, recently sampled by the Hawaii Undersea Research Laboratory (HURL) submersible *Pisces V*.
2. To sample hydrothermal precipitates, chimneys and surficial sediment deposits for geochemical and microbiological studies.
3. To collect altered host rocks from vent sites to quantify elemental changes due to enhanced weathering and hydrothermal exchange reactions.
4. To collect unaltered rocks from depths unreachable by *Pisces V* in order to increase the suite of samples available for petrological analysis.
5. To enhance the HURL deep water macrobenthos archive.
6. To measure hydrographic properties with conductivity-temperature-depth (CTD), eH and pH sensors.

2. Dive results

The dive covered the lower southeast rift zone of Loihi between 4425 and 3936 meters water depth. This site was chosen to maximize the potential of discovering deep hydrothermal vents, especially at a prominent topographic high between 4000 to 3920 meters. The results of the hydrographic survey conducted by HURL from the R/V *Kaimikai o Kanaloa* immediately before leg 2b of this cruise revealed a very large Mn anomaly (10x background) at 4175 meters water depth. Unfortunately the source of this dissolved Mn was not discovered on this dive. There were, however, signs of fairly recent hydrothermal activity around 3940 meters water depth. Many large pillows were coated with reddish iron oxide deposits along their lower rims. To the frustration of both pilot and observer these coatings were impossible to sample.

Some of the rocks collected did show signs of high temperature water-rock reaction. The inner surfaces, which were exposed during collection, were stained bright red. These stains are not uncommon in submarine basalts on Loihi. They are formed as water seeps into cooling fractures, leaches reduced iron, which then deposits as iron oxides on the rock surfaces. This process may occur without the presence of a true hydrothermal vent. Hydrothermal vent iron oxide deposits differ in that they are micobially mediated and filamentous and are commonly associated with nontronite (Fe smectite).

The suite of rocks collected for petrologic analysis covered a range of morphologies and lithologies. Most were highly enriched in olivine. Several pillow fragments were collected, as well as a cross section of an “elephant trunk” and an intact pillow lobe with several rounded dunite xenoliths visible on the surface. One sample was collected from the roof of a collapsed lava channel. This sample was intended to be representative of the collapse features observed near the end of the dive at depths less than 4000 meters where the slope was less steep and sheet flow lavas were more common.

The visual record of the dive included many macrobenthos and other fauna. These records will enhance the HURL library of deep-water biota, such as those in the publication “In Deeper Waters” by E.H. Chave and A. Malahoff.

CTD, eH, and pH measurements were made during the dive. The internally recording eH and pH sensors will be reconciled with the CTD data in post processing to describe the water column hydrothermal anomalies.

Samples.

Ten rock samples were collected from seven sites as follows:

1a; 4424 m, olivine rich fragment of bulbous pillow lobe.
1b; 4424 m, olivine rich fragment of bulbous pillow lobe.
2; 4340 m, flow-lobe cross section.
3; 4245 m, “elephant trunk” cross section.
4a; 4134 m, “elephant trunk” cross section.
4b; 4134 m, pillow lobe fragment.
5; 3995 m, intact pillow lobe with dunite xenoliths.
6; 3936 m, lava channel roof fragment.
7a; 3936 m, pillow lobe fragment.
7b; 3936 m, vesicular pillow lobe fragment.

Dive Log with collaboration of Malahoff, Ishizuka, and Thornber
Dive 513 99.15.9

TIME	DEPTH (m)	Heading	COMMENT
11:47:00	4425		pillows covered with mud.
11:49:00	4424		On bottom. Sampling of sedimet.
11:52:34			Pillow crust is broken (due to inflation).
11:54:00	4424		Sample #1a. Sampling of lava.
11:55:00	4424		Sample #1b. Sampling of lava fragment.
11:59:00		330	Finished sampling. Start moving.
12:03:00	4414		pillows covered with mud.
12:05:48	4405		elongated pillow.
12:06:18			long elongated pillow.
12:10:00	4378		Still sediment cover is thick.
12:13:00	4356		Still pillow lava dominant.
12:13:00	4340		Sample #2. (-770,210)
12:17:00	4340		Sampling. Lava coated with yellowish to reddish color coating.
12:19:19	4340	316	Sample#2: Interior of split pillow with rippled "pahoehoe" ribbon flow eminating from split area; In th area, the flow is generally comprised of elongate and flattened pillow lobes or concentrated areas of bulbous rounded lobes protruding from irregular sheet-like surface. Moving upward toward areas of densely overlapping elongate pillow lobes on more steeply inclined slope.
12:21:00			Finished sampling. Start moving.
12:25:00	4316		pillows covered with mud.
12:26:00	4308		elongated and bulbous pillow.
12:28:00	4283		elongated and spherical (normal) pillow covered with mud.
12:33:00	4248		relatively steep slope composed of pillows.
12:34:50	4245		dusting of sediment onrelatively young pillows. Fingers on pillows.
12:37:00	4244		Trunk of pillow. Try to sample.
12:38:00	4245	326	Sample #3: Two handed sample' typical small lobe tip- cylindrical piece with dark glassy rind and lighter colored, dense core.
12:44:40	4237	330	Start moving.
12:47:00	4206		pillows.

12:53:00	4170		tubial pillows
12:55:00	4157		tubial pillows
13:03:00	4160		dusting of sediment on pillows.
13:06:00	4140		lava tubes.
13:07:00	4141		finger on young pillow
13:09:00	4139		try to sampling. Many small pillows are observed.
13:13:00	4136		Many fingers on pillows.
13:19:00	4136		red to orange-colored staining on lava surface.
13:19:00	4134	356	Sample#4a,b: Bulbous to elongate lobes on small steep scarp. Sample of bulbous protrusion broken from larger bulbous pillow/lobe.
13:22:00	4134		columnar-shaped lava stained with hydrothermal precipitates.
13:28:53	4122	330	Start moving.
13:32:00	4119		pillow terrace deposit.
13:35:00	4084		fresh pillows.
13:41:00	4023		dusting of sediment on pillows.
13:41:00	4020	334	possible contact between flows. Overlying lobeate drips appear darker/fresher.
13:42:00	4016		tubial pillows. Very fresh.
13:48:00	3999	352	Bulbous pillow broken off, unsuccessful attempt to sample interior,
13:50:00	4000		yellowish-colored coating on glassy pillow lava surface.
13:52:00	3999	353	more unsuccessful rock sample attempts
13:58:00	3995		Sample #7. Collected lava tubes.
14:02:00	3994		tubial lavas
14:08:00	3974		tubial pillow lavas.
14:16:00	3977		tubial pillow lavas.
14:17:00	3977	180	Many fingers on pillows.
14:18:00			Many fingers on pillows.
14:19:00	3975		hydrothermal deposits on pillow surface.
14:22:00	3974		very young lava with sediment dusting.
14:24:00	3974		hydrothermal alteration on pillow surface.
14:25:00	3974	94	Large pillow lobe broken off; unsuccessful sample
14:30:00	3971	120	White "eel-like" fish
14:32:00	3971	120	390,-380 Start moving.
14:34:00	3963		tubial pillow lavas.
14:38:00	3958		pillows with dusting of sediments.

14:40:00	3949		tubial pillows
14:47:00	3940		surveying around summit area. Covered with pillow lava with thin sediment.
14:50:00	3936		relatively flat surface.
14:52:00	3936		white-colored sediment is thicker than before.
14:54:00	3936		cracked pillow.
14:57:00	3936		white-colored sediment covers everywhere.
14:58:00	3936		platy lavas are cracked and collapsed.
14:59:00	3936	156	Collapsed tube/channel roof.
15:02:00	3936	123	Sample#6, Flat chunk of collapsed channel roof rock.
15:13:00	3947		pillows with dusting of sediments.
15:16:00	3947		truncated pillow tubes stained with yellowish material.
15:19:49	3946		reddish color precipitates on pillow lava.
15:27:00	3936		Sample #7a,b. Lava block.(390,-180)
15:28:00	3937		lava stained with reddish colored precipitates.
15:31:00	3936		leaving bottom

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2B

DIVE No.	514	16 Sept 1999	

	NAME	AFFILIATION
Japanese	Alexander Malahoff	SOEST University of Hawaii Honolulu,Hawaii

SPECIALTY	Marine Geology and Geophysics
PURPOSE	Neovolcanism and Hydrothermal activity
AREA	Base of Loihi Submarine Volcano
SITE	Loihi Submarine Volcano

	LATITUDE	LONGITUDE	TIME	DEPTH m
LANDING	18°46.2060'N	155°7.4203'W	11:58:00	4819m
LEAVING	18°45.5284'N	155°7.9268W	15:01:00	4760m

DIVE DISTANCE:	1900m	DEEPEST POINT4821m:	4821m

DIVE SUMMARY	The purpose of the dive was to examine the westerly fault scarp and the Adjoining basin for evidence of fresh faulting and accompanying hyd rothermalmal activity.The dive commenced in the middle of the basin at a water depth of 4819 meters and proceeded south-east towards the scarp of the block.The sediment in the basin covered a smoth ocean floor.The face of the scarphad been recently disturbed by tectonic activityand largwe blocks of rock lay at the base of the scarpThe face of the scarp had originally been covered with a manganese coating indicating that faulting along this scarp had been inactive for along period of time.However the scarp now shows fresh exposures of sedimentary rock.Only one isolated yellow, presumably hydrothermally deposited stain was notedon the traverse along the fault
PAYLOAD	Grab,corers

VISUAL RECORDS	VTR1	VTR2	STILL CAMERA	400	ONBOARD CAMERA	YES	

SAMPLE	Organisms:O	Rocks:8	Cores:2	Water:0	cc
	Sediments:2	Others:	TOTAL:		

VIDEO HIGHLIGHTS	1)	2)	3)

KEY WORD	

Shinkai Dive 514

September 16,1999

Investigation of Hydrothermal Vent Sites at the Southern Fault Block,Basee of the Southern Rift Zone,Loihi Submarine Volcano

Chief Pilot:Satoshi Ogura
Co-Pilot :Itaru Kawama

Dive Objective

The primary dive objective was to map the northern fault boundary of the fault block and the northernfault boundary of the graben like basin for the site of the MIR vents mapped in 1991 with the Mir submersiblesThe objective also included the sampling of the vents if found.Sampling of the scarp of the fault block and rock sampling of the pillow basalts exposed along the southern edge of the basin.The ultimate objective was to find support for the hypothesis that these low temperature basal vents were the result of deep circulation of seawater along the basin-fault block boundaries.The venting would then result from seawater contact with deep seated hot rocks of the basement of the Loihi edifice,rather than through contact with newly extruded basalts.

Dive Results

The dive traversed along the northern wall of the southern end of the fault block and then cut across the southern edge of the graben-basin.The total dive duration was 186 minutes and extended for 1888 meters along the ocean floor The beginnig of the dive was located in the middle of the basin at a water depth of 4819 meters.The foor of the basin in this area was covered by smooth sediments.The water mass moved along the ocean floor at a steady rate.A careful observation was made of the nature of the suspended flocculant material being transported by the water mass.No yellow coloured suspended material of hydrothermal origin was observed.The dive continued to the wall of the fault block with a heading of about 45 degrees.The fault face was encountered at a water depth of 4815 meters.Large blocks of rock had fallen out of the face and were observed to be lying at the base.It appears that originally the wall was uniformally covered by a black probably manganese coating,showing a long term of stability before some recent tectonic event caused sections of the fault face to mass waste revealing freshly exposed rocks.the exposed rocks appeared to dip in diffirent directions with apredominant near vertical dip.Fractured blocks of what appeared to be breccia were the most commonly observed rocks.Exposures of white mylonite were alo common.Yellow stains indicating previou low temperature hydrothermal events were observed near the base of the fault scarps.A crossing of the sedimentary basin was made towards the end of the dive,ending at a water depth of 4786 meters where the distal edge of Loihi lava flows was encountered.No evidence of hydrothermal activity was noted in this area

Samples

A push core of the basin sediments was taken at 4819 meters at 1156h.

Rock samples 1A and 1B of fault scarp breccia was taken at 4812 meters at 1219h.
A small sample of whitish mylonite and a push core of the same material was taken at 1250 meters at 1254h
A large slab of pillow basalt was taken from the basal lava flows at 4782 meters at 1410h.
A sample of reddish coloured lava flow was taken at 4787 meters at 1430h.
A sample of the pillow lava front was taken at the end of the dive at 4768m at 1459h.

9-16-99 6K514 DIVE LOG Naka / Midson / Thornber			
Time	**Depth**	**Bearing**	**Comments**
11:58:00	4819	100	suspended fine sediment
11:59:00	4819	154	ON BOTTOM
12:00:00	4819	101	Push Core Sample, Black
12:04:00	4818	99	Leaving bottom
12:05:00	4816	99	soft sediment bottom/nondistinct surface, ripple marks
12:06:00	4811	107	Travelling over fine sediment,sediment particles
12:10:00	4818	122	ditto, ripple marks consitently vertical on screen
12:13:00	4817	136	Rock blocks in sediment , Indurated sandstone
12:13:00	4815	140	occational blocky and round rocks in flat sediment surface,base of fault
12:16:00	4810	179	Sample outcrop of sandstone, #1a, 30 cmsurface has, left basket, right side, inner portion
12:16:00	4810	175	Sample#1: from base of well consolidated , thin layer in low wall. Sample is flat, slabby sedimentary, Rock from blocky rubble beneath near horizontal ~12"-thick layer covered by soft oozey sediemnt.Base of fault block.
12:24:00	4808	200	Sample , #1b, no image.Sample from outcrop.
12:25:00	4812	250	Continue across fine sediment,thick flocks in water.
12:26:00	4813	247	slope upward to left ; near vertical wall of rock appears more like breccia/ or coarse sediment, massive /uniform coarse texture unit with denser, near horizontal layer at base.Appears to be shattered rock.
12:27:00	4814	240	Sandstone outcrop to left.Variable dip and texture.
12:30:00	4812	249	Steeply dipping to lower right, curved drape or "lobe" of coarse sedimentary rock comprised of alternating coarse-fine layered sequences, appears poorly consolidated but rock not probed with arm.

12:31:00	4812	225	Thick accumulated sediment at base of outcrop
12:31:00	4813	271	Bedded plane dipping to right
12:33:00	4820	186	Crossing flat mud/ fine sediment
12:36:00	4820	139	Brief view of very low relief outcrop protruding from soft sediment, dipping away from camera, breccia and sandstone.Chaotic dips.
12:37:00	4820	132	Change course toward sediment/ sanstone outcrop interface
12:38:00	4819	208	Sandstone outcrop to left
12:39:00	4816	208	steeper escarpment face comprising protrusions of shallow coarse sediment/breccia diipping away and left from camera.Sharp contact between sediment and breccia
12:42:00	4817	252	Breccia outcrop in fault wall.
12:42:00	4816	217	Steeply dipping or jointed coarse breccia to lower right of camera.Some yellow staining around rocks.
12:44:00	4819	206	White fish,thick flocculants in water.
12:45:00	4820	213	bedding surfaces of layerd rock toward lower left
12:48:00	4819	175	White surface on sediment/ sandstone interface.Holes in seds.
12:50:00	4815	143	rise up and face slope
12:52:00	4814	123	Dark patches on sedimented slope.Old manganese stains
12:52:00	4814	124	Breccia, or coarse/fractured sandstone in moderate slope on left side, also interspersed with lighter-colored patches.
12:54:00	4814	122	Sample?
12:55:00	4814	111	No Sample?
12:57:00	4812	50	Altered/hydrothrmal deposits amidst soft-sediment covered steep scarp slope (on left side of view) with occational protrusions of coarse sandstone breccia or pillow breccia like rock
12:59:00	4812	59	Yellow material seems thicker under sediment cover
13:01:00	4809	54	Sample #2, small, left side, center.
13:01:00	4810	64	Sample#2: small sample of such a protrusion (above)
13:03:02	4809	77	Sample#3: Push Core Blue into soft-sediment cover at base of altered, (rubbly) slope.
13:04:00	4809	63	Push Core Sample, Blue
13:08:00	4807	60	Sample, large light color, dropped?
13:09:00	4806	63	Sample#4: Grab sample of altered rock in slope; Large white sample apparently dense and well-consolidated,

			Sample is dropped.Rocks and holes in wall sediments.
13:15:00	4801	208	Layered sedimentary rock (with interlayered breccia), largely soft sediment covered slope dipping down to left and toward camera.
13:16:00	4802	222	Resume transit to SW, sandstone on left
13:19:00	4807	151	Brecciated sandstone outcrop
13:20:00	4809	173	Broken blocks of sandstone.
13:23:00	4813	227	Jointed massive volcanoclastic sandstone outcrop
13:24:00	4814	242	Cobble sized talus
13:25:00	4813	239	Indurated sandstone
13:28:00	4814	219	Continue across fine sediment
13:30:00	4816	236	Rock in steep but low relief scarp face seems to be coarse, poorly sorted sedimentary rock, blocky outcrops, of breccia.
13:31:00	4809	286	Massive outcrop of breccia with light colored anemone
13:32:00	4809	292	Meter-wide fracture or transition from light to dark material
13:33:00	4809	291	steeply dipping (toward lower left) block of well-consolidated, dense fine-grained sediment.
13:36:00	4808	284	Bedded plane dipping to right
13:36:00	4808	310	Near horizonal thin (15cm?) layers of finely bedded sandstone (two units) extending into soft sediment toward right side of view. May define dip-slope of ripply, soft sediment bottom here.
13:38:00	4808	358	Sedimented flat area
13:42:00	4812	202	Massive sandstone
13:42:00	4812	208	Brief view (to right side) of large talus pile or outcrop of Dense, well consolidated massive finegrained blocks= sandstone or breccia.
13:49:00	4802	231	Brief view on left of very low relief outcrop protruding from soft sediment, near horizontal layer of coarse grained sandstone with interbedded fine gained layers. All interim traverse view is rippled soft-sediment bottom.
13:51:00	4802	245	Sandstone outcrop, crack
13:58:00	4802	231	Continue across fine sediment
14:05:00	4788	231	Sandstone outcrop
14:08:00	4785	244	Broken angular sandstone
14:11:00	4782	211	turn towrd outcrop below
14:12:00	4786	355	Sample #3, 35cm angular, stain? Dropped?

14:13:00	4788	356	Sample#5 Dense, well consolidated and thick layer of fine grained sandstone or basalt, outcrop of blocky, angular surface fractures, difficult to discern dip slope -or joint fracture plane- is steep, toward camera and lower right of view
14:18:00	4786	325	Sample#6 Slabby chunk from Vertical scarp face to left, comprising blocky, fine grained, dense rock rubble. Most chunks appear to be insitu above talus-plie at base. This well-consolidated rock may be sandstone breccia or flow/pillow breccia -
14:20:00	4787	334	Sample #3B Wedge shaped
14:23:00	4782	230	Resume transit to SW
14:25:00	4783	230	Traverse over rippled, soft-sediment bottom continues.
14:31:00	4791	235	Pillow lava outcrop or lobeate sandstone?
14:31:00	4790	233	Elongate Pillow flow lobes, insitu, partially sediment covered, extending from top-left of view
14:36:00	4793		Traverse over rippled, soft-sediment bottom continues.
14:38:00	4786	185	Sample# 7 (14:45hrs) Pillow Toe, iron stained, from Elongate to bulbous pillow lobe flow on shallow dipping slope (dipping left to right).
14:45:00	4781	163	Pillow sample #4, surface stain, report 3 samples
14:49:00	4772	180	Resume transit to South
14:50:00	4770	172	Steep (near vertical) slope, insitu Pillow breccia
14:51:00	4770	172	Pillow stack
14:54:00	4763	144	Moving up pillow slope
14:54:00	4763	144	ditto, note some soft-sediment deposit on lava
14:59:00	4768	119	Collect one rock Sample #5
14:59:00	4760	121	Leaving bottom

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2B

DIVE No.	515	DATE	1999. 9. 17	
	NAME		AFFILIATION	
Japanese	石橋 純一郎		九州大学大学院理学研究科 Dept. Earth and Planetary Sciences,	
[illegible]	[illegible]			
PURPOSE	Search for active fluid venting			
AREA	South Rift of Loihi Seamount			
SITE				
	LATITUDE	LONGITUDE	TIME	DEPTH
LANDING	18 ° 48.22' N	155 ° 12.17' W	11:25	3060 m
LEAVING	18 ° 50.03' N	155 ° 13.22' W	15:56	2474 m
DIVE DISTANCE:	4000 M	DEEPEST POINT:	3060 m	
DIVE SUMMARY	For the purpose of identification of active venting, we surveyed south rift of Loihi Seamount. However, we could not find any fluid venting along the dive truck of 4km. Seafloor was covered with continuous lava flow with some sediment or broken lava fragments on terrace. Accumulation and collapse of pillow lava flow form complex topography. During the way, we collected rock and sediment samples from 4 points; #1: 18 ° 48.2'N, 155 ° 12.2'W depth=3060m #2: 18 ° 46.6'N, 155 ° 12.4'W depth=3023m #3: 18 ° 49.2'N, 155 ° 12.7'W depth=2818m #4: 18 ° 49.5'N, 155 ° 12.9'W depth=2474m			
PAYLOAD	Pump water sampling system with a temperature probe, 2 Push corers, 2 scoop corers, ROV homer Xponder and Xducer			
VISUAL RECORDS	VTR1 3	VTR2 3	STILL CAMERA 400	ONBOARD CAMERA NO
SAMPLE	Organisms: Sediments:	Rocks: 5 Others:	Cores: 2 TOTAL: 7	Water: cc
VIDEO HIGHLIGHTS	1) 11:25:30-26:30 Landing point	2) 13:40:00-41:00 Landing at #3	3)	

KEY WORD	Loihi Seamount, pillow lava, volcanic glass

Dive 515

Date: 1999/09/17
Pilot: S. Suzuki
Co-pilot: T. Maki
Observer: J. Ishibashi

Dive Log

Time	Depth	Heading	Position	Position	Log
	m	(。)	(x)m	(y)m	
11:20	3063	271			Arrive at bottom
11:22	3061	226			Intact mostly bolbus sharp pillows, which surface is little bit shiny. The dominant size is 50 cm in diameter.
11:24	3060	183	-1437	567	Landing at the seafloor. Current toward 180 0.1 kt. Bulbous and elongate sharp pillow lava and smaller size knobby pillows attached on them.
11:29	3060	146	-1440	570	Trial of rock sampling (failed). Reddish yellow stain attached on the cross cut surface pillow lava.
11:34	3057	120	-1440	570	Collected rock sample #1. Closed up of the samples. Reddish yellow stain attached on its crosscut surface.
11:37	3057	047	-1440	570	Collected fragments from the same rock.
11:42	3055	030			Five or six star fish, one red seaanemone, and galathied.
11:46	3055	300			Started cruising.
11:49	3052	299			Elongate or bolbus pillows.
11:53	3034	342	-1420	500	Change Course 300.
12:02	3080	339			Cliff of pillow lava.
12:05	3057	359	-1350	350	Slope of pillow lava.
12:07	3050	360			Change course 000.
12:12	3085	001			Collapsed pillows. Terrace deposit

12:13	3070	359			Cliff of lava
12:17	3015	003	-1100	340	Pillow and tubial (elongated) pillow flow.
12:19	2996	001			Pillow robe.
12:20	2991	330			Change course 330.
12:27	3046	328	-890	240	
12:32	3038	326			Pillow and elongated pillow flow.
12:38	3024	256	-690	140	Collected rock sample #2-A & B.
12:47	3021	330			Start moving, course 330
12:51	3041	329			Slope of intact pillow lava flow
12:58	2977	329	-570	60	
12:59	2961	330			Intact pillow lava flow
13:01	2950	330			Sediment-covered pillows. Sediment becomes thick.
13:04	2942	330			Slope of pillow. Sediment has gone.
13:08	2912	330			Pillow lava flow. Relatively flat shaped.
13:10	2910	330	-260	-90	
13:16	2914	333			Slope of pillow lava continues.
13:20	2901	331	-220	-50	
13:23	2916	349			Change course 350, fragments of pillow
13:29	2883	350			Cliff
13:31	2861	350	200	-280	
13:33	2863	344			terrace deposit of collapsed lava block
13:39	2820	354			Pillow lava tube.
13:41	2818				Crinid or Gorgonian?
13:44	2817	352	330	-280	Collected rock sample #3. Lava with red stain.
13:54	2826	350			terrace deposit of collapsed lava block
13:57	2813	348			Cliff
14:00	2785	330			Pillow lava tube
14:04	2766	350			Pillow lava fragments
14:07	2761	328	500	-270	
14:10	2753	300			Change Course 300. Pillow lava tube on slope.
14:15	2748	300	630	-420	
14:23	2806	300	730	-620	
14:24	2805	350			Change course 350. Lava fragments
14:25	2803	350			Cliff
14:28	2775	350			Pillow and tubial pillow.

14:33	2762	330	830	-670	Landing for sediment sampling.
14:40	2763	334			Sampling of sediment by SCOOP (black).
14:47	2783	325			Sampling of sediment by Push Core (green)
14:58	2783	350	830	-670	Collected rock sample #4.
15:02	2759	350			Start running along course 350
15:03	2757	350			Partly collapsed pillow breccia on slope
15:09	2675	351	1000	-660	Angular lava fragments
15:14	2654				Deposits of collapsed angular lava block.
15:17	2643	320	1230	-670	Change Course 320, pillow lava tube
15:21	2636	308			Angular lava fragments
15:26	2600	301			Deposits of collapsed large angular lava block.
15:28	2592	300	1370	-800	Angular lava fragments
15:36	2561	321			Pillow lava flow on slope
15:37	2549	319	1530	-1000	
15:39	2526	321			Pillow and elongated pillow flow.
15:41	2519	321			Lava fragments
15:44	2495	329	1700	-1100	
15:46	2496	333			Deposits of collapsed large angular lava block.
15:47	2498	320			Survey along ridge
15:50	2478	322			Pillow lava flow
15:53	2466	301	1880	-1210	
15:55	2474	250	1900	-1270	Pillow lava. Left bottom.

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2B

DIVE No.	516	DATE	19 September 1999

	NAME	AFFILIATION
Japanese	長沼 毅	広島大学 大学院 生物圏科学研究科 School of Biosphere Sciences

SPECIALTY	微生物生態学 Microbial Ecology
PURPOSE	ロイヒ海山における熱水性微生物相の系統分類学的解析 Phylogenetic analysis of the vent-associated microflora of Loihi Seamount
AREA	ロイヒ海山 南尾根 Loihi Seamount, Southern Ridge
SITE	水深 2000～2500 m water depth of 2000 to 2500 m

	LATITUDE	LONGITUDE	TIME	DEPTH	
	Ex). 24 ° 18.5' N	127 ° 36.2' E	13:35	6499	m
LANDING	18 ° 50.084' N	155 ° 14.110' W	11:07	2449	m
LEAVING	18 ° 51.667' N	155 ° 14.224' W	16:04	2035	m

DIVE DISTANCE:	Ca. 3200 m	DEEPEST POINT:	2449 m

DIVE SUMMARY	The dive was conducted on the eastern slope of the South Rift of the Loihi Seamount at water depths of 2499 to 2035 m. Maior objectives of this dive were to discover hydrothermal vents to collect the vent-associated macro/micro-organisms. The survey track, which complemented that of Dive 512, was decided based on the results of Towyo survey conducted by R/V KOK. The water depths where anomalies of temperature and nephelometry were observed were included in the dive track. Unfortunately, no signs of hydrothermal activity were observed during this dive except for several crevices in the pillow lava flow areas. Pillow lava and pillow breccia were the predominant lava morphorogy. Other morphology of lava flows including Pahoehoe and sheet flow were also observed occasionally. Topography along the dive course was very complicated, and ridges and troughs bounded by steep wall were often observed. Collapse of walls makes
PAYLOAD	Grab sampler, 4 push cores, 2 Scoopers, pH meter, Eh meter, ORI-model fluid sampler

VISUAL RECORDS	VTR1	VTR2	STILL CAMERA	400	ONBOARD CAMERA	YES	

SAMPLE	Organisms: 5	Rocks: 5	Cores: 1	Water: 0 cc
	Sediments: 1 scoop	Others:	TOTAL: 12	

VIDEO HIGHLIGHTS	1) 13:20:00~13:20:15 Swimming sea cucumber	2）14:42:10~14:42:30 'Black sand' stripes	3）15:51:45~15:52:00 Coral sampling

KEY WORD	Loihi Seamount, South rift, no hydrothermal activity, pillow lava, sheet flow

Shinkai 6500 Dive No.516 (September 19, 1999)

Phylogenetic analysis of the vent-associated microflora of Loihi Seamount

Chief pilot: Yoshitaka Sasaki

Co-pilot: Tsuyoshi Yoshiume

Observer: Takeshi Naganuma

(Hiroshima University, Japan)

1. Background

High abundance and activity of microorganisms inhabiting the hydrothermal vents on the summit of Loihi Seamount have been reported (Karl 1989). Maximum 1.3 x10^5 cells ml^{-1} was observed for the low temperature (30C) fluid collected at Pele's vent, compared with that of 9.0 x10^3 cells ml^{-1} in the ambient water. Also, microbial metabolism and proliferation, probably based on methane oxidation or methanotrophy, were reported to be active up to at least 60C. Autotrophic sulfide oxidation or thiotrophy, which is common for vent microorganisms, may not necessarily be the primary metabolic strategy of the Loihi microflora, because the Loihi vent fluid is depleted in hydrogen sulfide, a major electron donor (Karl et al 1988). Instead, the Loihi vent fluid is charactreristically rich in carbon dioxide (CO_2) and ferrous ion (Fe^{2+}). Fe^{2+} is a microbially utilizable electron donor, and microbial contribution to iron deposition in the Loihi hydrothermal systems is possible. However, the coupling of Fe-oxidation and microbial autotrophy in the Loihi vents is not confirmed to date (Juniper and Tebo 1995). Phylogenetic analysis of the mat-forming microorganisms in the Loihi (Pele's) Vents revealed the predominance of epsilon- and gamma-Proteobacterial rDNA sequences (Moyer et al. 1995), which is also reported from other hydrothermal vent sites such as Mid-Atlantic Ridge and Juan de Fuca Ridge.

2. Objectives

In contrast to the previous studies of the Loihi vent microorganisms, we target at the microbial community structure or microflora of the deep (>2000 m) vents in the Loihi Seamount, to comapre with the microflora of shallow (<2000 m deep) vents such as Pele's vents. [Categorization of 'deep' and 'shallow' is based on the capability of the DSV Pisces 5.] That is, depth-related changes in the Loihi vent microflora is one focus of the study. Another focus is the comparison of the mid-plate hot-spot vent microflora, deep and/or shallow, with the microflora of other hydrothermal vents such as Mid-Atlantic Ridge and East Pacific Rise. Species composition of the Loihi deep vent microflora will be analyzed based on 16S rDNA sequences (16S trees; Malahoff, Cowen and Naganuma). In addition, microbial enzymes of geochemical relevance such as RuBisCO (CO_2 fixation enzyme) and methane oxygenase will be analyzed for constructing phylogenetic trees (geochemical trees; Naganuma). Also, possible microbial activity influencing the rock/mineral weathering will be investigated by culturing technique (Naganuma).

3. On-board quick-look results

Although active high-temperature vents were not observed during the Dive 516, 'black sand' was collected , and portions were allocated for microbiological study. Although no vent-associated samples for microbiology were not collected. However, the black sand may be used for isolating the microorganisms that may be included in the vent-related mineralization and/or chemolithotrophy.

Macrobenthos such as alcyonacean anemone (preliminarily *Anthomastus stenstrupi*), angelskin coral, primnoid gorgonian, brittle star (prelimiarily *Ophiomyxa fisheri*) and sea star (prelliminarily *Calliaster pedicellaris*) was collected. These organisms will be used for the source of microbial islation and deep sea-adapted genes.

References

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Karl DM, Brittain AM, Tilbrook BD (1989) Hydrothermal and microbial processes at Loihi Seamount, a mid-plate hot-spot volcano. Deep-Sea Res 36: 1655-1673

Moyer CL, Dobbs FC, Karl DM (1995) Phylogenetic diversity of the bacterial community from a microbial mat at an active, hydrothermal vent system, Loihi Seamount, Hawaii. Appl Environ Microbiol 61: 1555-1562

#516					
Time	Depth	Heading	Position	Position	Comment
	m	(∘)	(x) m	(y) m	
11:04	2448	29			Arrive at bottom
11:07	2449	28	-1320	720	Current toward 200 0.3 kt. Lobate to flattened pillow lava.
11:15	2458	352			Lobate or bolbus sharp pillow lava.
11:19	2454	356	-1180	700	Slightly sediment covered bolbus shrap pillow lava.
11:25	2427	359			Lobate or flattened pillow lava.
11:32	2428	354			Lobate and bolbus sharp pillow lava
11:35	2412	356	-920	670	Lobate sharp pillow lava.
11:42	2395	352			Bolbus or lobate sharp pillow lava.
11:52	2331	351	-590	570	

12:01	2361	282			Bolbus or lobate sharp pillow lava.
12:01	2370	277	-580	370	
12:04	2382	281			Sheet flow with planar surface
12:07	2371	280			Pillow appeared again.
12:10	2360	355	-590	180	
12:14	2336	355			Steep slope of pillow and elongated pillow.
12:20	2354	355	-570	120	Bolbus pIllow.
12:21	2355	10			
12:23	2355				Sheet flow with cracked planar surface ane crevies.
12:25	2352	10			Slightly ropey surface.
12:26	2340	10			Bolbus pillow.
12:30	2333	11			Large block
12:31	2333	350	-310	180	
12:33	2339	350			Steep slope. Righthandside is deep and seafloor cannot be seen.
12:35	2331	350			Pillow flow. Black sand occur among pillows.
12:46	2332				Sediment sampling by Ekman grab. [G1]
12:49	2332				Sediment sampling by Scoop.[S1]
12:53	2331				Rock sample [R1], coral [B1]
12:56	2331	340			
12:58	2331	321			Pillow lava.
13:00	2326	340			Start moving.
13:05	2314				Steep slope covered with sediment. Small angular blocks of lava.
13:10	2308	340	-30	30	
13:12					Pillow with "ropey" surface.
13:17	2309		40	50	Sediment with ripple mark. Core sample [C1].
13:20	2309		40	50	Swimming sea cucumber Enypniastes sp.
13:24	2310	340			Start moving.
13:28	2307	340			Collapsed pillows
13:31	2304	340	180	20	
13:33	2286	341			Pillow robe.
13:34	2276	339			Small lava fragments on the slope.
13:36	2273		300	-20	
13:38	2277	320			PIllows and elongated pillow.
13:40	2264	320			Elongated pillow with inflared? feature.
13:43	2256				Pillow with ropey texture.
13:45	2261	320	420	-120	

13:47	2252	320			Bocky (collapsed) lava
13:49	2237	320			Sediment on lava flow thickened.
13:53	2221	320			Sedimment widely cover the slope.
14:00	2206	320	590	-240	Steep slope of pillow. Cliff in the right part of the screen.
14:02	2203	321			Sheet flow with wrinkled surface.
14:05	2199	309			Stopped. Sampling of rock.
14:09	2196		780	-350	Rock sample #2 [R2]
14:16	2177	338			
14:19	2183	340			Sheet flow with some pillow.
14:33	2151				Rock sample #3 [R3] Gorgonian [B2] and seastar [B3]
14:34	2148	320			Start moving.
14:39	2161	340			Intact pillows.
14:42					Longitudinal stripes of 'black sand'
14:45	2146	321	1080	-470	Sediment-covered slope.
14:47	2136	300			Collapsed lava fragments.
14:48	2123	300			Eel-like fish
14:51	2114				Stop for sampling.
14:53	2114		1140	-550	Rock sample [R4] with a sea anemone [B4]
14:58	2105				Start moving.
15:01	2096	282			Porous sponge
15:07	2085	300			relatively planar (lobate) flow.
15:09	2079	300			Sheet flow with cracked (collapsed) surface
15:11	2070				Steep slope of sheet flow.
15:15	2070				Collapsed slope, breccia, with angular lava block. Stop for sampling.
15:19					Rock sample [R5]
15:27	2061	298			Pillow basalt.
15:29	2058		1290	-700	
15:30	2056				Sediment covered slope with gravel.
15:36	2042	300	1370	-880	
15:37	2046	360			
15:45	2050	0			Sheet flow.
15:48	2032				Cracked sheet flow.
15:49	2032				Ropey flow
15:50	2032				Coral[B4] and brittle star [B5]
16:02	2035		1600	-900	White sponge
16:04	2035				Left bottom.

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 1A

DIVE No	517	DATE	1999 9 20
	NAME	AFFILIATION	
Japanese	大 森 保	琉球大学理学部海洋自然科学科 Department of Chemistry, Biology and Marine Sciences	
[illegible]	[illegible]		
PURPOSE	To survey and to find the active hydrothermal vents at the deep ocean of the end of south-eastern slope of Loihi sea mountain		
AREA	Loihi sea mount		
SITE	Fracture zone located at south-eastern side of Loihi sea mount		
	LATITUDE / LONGITUDE / TIME / DEPTH Ex). 24_ﾟ18.5ﾕ N 127_ﾟ36.2ﾕ E 13:35 6499 m		
LANDING	18 46.3470ﾕ N 155 7.2268ﾕ W 11:59 4821 m		
LEAVING	18 46.1301ﾕ N 155 7.8756ﾕ W 15:30 4763 m		
DIVE DISTANCE:	2000 m	DEEPEST POINT:	4821 m
DIVE SUMMARY	Survey of active hydrothermal vents have been carried out through dive #517 both east and west sides of graben-like depression at the end of south-eastern slope of Loihi submarine volcano. The following results are found; 1) Low temperature(6.88℃) active hydrothermal vents were discovered at deep-ocean of 4772m. There several Yellow (nontronite) and black (Mn-oxide) coloured spots or patches are distributed around vent site. Tube-like organisms, shrimp and others were recognized. Vent water and ore samples were successfully cpllected.		
PAYLOAD	Grab sampler, 3 push coreers, 2 scraper, pH sensor, Eh sensor		
VISUAL RECORDS	VTR1 2 VTR2 2 STILL CAMERA 222 ONBOARD CAMERA YES		
SAMPLE	Organisms: Rocks: 2 Cores: 3 Water: 8 cc Sediments: 2 Others: TOTAL: 15		
VIDEO HIGHLIGHTS	1) 12：22：24-12：23：19 2) 13：10：40-13：11：30 3) 14：03：00-14：03：45		

KEY WORD	Loihi Seamount, hydrothermal activity, Sinkai 6500, deep water active vent, nontronite

Sinkai 6500 Dive #517 September 20, 1999

Title:

Survey and Discovery of active hydrothermal vents at deep-ocean of the margin of southern-east slope of Loihi submarine volcano

Chief pilot : Satoshi Ogura
Co-pilot : Tetsuji Maki
Observer : Tamotsu Oomoli (Univ. of the Ryukyus)

Abstract

During #517 dive study, active hydrothermal vent sites were discovered at the end of south-east slope of Loihi sea-mountain(4772m). The temperature of venting water was 6.88 ℃. Yellow coloured ore precipitates are accumulated around the venting mouths, and the black coloured patches or small chimney-like materials are distributed around this field. It is noted that the depth of the discovered vents is much deeper than those of previously reported ones. Two water samples within 8 bottles, and 4 samples of yellow(nontoronite) precipitates and black(Mn-oxides) ore sediments are successfully collected.

Two important brrecciated rock samples were collected from the outcrop of east wall of graben-like basin. The texture of these rocks may suggest that this area might recieved intenssive tecktonic stresses.

要旨

しんかい６５００第５１７潜航によって、ロイヒ海山南東側斜面の縁辺部の枕状溶岩と海底堆積物と境界部（水深 4772m）において active vents を発見した。水温 6.88℃の低温の湧水ではあるが、世界最深部でのactive vent である．湧出口の周囲には、黄色物質が沈積し、その周辺には黒色の斑状の沈積物が点在する。エビおよびチュウブ状の生物が確認された。低温湧水（２試料＝８本)、黄色沈積物試料、黒色沈積物を含む堆積物試料の採集をおこなった。また海盆状の凹地の東側斜面の露頭でテクトニックな破砕構造を有する岩石を２試料を採集した。

低温湧水が確認された地域は、枕状溶岩と堆積性の岩石の境界であり、周囲の地層は断層などによって強く破砕され、地形が複雑になっている。今回確認された低温湧水が、ロイヒ火山に由来するものか、それともテクトニクスに関連したものであるのか、大変興味深い。

Video Highlights

1) Sampling of brrecciated rocks.

(No.2 camera:　12:22:24 - 12:23:19)

Brrecciated rock samples were taken from the large outcrop of east side of of graben-like basin. The rocks are easy to fragile. The topographycal feature around this site is irrregular awing to the presence of large brocks which might be formed by tectonic activity.

2) Pit holes on the bottom sediments.

(No.2 Camera: 13:10:40 - 13:11:30)

Many crater-like pit holes ranging from several tens to 100 cm in diameter are distributed around this area on the botom sediments overlaying the pillow lavas. These holes might be formed by the collapse of under lying pillow basalts.

3) Active hydrothermal vents were found at 4772 m depth.

(No.2 camera: 14:03:00 - 14:03:45)

Simmering of low temperature (6.88 ℃) hydrothermal water was recognized in this active vent. Yellow coloured ores (nontronite) are precipitates at the mouth of vent. Black coloured patches (Mn-oxide) are seen around this site. Shrinp, tube-like shape organisms and other benthic organisms are seen around this vents.

1. Objective of the Dive

Objective of the Dive 517 was to to survey the geology of fault zone located at the end of south-eastern slope of Loihi sea-mountain, and also, to find the active hydrothermal vents. Foutunately we could find them, we try to collect samples such as hydrothermal fluids, ore sediments, sediment cores, organisms and the sorounding rocks, as far as possible.

Geological survey around hydrothermal fields and the collected samples will be useful for considering how the deep-submarine hydrothermal activity would be originated; how it relates to Loihi submarine volacanism and/or tectonic activity.

2. Dive results

We landed at the central part of graben-like basin at the end of south-eastern slope of Loihi seamountain(1487m depth), where thick sediment were present.

First, we moved to eastern wall of fault zone. Large outcrop of fractured massive rock was laied. The direction of fault may be NW-SE. We collected two rock samples. Then, moved toward west. Topographic level was irrregular awing to the presence of tectonically fractured large blocks at the east side of the basin.

Towards the west side of the basin, bathmetrical depth become shallow (4755m) and topographical structure become irregular again. At the west end, pillow basalt was seen, however the sediments are still thick.

We turned to 220 degree directrion. and surveyed the boundary zone between pillow basalt and sediments. On the sediments, there are many pit holes (10s to 100 cm size), which might be formed by collapsed pillow lavas. We surveyed for about one hour, along the 4745-4760m depth level, however we could not find any hydrothermal signature. Keeping the same level was not easy and time consuming, because the topographc feature was irregular. Bathmetry on the lava-sediment boundary becomes slightly deeper towards south,

In order to save time, we jumped 100m beyond the sediment-covered pillows toward 200 degree, and landed again. We recognized the yellow spots and/or black coloured patches on the sediments. Some(at least 2 or 3) of yellow spots are venting. We found active hydrothermal site at 4772m depth! We observed the hydrothermal vent field and collected water samples first. The temperature of venting water was 6.88 ℃. Then we took yellow and black ore samples and sediments. Put the marker #2 and transponder besides the vents, then recovered from the bottom.

3. Sample and sampling location

1) two rocks : #517-A, #517-B (east wall of foult zone)
2) two waters : #517-1, -2, -3, -4(Vent-1),
#517-5, -6, -7, -8(Vent-2).
3) Grab core sample : # G-1(yellow ores and sediments of Vent-1)
4) push cores : #C-1(blue: black patch), #C-2(black: black patch),
#C-3(yellow: cored sediments)
5) M-type sample : #S-1(black patch: yellow spot, Vent-2)

#517						
Time	Depth	Hedding	Position		Position	Sample
	m	(。)	(x)m	(y)m		
11:59	4820	90	640	1710	Arrive at bottom	
11:59					Started steering	
12:04	4820	91			Covered with thick yellowish gray sediments (ooze)	
12:10	4795	91			same as above	
12:13	4795	171			Stopped for sampling	
12:19	4795	185			Hard rock outcrop with stratification	
12:27	4791		660	1950	Collected rock samples	sample#1-A, -B
12:29	4791	270			Resumed steering	
12:33	4820	271			Covered with thick yellowish gray sediments (ooze)	

12:36			650	1770	same as above	
12:41			640	1590	same as above	
12:42	4819	271			Hard rock outcrop	
12:44	4804	270			Covered with thick yellowish gray sediments (ooze)	
12:50	4788	271			same as above	
12:51	4783	271	630	1300	same as above	
12:53	4775	269			Rock boulder? on the sedimented floor	
12:54	4777	271			Covered with thick yellowish gray sediments (ooze)	
13:00	4784	271	620	980		
13:02	4758	270			Yellowish gray sediments (ooze)	
13:06	4758	271	620	780	same as above	
13:08	4750	271			Stopped for sampling	
13:21	4746	180	650	650	Resumed steering	
13:23	4746	137			Yellowish gray sediments (ooze)	
13:34	4757	221			Sediment-covered pillow lava?	
13:41	4762	248			White colored-sediment.	
13:47	4760	217			Blocked pillow lava block	
13:49	4761	213	300	710	Sediment-covered lava block	
14:00	4769	201	200	630	Sediment	
14:01	4771	189			Vent! Shimmering discovered!	
					Several small vents.?	
14:15	4772	151			Sampling water. 6.7oC!	Vent-1, -1,2,3,4
					Two vents. Ecman sampling	#G-1
14:34	4772	143			Push core (blue)	Push core (blue)#C-1
14:40	4772	155			Dead chimney	
14:52	4771	146			Water sampling of 2nd vent.	Vent-2, -5,6,7,8
14:56	4771	145			Stop core sampling (black)	
15:00	4771	143			Sediment sampling by M-type sampler.	
15:05	4771	141			Sediment sampling by M-type sampler.	#S-1
15:09	4771				Push core sampling(black)	Push core (black)#C-2
15:12	4771	880			Sediment sampling by M-type sampler.	Push core (yellow)#C-3
					2-3 vents are observed around here.	
15:19	4771	55	220	540	Marker and transponder settled.	
15:30					Left bottom.	

Dive Log Sheet of SHINKAI 6500

HAWAII Leg 2B

DIVE No.	518	DATE	1999.9.21

	NAME	AFFILIATION
Japanese	石塚　治	地質調査所地殻化学部 Department of Geochemistry
SPECIALTY	Geochemistry, Economic geology	
PURPOSE	Geolological and geochemical study of Loihi hydrothermal system	
AREA	Loihi Seamount	
SITE	East off the South rift zone	

	LATITUDE	LONGITUDE	TIME	DEPTH
	Ex). 24 ° 18.5’ N	127 ° 36.2’ E	13:35	6499 m
LANDING	18 ° 46.2548’N	155 ° 7.6536’W	12:02	4774
LEAVING	18 ° 46.1247’N	155 ° 7.8471’W	15:32	4761

DIVE			

DIVE SUMMARY	The dive was conducted on the eastern end of the slope of the South rift of the Loihi Seamount at water depth ranging from 4780 to 4750m, where low temperature hydrothermal activity was found in Dive 517. In the area northeast to the vent site, steep slope of pillow lava flow was observed. This lava flow seems to be much older than those observed on the South Rift of the Loihi Seamount. At a water depth of 4767m on the slope of small mound of pillow lava, yellow-colored patches of hydrothermal precipitates were found on the sediment. The yellow patches were surrounded by black-colored sediment, which probably contains hydrothermal Mn-oxides. The distribution of yellow patches continued to the vent site.
PAYLOAD	2 Grab sampler, 6 push cores, 2 scoop (M-type sampler), Eh meter
VISUAL RECORDS	VTR1 2 VTR2 2 STILL CAMERA 152 ONBOARD CAMERA No
SAMPLE	Organisms: Rocks: Cores:3 Water: cc Sediments:1 grab Others: TOTAL:4

VIDEO HIGHLIGHTS	Yellow patch 1) 12:26	A line of yellow patch 2) 13:29-13:30	Sampled yellow patch 3) 13:39-13:49
KEY WORD	Loihi Seamount, off South rift, hydrothermal precipitate, yellow patch, pillow lava		

Shinkai 6500 Dive No.518 (September 21, 1999)

Investigation of hydrothermal vent area east off the South Rift of the Loihi submarine volcano

Chief pilot: Shin-ichi Suzuki

Co-pilot: Haruhiko Higuchi

Observer: Osamu Ishizuka

(Geological Survey of Japan)

1. Objective of the Dive

The primary goal of this survey was to provide samples and information for geological and geochemical investigation of the Loihi hydrothermal system. Specific objectives were as follows:

1) Obtain information on the geologic situation of hydrothermal deposits, and document their size, distribution, structure, and precipitation (growth) rate.

2) Obtain a representative sample suite of hydrothermal precipitates in order to establish variations in mineralogical and chemical characteristics and to investigate constraints on metallogeny and petrogenesis.

3) Evaluate the physicochemical condition of hydrothermal activity by geochemical analysis (i.e., fluid inclusion analysis, S isotope analysis)

4) Investigate the evidence of microbial activity associated with hydrothermal deposits and assess the biologically mediated deposition of iron oxides.

5) Collect and study hydrothermally altered host rocks to quantify the chemical exchange reactions between rocks and hydrothermal fluids.

This survey was conducted with the hope of gaining new insight into the characteristics of hydrothermal activity along the upper portion of the south east rift zone of Loihi. These new observations of rift zone hydrothermal phenomenon, combined with previously obtained information on hydrothermal vents in the summit area, will allow evaluation of differences in chemical flux between summit and rift zone venting and contribute to a more comprehensive assessment of the Loihi hydrothermal system. New data on the mode of occurrence, and mineralogic and geochemical systematics of hydrothermal deposits along the rift zone is also pertinent to evaluating the degree to which water depth may effect the volatile and metal content of hydrothermal vents. Such studies of Loihi hydrothermal deposits and active vents provide a basis for modeling hydrothermal systems associated with submarine hot spot volcanism in general. Our longer term goals are to conduct comparative studies of hydrothermal systems associated with back-arc and hot spot volcanism in order to address fundamental aspects of tectonic and geochemical constraints on the character of submarine hydrothermal activity.

2. Dive results

The dive was conducted on the eastern end of the slope of the South rift of the Loihi Seamount at water depth ranging from 4780 to 4750m, where low temperature hydrothermal activity was found in Dive 517. Landing point of this dive is northeast of the vent site. Around the landing point, thick and smooth white-colored sediment covers the seafloor. West of the landing point at a water depth of 4763m, fault scarp of less than 1m high was observed. Sedimentary rocks (?) seems to have been outcropped on this escarpment. This escarpment extends in NW-SE direction. The sub proceeded further to the west, and at a waterdepth of 4758m, we reached a steep slope of pillow lava flow, which might be an end of the flow. Both bolbus and elongated pillows were observed. This lava flow is covered with thick sediment. The surface of this lava shows reddish color and glass of the pillow surface appears to be altered (oxidized and/or hydrated). This lava flow seems to be much older than those observed on the South Rift of the Loihi Seamount.

After observation of the pillow lava, the sub turned to southwest and proceeded to the vent site. On the way to the vent site, pillow lava blocks half buried in the sediment were observed.

At 12:56 (at a water depth of 4767m), slope of small mound of pillow lava about 10m high appeared. Most part of the slope is covered with sediment. On the sediment, yellow-colored patches of hydrothermal precipitates were found. Some patches have holes, which are probably vents of hydrothermal solution, in the central part of them. However, shimmering of water was not observed. The yellow patches were surrounded by black-colored sediment, which probably contains Mn-oxides precipitated from hydrothermal solution. The distribution of yellow patches continued to the vent site which was found during Dive 517. One of the yellow patches was collected by Ecman Burge sampler (G-1), which is revealed to contain orange-colored soft iron-rich clay or iron hydroxide and basalt lava fragment. After passing through the slope of the pillow lava mound, Shinkai reached the relatively flat vent site. Due to the very poor visibility caused by sediments flied up by Shinkai, it was very difficult to observe the distribution of hydrothermal vents (yellow patches) and recognize the venting of hydrothermal solution. One yellow patch (10 to 15cm in diameter) forming a pit of several centimeter depth was sampled by push core sampler (C-1). Furthermore, a patch of sediment showing inflated feature with cracks on its surface in a distance of 20 to 30 cm from the yellow patch was also collected by push core sampler (C-2).

After sampling in the vent site, we surveyed around the area west and north to the vent site. We could not find any features showing occurrence of hydrothermal venting in these areas. The vent site is revealed to be bounded by small mound of pillow lava of 10 to 20 m high in its north and west margin.

Based on this dive result, hydrothermal activity in this area appears to have been limited in the area of 50 to 60m across in E-W direction and not to have so much extension to the N-S direction. Since outcrop of pillow lava is widely observed in this region, hydrothermal vent area is supposed to be underlain by pillow lava. Low temperature hydrothermal solution might circulate in the porous pillow lava flow.

3. Sample

During Dive 518, 4 sediment samples were collected by push core samplers and Ecman Burge grab.

#518 C-1 (9 cm long): Target of this sampling is yellow-colored patch. Upper 1.5 cm of this core contains yellowish-colored hydrothermal precipitates and fragment of basaltic lava. In the middle part (1.5 to 4.5 cm), black-colored sand layer exists. Lower portion of this core (4.5 to 9 cm) is light to dark gray-colored mud.

#518 C-2 (10.5 cm long): Target of this sampling is a patch of inflated sediment with cracks on its surface. This sample consists mainly of light gray-colored mud. Black-colored staining of the mud is partly observed probably due to the precipitation of Mn-oxides. And voids occur in the middle of this core. At the bottom this core yellowish to orange-colored hydrothermal precipitated occurs.

#518 C-3 (8 cm long): Target of this sampling is yellow-colored patch. In the uppermost portion of this core contains yellow to orange-colored precipitates. Black-colored sand? layer occur in the middle of this core. Lower half of this core is light gray-colored mud.

#518 G-1 (about 9cm thickness of sediment: Target of this sampling is also yellow-colored patch. Surface portion of this sample contains fragment of aggregate of yellow to orange-colored precipitates. Upper portion of this sediment (0-3.5 cm) is orange-colored mud. In the middle layer (3.5 to 4.5 cm) of the sample is dark brown-colored mud. Lower portion of this sample is light gray to orange-colored mud and/or sand.

Dive 518

Time	Depth m	Heading (。)	Position (x)m	Position (y)m		Sample
12:02:00	4774		440	1010	Arrive at bottom. Thick grayish sediments (ooze)	
12:05:00	4774	270			Started steering	
12:08:00	4772	270			Thick grayish sediments	
12:12:00	4760	271	440	830	Fine sediment on flat and smooth floor.	
12:12:11	4763	305			Fault scarp of sediment rock? Striking of the scarp is NW-SE.	
12:20:37	4758				Tubial pillow lava covered with thick sediment. Striking of the pillow slope is NW-SE.	
12:21:00	4758	305	450	720	Stop and looking around.	
12:26:00	4760	7			Sediment-covered mostly bolbus pillow lava (12:24-29).	
12:37:00	4763	169			Top part of bolbus pillow in the fine sediment field (12:36-38).	
12:40:00	4762	270			Sediment covered pillow and elongated pillow lava.	
12:43:00	4782	282	280	670	White sediment.	
12:45:00	4759	266			Move toward the homer. The distance to homer is 115m	
12:49:00	4774	207			Confirm D517 drop weight.	
12:52:00	4771	220			Confirmed No2 marker.	
12:56:55	4767				Yellowish-colored patch surrounded by Mn-oxide black-colored staining.	
13:05:00	4768	310			Close up of yellow patch with small vent.Several yellow patches on the slope.	
13:07:00	4766	308			Yellowish pached on the fine sediment.	
13:08:00					Pillow lava partly outcrops on the slope.	
13:25:00	4766				Sampling of yellow patch by Eccman burge.	Ecman (G-1)
13:28:00	4765	329	190	560	Toward No.2 marker.	
13:29:00	4766	350			A line of yellow patches on fine sediment.	
13:35:00	4767	72			No.2 Marker	
13:40:00	4772				Small hole with yellow-colored precipitates. This preciitate was sampled (13:49-55) by push core (tiger-colored).	Push core (C-1)

13:59:00	4772				Sampling of inflated and cracked sediment by push core (13:59-14:05). Probably site of very weak emanation of hydrothermal solution.	Push core (C-2)
14:05:00	4772	101	240	550		
14:10:00	4769	269			Sediment covered pillow lava.	
14:12:00	4758	271	260	500	Fine sediment on flat and smooth floor. Many large holes on the slope. Sediment seems to have been collapsed into it.	
14:15:00	4758	307			Change course to 0. Fine sediment on flat and smooth floor.	
14:20:00					Tumulus feature of pillow lava. 4-5m high?	
14:22:00	4749	26	350	440	Fine sediment on flat and smooth floor.	
14:23:00	4748	67			Move toward to No. 2 marker.	
14:25:00		90			Heading to west.	
14:30:00	4746	90				
14:33:00	4755	90			Sediment covered pillow lava.	
14:37:00	4749				Top of pillow mound about 20m high.	
14:40:00					Trough like topography. Direction(NE-SW).	
14:41:00	4789	208			Sediment covered pillow lobe.	
14:43:00	4774	217			Fine sediment on flat and smooth floor. Yellow patch? Was observed.	
14:50:00	4768	241			Fine sediment on flat and smooth floor.	
14:55:00	4772	14	120	590	Fine sediment on flat and smooth floor.	
15:07:00	4762	10	300	640		
15:14:00	4771	227			Fine sediment on flat and smooth floor.	
15:15:00	4773	238			Sediment covered pillow lava. Found No. 2 marker.	
15:18:00	4773	241			Yellow patch on fine sedniment. Sampled by push core.	
15:21:00	4769	225			Sediment covered pillow lava.	
15:25:00	4771	193			Hold homer.	Puch core (C-3)
15:31:00	4759	89			Ascend	

5. Summary

1. Nuuanu Landslide

The Nuuanu landslide is one of the largest of the numerous giant landslides on the Hawaiian Ridge. It extends from the northeast coast of Oahu more than 250 km out on the flat sea floor and contains giant blocks, the largest of which, Tuscaloosa Seamount is 20 by 30 km miles in size (about the size of the island of Lanai). In 1998 detailed ocean floor mapping, piston coring, dredging and deployment of a remotely operated vehicle (KAIKO) were all used to investigate this landslide. Based on the knowledge gained from those surveys, six deep dives in a manned submersible (SHINKAI 6500) have just been completed on the Nuuanu Landslide and adjacent areas.

One of the dives investigated part of the steep 1500m high east wall of Tuscaloosa Seamount, and two other dives investigated cliffs on other large landslide blocks. The samples collected with the SHINKAI's mechanical claws, as well as visual observations, indicate that these giant landslide blocks are formed, not of lava flows, but of shattered fragmental lava. This is the same type of lava rock that is presently forming where Kilauea lava flows enter the ocean and are shatter as they quench upon contact with seawater. We have discovered that these deposits form a vast slope of fragmental debris on the slopes of Hawaiian islands. The fragmental nature of the rocks in the landslide block provided a weak foundation for Koolau and East Molokai volcanoes that abruptly failed and hence promoted the landslide process.

Two SHINKAI dives investigated the region to the north of where the Nuuanu landslide broke loose from Oahu in order to investigate the deep rock structure of the Koolau volcano. The lavas from this volcano are different in composition from other Hawaiian volcanoes and scientists are attempting to explore the origin of this difference and how it relates to the history of the Hawaiian plume which arises from deep in the Earth's mantle.

Aside from investigating the basic structure and makeup of the giant landslides, a battery of analysis of rocks and sediment will attempt to date the time of their catastrophic movement, and will also focus on reconstruction of the history of the Hawaiian plume, which has built "the most beautiful fleet of islands anchored in any ocean".

2. North Arch Volcanic Field, 500 to 700 km off Oahu

The North Arch volcanic field is one of the largest young volcanic regions on earth covering 3,000 square kilometer of the seafloor north of Oahu, an area roughly the size of all the Hawaiian Islands combined. These extensive submarine lava flows were discovered in the late 1980's. No direct observations had been made prior to our dives with the SHINKAI 6500. The lava flows are similar in age and composition to the youngest eruptions on Oahu, Kauai and Niihau, including the landmark Diamond Head in Honolulu. Such eruptions on land are explosive, creating large ash cones like Punch bowl crater.

Two SHINKAI 6500 dives examined several vents of these giant lava flows to evaluate the style of eruptions under 5000 m of water. Most of the flows were very fluid, making low broad shields, and flowed as far as 100 km down gentle slopes. Other vents had explosive eruptions with lava fragments

ejected into the water, which made steep cones similar to cinder cones on land. We also discovered and examined a pit crater similar in size to Halemaumau on Kilauea and the pit on Loihi Seamount that formed in 1996. Much to our surprise, the wall of the pit has about 150 m of the young lavas exposed. This
discovery means that the volume of flows might be 10 times greater than previously thought.

3. Loihi Submarine Volcano

Loihi volcano is the site of the next Hawaiian Island. This set of dives investigated the nature of the lava flows and signs of any fresh activity between water depths of 5000 and 2500 m.

We conducted 4 dives along the South Rift Zone of Loihi volcano. We observed mostly fresh basaltic pillow lava. Several volcanic cones similar to the ones observed on subaerial Kilauea and Mauna Loa rift zones were visited during the dives on the deep portions of the south rift at 5000 - 4500 m and at about 2500 m. Basalt samples collected deeper than 4000 m were rich in olivine. Olivine-rich lavas are commonly found in the lower parts of rift zones in Hawaiian volcanoes, but the transition from olivine-poor to olivine-rich rocks on Loihi is much deeper than on Kilauea and Mauna Loa volcanoes. These data are essential in understanding the eary stage of growth of oceanic island volcano.

The other dive objectives were to investigate possible newly formed lava flows and its related hydrothermal activity, which should have resulted from the large 1996 eruption and to find active hydrothermal vents at the deeper portions of the south rift. We observed fresh glassy sands and evidence of recent low level hydrothermal activity amongst the pillow basalts at a water depth of 2500 m along the South Rift.

We conducted another dives to explore the hydrothermal vent field deeper than 2000m during the Leg2 B. Prior to the Leg 2A, UH research ship Kaimikai-O-Kanaloa carried out Tow-Yoo and hydrocast survey along the Loihi South Rift. During this cruise, two Mn content anomally were observed using hydrocast, one is around 2200 to 2400m and the other is around 4200m. In 1990, Russian DSRV Mir found hydrothermal deposit at the base of the NE-SW trending small ridge located the southeast extention of the south rift. We selected these three sites as the possible target for the search for hydrothermal vents.

As the results, we didn't fined any sign of hydrothermal activity saround both 2200-2400m and 4200m, and we observed basaltic pillow and sheet flow lavas.

However, around the area of the foot of south rift (near Mir site), we found few to few tence centimeter size yellow spots on the fine sediment covered flat floorC), and we collected yellowish broun deposit and fluid samples around there.

4. Deep portion of Kilauea East Rift, east of Hawaii Island.

Kilauea is one of the most active volcanoes on Earth but much of it is hidden underwater. To investigate recent volcanism and compare it to that on land, we conducted 2 dives around the submarine portion of Kilauea's East Rift Zone (Puna Ridge). One dive on the northeast end of the Puna Ridge investigated two large lava benches or terraces at a depth of about 4300 m near the deep end of the Ridge. We are interested in knowing how magma from the summit of Kilauea can be transported up to 100 km underground from its source and what happens to it along the way. On this dive we observed many large mounds 10 - 70 m tall made up of pillow lavas erupted from individual vents on the deeper of the two terraces. This lower terrace appeared to have been very volcanically active and the lavas are young. The upper terrace was very different from the deeper terrace. It was very smooth and contained many features that we recognized from the subaerial portions of Kilauea, such as lava tubes, skylights, pahoehoe lava flows, and large, smooth sheets of lava.

We also dove into a 300 m-wide, 70 m-deep pit crater formed when the surface of the terrace collapsed into a void space left after the lava was drained out.

The other dive was carried out on the southeast margin of the Puna Ridge at around 5600 m. This was the deepest manned submersible dive ever done around the Hawaiian Islands. The area is of interest because it is a broad, very flat, very young lava flow and is not associated with any noticeable vent.

We are interested in learning how the flow was formed and how it relates to other volcanism in the area. We hoped to find the eruptive vent for this large flow but were unable to detect any features indicating the vent site. We hope to determine if this is a ner type of lava flow in Hawaii.

5. Hilina Slump

The Hilina fault system, along the subaerial south flank of Kilauea Volcano, bounds an active block slump traceable for 50 km underwater.

Underwater slopes of the Hilina slump are characterized by scarp and bench bathymetry, including a prominent mid-slope bench and 2-km-high lower scarp (Chadwick, et al., 1993), but no direct observations of underwater rock types or structures were available prior to this project.

Four Kaiko (in 1998) and six Shinkai dives were made in order to determine rock types, structures, and deformational processes along the deep water frontal scarp and mid-slope bench of the Hilina slump, features for which no direct visual observations or rocks samples were previously available. Five dives along the frontal scarp below wide parts of the mid-slope bench (K91, K98, S505, S508) and an isolated east-west ridge (K93) encountered purely volcaniclastic sequences, consisting of well-indurated sandstone and siltstone interbedded with massive breccias containing basalt clasts; primary eruptive deposits such as pillow basalt flows or hyaloclastite breccia were unexpectedly absent. Microprobe analyses of glass grains in the sandstones have dominant tholeiitic compositions, but sparse grains of alkalic basalt of uncertain source are present in all the Kaiko samples-the only ones analyzed to date.

Indications of compressional and shear deformation in these dive traverses include: widepread brecciation and closely spaced jointing on outcrop scale, breccia layers containing clasts of recycled volcaniclastic sandstone, microshears in some sandstone samples, and slickensided surfaces on basalt clasts.

In contrast, two dives above and below the level of the mid-slope bench near its eastern terminus (K95, S504) encountered only pillow lava and pillow breccia fragments, without bedded sedimentary interlayers. Glass rinds of pillow fragments analyzed to date (dive K95) are high in sulfur (>1100 ppm), indicating eruption without low-pressure degassing, and requiring that the source vents (presumably along the Kilauea east rift zone) were below sea level at the time of eruption. A third dive up the base of the frontal scarp in this area (S509) encountered, sandwiched between volcaniclastic breccia beds, a thick brecciated unit of distinctive coarsely devitrified vuggy (diktytaxitic) basalt, unlike typical Kilauea lava flows on land or underwater elsewhere; no primary pillow lavas were found. Along this eastern margin of the main Hilina slump structure, the boundary between pillow lavas of the primary volcanic edifice and the flanking volcaniclastic apron must be stratigraphically and/or structural complex, probably due to wedge-outs of bedded volcaniclastic deposits against the volcanic edifice in combination with structural discontinuities associated with compressional deformation and thrusting at the toe of the slump. Two additional dives provide boundary controls and comparisons with central part of the Hilina slump. A deep dive near the boundary between the Hilina slump and the lower south flank of the Puna Ridge (S506) examined an area characterized by distinctive lobate-terrace morphology. Morphologically similar lobate-terrace features are common near the bases of many large subaqueous volcanic constructs, as widely imaged during prior sidescan-sonar surveys in the Hawaiian region (Lipman et al., 1988). The dive traverse, up the steep frontal slope of a large lobate terrace, encountered pillow lavas and talus breccias, characterized by structural features indicative of origin by gravitational slumping and spreading rather than primary volcanic deposition. Such lobate terraces may represent small-scale analogues for process operating on larger scale within the Hilina slump. Another dive (S507), on a steep lower scarp of the Punaluu slope, inferred to constitute a slump derived from Mauna Loa (Lipman et al., 1991) or alternatively an underwater continuation of the Kilauea southwest rift zone, provided observations and samples from thick volcaniclastic breccia and a massive lava flow for comparison with the Hilina slump; no young primary pillow that could have erupted from Kilauea were observed.

Research plan and data description

LOIHI

1. Magma dynamics (Malahoff, Shibata and Kaneoka)
2. Studying mantle melting (Pietruszka and Malahoff)
   U-series Isotope
3. Magmatic evolution of Loihi volcano (Shibata, Malahoff, Umino and Ishizuka)
   Sr Nd Isotope trace elements major chemistry and mineralogy
4. Volcanic geology and flow lobe morphology (Umino, Shibata, Smith and Naka)
5. Noble gas systematics (Kaneoka)
6. Origin of picrites (Takahashi, Malahoff, Shibata and Thornber)
7. Time series morphology (Smith, Malahoff and Tsuboyama)

KILAUEA

1. Magmatic Evolution of Puna Ridge (Johnson, Takahashi and Pietruszka)
   Petrology, geochemistry, trace elements major, isotope
2. Volcanic geology, lava morphology (Umino and Johnson)
3. Sedimentological study, or volcaniclastics pyroclastic materials on the South flank on Hawaii (Naka, Tsuboyama and Malahoff)
4. Crustal contamination processes (Pietruszka and Johnson)
5. Age of U-series Isotope (Pietruszka and Johnson)
6. Noble gas systematics of Kilauea (Kaneoka and Johnson)
7. Comparative picrite and basalt study (Takahashi and Johnson)
8. Time series morphology (Smith and Tsuboyama)

NUUANU

1. Sedimentological study for push cores, grabs and pistoncores (Kanamatsu and Naka)
2. Geomorphological study of landslides and debris avalanches from SeaBEAM, SBP and SCS data (J. Moore, Ui, Smith, Tsuboyama, Satake, Takahashi and Shinozaki)
3. Transport mechanism and depositional feature study using image analysis (Ui, Takarada, Yoshida, Miura and Yoshimoto)
4. K-Ar and $^{40}Ar/^{39}Ar$ dating on basalts from Koolau volcano and Nuuanu and Wailau blocks (Uto, Takahashi, Garcia and Ishizuka)
5. Petrology and geochemistry of Koolau, Nuuanu and Wailau landslide rocks (Takahashi, Garcia, Shinozaki, Yokose,

Trusdell, Hanyu, Kaneoka and E.Nakamura)

6. Picritic basalt from Koolau volcano : comparison between subaerial and submarine lavas (Garcia, Takahashi, Hanyu and Kaneoka)
7. Compositional variation of volcanic glass from hyaloclastites pillows and mud from Koolau, Nuuanu and Wailau areas (Garcia and Takahashi)
8. Origin of hyaloclastite and volcanic breccia (J. Moore, Clague, Naka and Morgan)
9. Gravity & Magnetics of Nuuanu area (Tsuboyama, Kanamatsu, Smith, Morgan and G. Moore)
10. Reconstruction of Nuuanu and Wailau landslides (J. Moore, Takahashi, Garcia, Satake, Naka, Ui, Takarada, Yokose, Tsuboyama, Kanamatsu, Hanyu, Kaneoka, G. Moore and Morgan)
11. Tsunami generation (Satake)

NORTH ARCH

1. Geochemistry and geochronology of North Arch basalts (Uto, Clague, Kani, Hanyu, Kaneoka, Dixon and Ishizuka)
2. Volcanology, physical volcanology using SeaBEAM data (Clague, Uto, Satake and Tsuboyama)
3. Manganese & Palagonite in the hyaloclastite (Clague)
4. High pressure experimental study (Takahashi, Clague and Uto)
5. Stratigraphy (Naka)

HILINA SLUMP AREA

1. Stractual evolution of Hilina Slump (Ui, Lipman, Smith, Morgan and Naka)
2. Study of volcaniclastic rocks from Hilina Slump (Naka, Morgan, Lipman, Sisson,Garcia and Clague)
3. Tsunami generation (Satake, Smith and Morgan)
4. Volcanic geochemistry and petrology (Sisson, Lipman and Takahashi)
5. Sedimentological and stratigraphic study on core, grab and rock samples (Naka and Kanamatsu)
6. Clay sedimentology push core and grab rock sample (Morgan)
7. Comparative study of Picrite (Takahashi)
8. Comparative study of fractures on avalanche between Hilina andNuuanu (Ui, Takarada, Yoshida and Miura)
9. Kohala and Mauna Kea submarine flank compare with Nuuanu and Hilina (Smith, Satake, Morgan and Lipman)
10. Ridge topography (Takahashi, Smith, Johnson, Umino, Clague, Satake and Garcia)
11. Punaluu Slump (Smith and Lipman)
12. Origin of lobate taluses (Lipman, Smith and Satake)
13. Physical properties of rocks (Morgan)
14. Geophysics (KAIREI & YOKOSUKA) (Tsuboyama, Morgan, Smith and G. Moore)