KAIREI CRUISE

KR98-08 LEG 1
&
KR98-09 LEG 2 SEGMENT A

(Submarine Landslides And Magmatic Processes of Koolau and East Molokai volcanoes, HAWAII)

KR98-09 LEG 2 SEGMENT B

(Loin seamount and Hilina landslide, HAWAII)

ONBOARD REPORT

(LEG 1: AUGUST 24, 1998 – SEPTEMBER 2, 1998)
(LEG 2: SEPTEMBER 4, 1998 – SEPTEMBER 19, 1998)

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Tamotsu OTANI	Able Seaman
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CRUISE LOG

23-Aug	14:00 17:00	setting of laboratories Sci.Mtg. : genral frame work of leg1
24-Aug	9:00 14:00 14:30	setting of Dredger and Piston corer Sci. Mtg. All passengers should be on board
Start of Leg 1 ; Geological & topographical surveys at Nuuamu slide		
	15:00 15:30 16:00 16:35 18:00	Depature: Sailing to North of Oahu Is. Living instruction by Chief officer Proton magnetometer diployment Kompira-san Pray for god! at Bridge Sci. Mtg.
25-Aug	6:00 8:00 12:05 16:05 18:00	arrival at survey area Seabeam survey with SBP Star of P-1 Recovery of Piston Corer Start of D-1 Proton magnetometer diployment Sci.Mtg.
26-Aug	6:00 8:45 9:35 14:45 18:00 18:00	SBF survey Proton recover P-2 start Psiton Core recovery D-2start Dreger recovery Proton dyplyment with 8 figure shape Sci.Mtg.
27-Aug	6:55 7:00 8:00 12:55 13:20 17:00 17:15 18:00	proton recover D-3 start Pushing-out of P-1 D3 recovery D4 start Dredger recovery Proton magnetometer diployment Sci. Mtg.
28-Aug	6:55	proton recover

	7:00	D-5 start
	10:50	D-5 recover
	12:25	D-6 start
	17:45	D-6 surface
	17:50	proton deplyment
	18:00	Sci.Mtg.
29-Aug	6:00	SBF survey
	9:02	proton recovery
	9:25	P3 start
	12:32	P3 recovery
	14:00	Sci. Mtg.
	19:00	Sci.Mtg. sample distribution for sediments
30-Aug	6:55	protn recovery
	7:15	D7 start
	10:00	D7 recovery
	12:40	D8 start
	15:45	D8 end
	16:00	proton dyplyment
31-Aug	7:20	proton recovery
	7:50	P-4 start
	10:30	P-4 recovery
	11:00	D9 start
	15:00	D9 recovery
	15:10	proton
	18:00	Sci.Mtg.
1-Sep	6:50	proton recovery
	7:00	D-10 start
	16:00	D-10 recovery
	18:00	Sci. Mtg.
2-Sep end of Leg1	9:00	port call
3-Sep	13:00	Sci.Mtg
start of Leg 2 segment A; KAIKO DIVE at Nuuamu slide		
4-Sep	9:00	Mtg. with KAIKO team
	15:00	Depature: Sailing to North of Oahu Is.
	16:40	Kompira-san Pray for god! at Bridge
	18:00	Sci. Mtg.

5-Sep	8:00 16:00 18:00	start of KAIKO #89 DIVE KAIKO recoverd Sci.Mtg.
6-Sep	8:00 16:00 18:00	start of KAIKO #90 DIVE KAIKO recoverd Sci.Mtg.
7-Sep	8:00	anchering for scientist exchnage
End of Leg 2 segment A Start of Leg 2 segment B KAIKO DIVE & Survey at Hilina and Loihi		
	13:00 14:00	Sci.Mtg. SeaBEAM survey start
8-Sep	9:00 16:00 18:00	start of KAIKO #91 DIVE KAIKO recoverd Sci.Mtg.
9-Sep	9:00 16:00 18:00	start of KAIKO #92 DIVE KAIKO recovered Sci.Mtg.
10-Sep	9:00 16:00 16:40 18:00	start of KAIKO #92 DIVE KAIKO recovered Proton deplyment Sci.Mtg.
11-Sep	8:00 13:10 18:00	start preparation of P-5 recovery of P-5 8 figure turn of Proton Sci.Mtg.
12-Sep.	8:00 10:00 16:00 18:00	start of KAIKO #93 core pushing out KAIKO retrived Sci. Mtg.
13-Sep.	8:00 16:00 18:00	start of KAIKO #94 KAIKO retrived Sci. Mtg.

14-Sep.	8:00	start of KAIKO #95
	16:00	KAIKO retrived
	18:00	Sci. Mtg.
15-Sep.	8:00	start of KAIKO #96
	16:00	KAIKO retrived
	18:00	Sci. Mtg.
16-Sep.	9:00	Sci. Mtg.
	13:00	Photo of cores
	20:00	Party Brian
17-Sep.	8:00	start of KAIKO #97
	16:00	KAIKO retrived
	18:00	Sci. Mtg.
17-Sep.	8:00	start of KAIKO #98
	16:00	KAIKO retrived
		Sci. Mtg.

1. INTRODUCTION

The Hawaiian Islands are the most well developed example of volcanism generated by a hot spot or upwelling mantle plume. The United States Geological Survey (USGS), University of Hawaii (UH) and other US institutions are surveying the geology, geophysics and other earth science topics of the islands. The deep sea areas surrounding the islands have received substantially less attention because of the difficulty accessing them. In many areas important geologic features lie at water depths exceeding those accessible by current US submersibles. Therefore, some Japanese and US scientists with interests in the earth science of the Hawaiian Islands discussed the feasibility of cooperative work using JAMSTEC's deep-sea research capability to investigate the deep portion around the Hawaiian Islands. Based on these discussions, Japanese scientists developed a two year research plan as one of JAMSTEC's deepsea programs, using 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 using ROV KAIKO and R/V KAIREI during August 24 to September 19, 1998 around the Hawaiian Islands. 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, and UH and USGS scientists participated in this cruise under the arrangement.

Pre-cruise meetings among US and Japanese scientists identified the following research fields for this cruise.

1) Nuuanu Slide (Northeast of Island of Oahu)

The Nuuanu Landslide located northeast of the island of Oahu is the largest landslide in the Hawaiian Islands. The main objectives of the research were to identify the origin and age of the landslide, and to observe the deep structure and materials comprising the Koolau volcano.

2) Loihi Seamount (Southeast of Island of Hawaii)

Loihi Seamount, located on the southern flank of the Island of Hawaii, is an active submarine volcano which represents the immature stage of Hawaiian hot spot volcanoes. The main objective was to conduct geological research on the volcano, and to study the hydrothermal vents located around the volcano.

3) Hilina Slump, Kilauea volcano (South of Island of Hawaii)

The Hilina Slump is an active landslide body located on the southern flank of the Island of Hawaii. The main objective was to investigate the geologic structure, age, and origin of the landslide body.

During this cruise we conducted 10 KAIKO dives, 10 dredge hauls, and 6 piston cores to directly observe the seafloor geology and to obtain samples necessary 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. These results were very useful to our research and next year we will propose a SHINAKI 6500 diving expedition in these areas.

We acknowledge Captain Yukawa and the entire crew of KAIREI and Mr. Fukui and KAIKO operation team for their highly skilled operation and kind support during this research cruise.

2. SCIENTIFIC OBJECTIVES

2-1. Objectives of deep sea survey of Nuuanu slide and debris field

Overview

Hawaiian volcanoes are the largest on Earth and are among the best studied. The relatively quiescent nature of their eruptions and their rapid growth make Hawaiian volcanoes ideal natural laboratories for developing and evaluating hypotheses for processes at active volcanoes. The Nuuanu landslide provides two outstanding research opportunities: To study the mechanics of giant landslide formation, which is common on oceanic island volcanoes, and to determine the early magmatic history of Koolau volcano, which is the most geochemically distinct Hawaiian volcano. Although some of the world's largest landslides have formed on the flanks of Hawaiian volcanoes, the mechanics of their formation are poorly understood. The geochemistry of Koolau volcano lavas presents an enigma to those who attempt to understand the origin of its lavas. A field program was designed to combine: 1. detailed surveying of the northern flank of the Koolau Volcano and the debris from the giant landslides from this volcano and neighboring East Molokai volcano; with 2. sampling by dredging and piston coring and 3. two ROV KAIKO dives to explore the deep submarine flanks of these Hawaiian volcanoes. This field program should also allows us to examine the internal structure of Hawaiian volcanoes and melting processes within the plume. The ideas developed from studying Hawaiian volcanoes should be applicable to other oceanic volcanoes. These studies are essential preliminary investigations to determine sites for Shinkai 6500 dives which are proposed for 1999.

The Hawaiian Islands are products of a mantle plume, which is thought to have originated at a boundary layer deep within the mantle, perhaps at the 660 km discontinuity or at the core-mantle boundary (e.g., Davies, 1988). 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 (e.g., Hofmann and White, 1982; Hart et al., 1992). The Hawaiian plume is the Earth's hottest, most productive (Sleep, 1990) and most thoroughly studied mantle plume (e.g., Tilling and Dvorak , 1993). Nonetheless, a lively debate continues on such fundamental questions as the nature and scale of heterogeneities within the plume, magma generation processes and the composition and temperature of the magmas that supply Hawaiian volcanoes (e.g., Rhodes & Hart, 1995; Hauri et al., 1996; Bennett et al., 1996). A controversy continues over whether the magmas that supply Hawaiian volcanoes are basaltic, similar to those commonly erupted (8-12 wt% MgO; e.g., Hart and Davis, 1978), or whether they are picritic (MgO >15 wt%; e.g., Wright, 1984; Clague et al., 1991; Garcia et al., 1995). Resolution of these questions is critical if we are to understand the nature and dynamics of the Hawaiian plume and the processes of magma generation within it. We must determine the long-term compositional variations of lavas from the tholeiitic shield-building stage of Hawaiian volcanoes (Frey & Rhodes 1993) to resolve these questions. The subaerial portions of oceanic volcanoes provide us with a very small fraction of a volcano's overall history (5-10%), biased in favor of its most recent development, and largely ignores the vast bulk of the volcano. Submarine landslides provide the opportunity to sample the deep interior of Hawaiian volcanoes (Garcia et al., 1995).

Giant landslides are now widely recognized along the flanks of many oceanic volcanoes, such as Hawaii, Marquesas, La Reunion, Galapagos, and Canary Islands. These landslides form during the growth of the volcano as it is centered over the plume (e.g., Fornari et al., 1988) and after it drifts off (Moore et al., 1994). The abundance of these landslides on oceanic island volcanoes demonstrates that mass wasting processes play an important role in the construction and evolution. Not only do such processes modify the surfaces and slopes of these islands, they 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 (e.g., Moore and Moore, 1984). Due to the unpredictable and sporadic nature of these events, the processes and timing associated with these massive landslides remain poorly understood. Yet the significance of these landslide features in the evolution of volcanic islands, and their extraordinary destructive potential, make it imperative that we understand their history and behavior, and assess their impact on human development of volcanic islands and adjacent coastlines.

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 hills 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 this 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 Wailau slide from East Molokai. The debris from this younger volcano on Molokai is thought to partially cover the Nuuanu slide (e.g., Moore et al. 1994). However, the age relationships between these two slides is not known and resolving this question is one of the goals of our research.

Proposed research

Magma Formation from the Hawaiian Plume; Rock Sampling. Fundamental uncertainties still remain about the basic conditions of magma formation (temperature, depth and source composition) for Hawaiian volcanoes (Francis 1995). These uncertainties stem in large part from our poor understanding of the parental magma compositions for Hawaiian lavas. Hauri (1996) has shown that there is a good correlation between the 'normalized' parental magma major element composition and Nd, Sr, Pb and Os isotopic ratios for Hawaiian tholeiites and that this correlation is not related to shallow level processes. The normalized SiO_2 compositions for the some Hawaiian lavas (e.g., Koolau volcano) are high compared to the melts from experimental studies on mantle peridotites. This led Hauri (1996) to propose that a small component of high silica melt, derived from recycled, eclogitic oceanic crust, is added to plume-derived melts. This model would also help resolve an apparent paradox between trace element data that require garnet in the source (Hofmann et al. 1984) and experimental work that does not (Eggins 1992). One complication for this model is that the mixing of a high-silica melt with a melt from a lherzolitic plume source would create a basaltic hybrid, unless the plume melt was strongly picritic (>20 wt% MgO; Hauri 1996 pers. comm.). Such a melt composition has not been observed in the Cenozoic, although glass sands and silts collected in box cores off Kilauea volcano are remarkably MgO-rich (15 wt% MgO; Clague et al. 1991).

Our work will expand on these studies by sampling in more detail and at greater depth in an attempt to focus on the important questions of whether the source and magmatic processes for Koolau magmas have remained relatively constant during the growth of these volcanoes (Hauri et al. 1996) or whether there have been fundamental changes in the plume source as the volcano drifted over the Hawaiian plume (Rhodes & Hart 1995). Answers to these questions will shed light on the nature of the plume, the scale of zoning within the plume, and the associated magmatic processes.

Landslide processes on oceanic volcanoes; geologic observations

Our overall goal is to reconstruct the deformational sequence of Hawaiian slides to better constrain static and kinematic models of landslide initiation and movement, and to provide data for the development of models for destructive landslide-generated tsunamis. It has become increasing apparent that many other oceanic volcanoes and seamounts worldwide are drastically modified by giant landslides (Moore et al., 1994). Earlier high-resolution seafloor mapping of the U.S. Exclusive Economic Zone (EEZ) using the GLORIA side-scan sonar system (Moore et al., 1989, 1994; Smith et al., 1994, Smith, 1996) revealed the presence of more than 68 giant landslides along the flanks of the Hawaiian volcanoes. We expect our study to provide greater insight into landslide processes and better assess the potential hazards they present to human life and property in Hawaii and around the Pacific from the associated seismic sea waves.

Dating Landslides using Sediment Accumulation Rates, Paleomagnetic Stratigraphy, and Geochronology of Piston Cores. Quaternary deep-sea sediments can be dated utilizing the disequilibrium between excess or unsupported ^{230}Th and its parent radioisotope, ^{234}U (e.g., McMurtry et al., 1991) to about 300,000 y. cosmogenic ^{10}Be profiling (e.g., Krishnaswami et al., 1982) for sediments to about 15 Ma (e.g., McMurtry et al., 1994). Paleomagnetic stratigraphy is another valuable method for estimating the age of the landslide deposits (Garcia and Hull, 1994), especially for the Koolau slide. The presence of numerous volcanic ash (tephra) layers and dispersed glass shards within the sediments of the study area make possible their stratigraphic correlation via marine tephro-chronology (c.f., Kennett, 1981; Garcia, 1996). Glass shards separated from the samples will be analyzed for their distinctive major and minor elemental composition by electron microprobe, using methods described in Sarna-Wojcicki et al. (1984). The lithologic and chemical data obtained from the tephra in these cores will be cross-correlated to aid and test the precision and accuracy of ages determined by other methods on the same sediments (e.g., Sarna-Wojcicki and Davis, 1991). In addition, if suitable materials are found (units containing coarse volcanic clasts that are within a suitable age range and K_2O content), absolute dating of selected tephra layers is possible by K-Ar or $^{40}Ar/^{39}Ar$ dating (e.g., Uto et al., 199x; Herrero-Bevera et al., 1994). Direct dating of rocks involved in the landslide may provide maximum ages for the landslide deposits

Internal structure of oceanic volcanoes

Moore & Chadwick (1995) have proposed that Hawaiian volcanoes are mostly composed of sand-size, fragmental lava. Such debris mantles the submarine slope offshore from areas of active volcanism and is hypothesized to represent the bulk of Hawaiian volcanoes. This new model for the internal structure of Hawaiian volcanoes has fundamental implications for the physical properties of, and geologic hazards associated with, oceanic volcanoes. If correct, it would indicate that the bulk density of oceanic volcanoes is much lower and the seismic structure of oceanic volcanoes is slower than our current models (e.g., Klein et al., 1987), which are based on the assumption that pillow lavas form the bulk of Hawaiian volcanoes. An additional corollary of this hypothesis, is that seaward-dipping bedding planes of fragmental deposits provide excellent slip surfaces for landslides on the flanks of these volcanoes. Current models for landslides do not consider such deposits in attempting to explain why the flanks of these volcanoes are so prone to landslides. It is essential that we test the fragmental debris model to insure that our physical models for oceanic volcanoes are realistic and to better understand the causes of giant landslides on oceanic island volcanoes.

Objectives

The Nuuanu slide and debris field offers a rare chance to look inside an ancient Hawaiian volcano and to sample the volcanic compositions and stratigraphy, and an excellent opportunity to explore the causes and consequences of catastrophic flank collapse on oceanic island volcanoes. The Koolau volcano is especially important for this study because the geochemistry of its lavas are distinct among Hawaiian volcanoes (Hauri

1996) and its slide is dramatically well exposed. In order to develop and test models for the origin of this distinct geochemistry, it is essential to sample the deep interior of the volcano and to compare these lavas with the younger subaerial lavas.

The major objectives for the JAMSTEC Hawaii Koolau-Molokai program are to:

A. Understand the origin and emplacement mechanics of giant landslides.

This requires:

1. making a detailed bathymetric map of the landslide (the first ever made);
2. collecting rocks from the landslide deposit for comparison with subaerial Koolau volcano lavas;
3. collecting sediments deposited by turbidity currents possibly associated with the landslide and pelagic sedimentation, especially above the calcium compensation depth; and
4. examining the internal structure of individual hills to determine whether they were transported chaotically or as coherent masses sliding along a basal decollemont.

B. Determining the magmatic history of Koolau Volcano and the origin of its lavas from sampling older Koolau lavas from the deeply dissected interior of the volcano.

Detailed bathymetric and side-scan data are critical for detailing the morphology of the slide features and for identifying potential KAIKO and SHINKAI 6500 dive targets.

2-2. Objectives of Kaiko Dives at Loihi Submarine Volcano

Loihi Seamount, located 34 kilometers south of the Island of Hawaii, is the most southern volcano of the Kahoolawe-Hualalai-Mauna Loa volcanic line and is the most recent volcano produced by the Hawaiian hotspot. Among the currently active Hawaiian volcanoes, Loihi is unique in that it still remains underseas and represents the preshield stage in the evolution of Hawaiian shield volcanoes. Previous studies indicate that a wide range of rock types including tholeiites, alkali basalts, and basanitoids occur on this immature volcano and the ratio of alkalic to tholeiitic lava varies systematically with depth from predominantly alkalic toward the base to tholeiitic at the top; these results required modifing the widely accepted view for the evolution of Hawaiian volcanoes, i.e., the growing stages of Hawaiian shield volcanoes are characterized by predominantly tholeiitic volcanism (e.g., Moore et al., 1982, Clague, 1987). Thus, Loihi is the only volcano for which we can explore the preshield stage magmatic processes of Hawaiian shield volcanoes. In addition, the occurrence of submarine hydrothermal activity at Loihi provides a unique opportunity to study the hydrothermal systems associated with hotspot magmatism and their geochemical fluxes as well as to study an isolated colony of deep-sea biota.

Recently, Loihi underwent a major volcanic episode marked by the collapse of its summit caldera in the summer of 1996. By analogy with the subaerial Hawaiian shield volcanoes (Kilauea and Mauna Loa), the 1996 summit collapse could have accompanied voluminous extrusion of lava flows along the rift zone. To investigate this possibility, we will survey areas of the Loihi south rift zone to search for very fresh young lava flows and associated hydrothermal sites. Since the south rift zone extends directly to the deep ocean floor, this will be the areas where JAMSTEC's deep-sea capabilities with ROV-KAIKO and SHINKAI-6500 are best utilized. A submersible survey with SHINKAI-6500 will be conducted at Loihi Volcano in the summer of 1999, which is presently planned to cover the entire length of the south rift zone. In order to prepare for this 1999 submersible survey with SHINKAI-6500, we planned to carry out 4 KAIKO dives along the south rift zone at the deeper, basal parts of Loihi Volcano.

The purpose of these Kaiko dives is twofold: (A) geological observations and rock sampling along the Loihi's south rift zone and (B) visual observations of hydrothermal venting sites, fluid sampling from emanating hydrothermal vents, and sampling from chimneys and hydrothermal precipitates. The more detailed objectives are enumerated below:

(A) Loihi Petrology and Geochemistry
Purposes:

1. To observe morphological and construction features of lava and other volcanic ejectas, tectonic displacements such as faults and fissures, and their mutual geological relations.
2. To record video images of these geological features mentioned above.
3. To collect fresh basalt samples in order to study petrologic characters of magma(s) erupted at the deeper, basal parts of the Loihi South Rift.

We plan to conduct fine scale geological mapping of volcanic outcrops by visual observation aided with the KAIKO TV camera system and also plan to record continuous video images. The view area of KAIKO TV camera is limited; therefore, we will use the forward looking sonar record to conduct mesoscale mapping as well. Lava morphologies are a function of various parameters, but primarily these are defined by the fluidity of magma and the eruption rate at which magma was supplied. For this reason, it is worthwhile to describe various lava morphologies and to map their distributions in the hope of locating the eruption centers from which magma was supplied.

During each dive, we will collect rock and sediment samples by using the manipulators and push core samplers. The purpose of this rock sampling is to reveal any regular variability in the occurrence and petrologic characters of volcanic rocks with respect to water depth and stratigraphic horizons.

(B) 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.).

2-3. Hilina Slump: Objective

A part of Leg 2B focuses on the morphology, structure, mechanical state, and kinematic history of the mobile south flanks of Kilauea and perhaps Mauna Loa volcanoes. The south flank of Kilauea volcano, one of the most active slides on earth, is currently moving seaward at rates of up to 10 cm per year and represents a major landslide and tsunami hazard for the entire Pacific Basin. In 1868 and 1975 this region moved abruptly several to tens of meters during major earthquakes (M7.9 and M7.2, respectively) with attendant destructive tsunamis. The tsunami generated in both 1868 and 1975 resulted in extensive damage and fatalities on Hawaii, and the 1975 tsunami produced minor damage in California. Additional detachment movements of this type, or far more extensive and catastrophic debris avalanches, are likely to occur in the future.

The entire south flank of the island was probably once a single landslide structure on the slope of Mauna Loa that has subsequently been overprinted by the growth of Kilauea and disrupted by the appearance of Loihi Seamount. This proto-slump has now broken into two slumps that are butressed in the middle by Loihi. These are the Punalu'u slump west of Loihi and the Hilina slump east of Loihi. Even more catastrophic failures have apparently occurred repeatedly in the past, as many of the landslides around the older Hawaiian Islands are debris-avalanche deposits rather than rotational slumps.

As part of the landslide study, a related objective will be to sample deep scarps along the Hilina slump system in order to constrain the submarine extent of the Mauna Loa edifice beneath Kilauea. No petrologic samples or structural data are available for the Punalu'u slump northwest of Loihi seamount, where Mauna Loa slump benches are present at similar depths to lower parts of the Hilina slump. Information on the eastern extent of Mauna Loa beneath Kilauea is critical for determining growth rates of these two volcanoes and for constrain magma production along the Hawaiian hotspot. Such magma production data would be valuable complements to goals of the in-progress Hawaii Scientific Drilling Project.

Proposed research projects are as follows:

1) Landslide Kinematics and Mechanics
2) Sidescan Sonar Mapping
3) Ar-Ar Dating
4) Eruptive Sources: Kilauea vs. Mauna Loa
5) Volatile contents of basaltic glass fragments: Volcanic degassing history and subsequent tectonics

3. SEA BEAM

3-1. SeaBeam 2100 multibeam sonar

The SeaBeam 2100 multibeam sonar seafloor mapping system was run almost continuously from August 24 to September 02, even during dredge and coring operations. Dedicated surveying took place for 12-13 hours every night, roughly between 1700 to 0600. Subbottom profiler surveys were typically run between 0600 to 0800 over the sampling target of the morning. Several afternoons 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 also the most efficient orientation to complete the survey. Closer spacing was necessary on the NE heading lines early in the survey due to rougher seas. The SeaBeam system would lose outer beams and/or report bad data there. Editing of the data was performed by the R/V Kairei SeaBeam technical staff. Final grids and maps were prepared separately by both the staff and J. 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.

Roughly 25,000 km^2 of seafloor were surveyed, covering the entire Nuuanu and Wailau landslide deposits off Oahu and Molokai islands, respectively. The surveys extended to over 230 km from the Oahu shore, with exploratory lines out to 300 km away on top of the arch. The distal limit of the slides appears to be 230 km, which matches the interpretation from the GLORIA sidescan sonar surveys (Moore et al., 1989).

The improved resolution over previous survey data has allowed for the detailed mapping of the block distribution, orientation, and structure of the landslide. In addition, more reliability in the definition of blocks from the two overlapping slide deposits has become possible, partly aided by petrologic studies from dredged samples. This has provided better definition of the boundary between the two slide deposits as well as improved interpretations regarding the relative timing of the events. Fifty to sixty large blocks occur within the boundaries of the Nuuanu and Wailau slide deposits. These blocks are 5-20 km long, 2-20 km wide, and 300-1500 m in relief above the surrounding seabed. Numerous smaller blocks are located within the major block facies while others are dispersed farther afield.

3-2. SeaBeam report for KR9809, Hilina slump and Loihi seamount

The SeaBeam 2112 multibeam sonar seafloor mapping system was run during nighttime operations following Kaiko diving or piston coring from September 7-19. Dedicated surveying took place for approximately 15 hours every night, usually between 1700 to 0800, although an increasingly large portion of this time was taken up by transit out of, and back to, the diving areas. One entire Kaiko maintenance day (9/16) was also dedicated to SeaBeam surveying. Typical survey speeds ranged from 10-15 knots, depending on sea conditions.

A typical swath width for these depths (1000-5000 m) was 10 km. Lines were run mostly to the NE and SW (Fig. __cite earlier track map figure with Kaiko dive sites__). The NE lines were almost directly head seas, but this was also the most efficient and structurally valid orientation to complete the survey. The SeaBeam system would lose outer beams and/or report bad data there sometimes during the rougher NE heading lines. Editing of the bathymetric data was performed by the R/V Kairei SeaBeam technical staff. Sidescan processing was performed in part by the staff and partly by J.R. Smith. Final grids and maps were prepared separately by both the staff and K. Satake and J.R. Smith.

Roughly 18,000 km^2 of seafloor were surveyed, covering the entire Hawaii Island southeast flank (Fig. _1_), including the Hilina slump (Fig. _2_), Loihi (Figs. _3, 4_), and Puna Ridge (the submarine extension of Kilauea's East Rift Zone) from nearshore to abyssal depths. The surveys extended up to 120 km from the southeast coast, with exploratory lines out to 260 km, which is near the top of the arch. We extended the SeaBeam coverage between 155°W and 154°10'W to 18°30'N. However, only a few more blocks or small seamounts were located and/or mapped in more detail than presented in the GLORIA images. Due to an excess of time, we added additional survey lines between the original Hilina slump track lines in order to increase the data quality with a greater percentage of overlapping swath data. Smaller areas, such as Loihi seamount, were gridded at finer intervals to increase the resolution (Figs. _2, 3_).

This area was already surveyed by several different vessels using the original SEA BEAM systems (Chadwick et al., 1993). In addition, HAWAII MR1 (Smith et al., 1994) and GLORIA (Groome et al., 1997) sidescan data has also been published for this area. The contiguous data acquired on Kairei will help with new interpretations of the area resulting from Kaiko observations and samples collected on these dives.

3-3. Summary of the bathymetric map

For the first time, we have obtained complete bathymetric coverage of the Nuuanu landslide (derived from Koolau volcano, Oahu), and Wailau landslide (from East Molokai volcano). It is important to note that our bathymetric map provides a basis to discuss the dynamics of the landslide, its emplacement mechanism and possible origin. Both geological and geophysical studies of the land slide will be carried out jointed by Dr.Ui (Hokkaido Univ.) and Dr. J.H. Smith (Univ. of Hawaii). Based on these analysis, tsunami waves caused by the landslide will be simulated numerically by Dr. H. Satake (Geol. Survey of Japan).

Even before such detailed analyses are undertaken, it is suggested that the Nuuanu slide is younger than the Wailau slide, judging from the overlapping relation of contour lines of their basal deposits. This interpretation is on the contrary to the prediction by Moore et al.(1994) based on the GLORIA side scan sonar image. The previous view stems partly from the analogy based on Hilina landslide in active Kilauea volcano. If in fact Nuuanu slide (belongs to Koolau volcano, 2.5-1.8 Ma) is younger than Wailau slide (East Molokai volcano, 1.8-1.3 Ma), this indicates that timing of the giant landslide is not necessary limited at the growing stage of the volcano. Series of important questions then follow; What is the cause of the landslide?　Is it related to the post-erosional magma activity? If so, when and how?

We have mapped volcanic structure of the Koolau volcano undisturbed by the Nuuanu landslide, near the North corner of the Oahu island. Preliminary survey by dredges (D-7, D-10) and a Kaiko dive (K-89) proved that the outcrop consists of submarine lava sequence (mostly pillow lava and some sheet flow). This finding is important for future research, because such continuous exposures of the volcano provides us with information about evolution of magmas as the Hawaiian volcano grows.

4. SUB BOTTOM PROFILER IMAGES

The subbottom profiler was operated for site selection of piston cores, dredges and KAIKO dives. It was also operated to investigate the stratigraphic position of Nuuanu slide and related debris avalanche. A list of subbottom profiles is shown in the appendix.

4-1. Dredge sites

Subbottom profiles are available for dredge sites 3, 6, 7, 8 and 10.

1-1 D-3 site (21deg46.3'N, 157deg30.2'W, 3818-3464 m depth)

Strong reflection plane appeared approximately 2 ms below the sea floor at the starting point of the dredge.

1-2 D-6 site (22deg16.5'N, 156deg52.7'W, 4646-4085 m depth)

Dredge has started from a site where soft sediments cover the sea floor. Basement rocks were not detected on the subbottom profiles.

1-3 D-7 site (21deg50.9'N, 157deg45.9'W, 2742-2582 m depth)

A sharp signal of basement rocks was detected on the profile.

1-4 D-8 site (21deg31.7'N, 157deg25.3'W, 2680-2253 m depth)

A sharp signal of basement rocks was detected on the profile.

1-5 D-10 site (21deg52.3'N, 157deg46.2'W)

Reflection signal from the sea floor is not sharp at the dredge site.

4-2. Piston core sites

2-1 P-1 site (22deg04.7'N, 157deg07.8'W)

The site is topographically flat. A strong reflection plane was detected 5 ms below the sea floor. A shallower and weaker reflection signal was detected 1 ms below the sea floor. Another weaker reflection plane may exist 7-12 ms below the sea floor, but the record is not clear.

2-2 P-2 site (23deg20.2'N, 155deg36.8'W)

This site is also topographically flat. Several parallel reflection planes were recorded. Depth of the two parallel strongest planes are 5 and 11 ms below the sea floor. Moderate reflection planes appear at 3, 6, 10 and 13 ms below the sea floor. Additional weak reflection planes were detected at 1, 9 and 18 ms below the sea floor.

2-3 P-3 site (22deg53.1'N, 156deg17.5'W)

This site is topographically flat. Two groups of strong reflection planes were detected. The upper group consists of two planes, the strongest is a 7 ms signal and an associated 8 ms signal as measured from the sea floor. The lower group consists of 3 parallel planes. A stronger reflection plane is located at the 12 ms level. Others are at the 13 and 15 ms levels from the sea floor. Additionally, two shallower and weak reflections, 2 and 3 ms were observed. The lower one is a thicker signal.

2-4 P-4 site (21deg32.3'N, 156deg56.2'W)

This site is topographically flat. Strong reflections were detected within the 5 ms range from the sea floor, but the depth of the signal is not stable in the record. Two strong reflection planes may exist at the 2 and 5 ms depth.

4-3. Nuuanu slide and debris avalanche (Profiles 8, 13 and 19)

Two debris avalanche deposits, Nuuanu and Wailau derived from Koolau and Molokai, are distributed within the surveyed area (Moore et al., 1989). The exact boundary of both deposits and their stratigraphic relations are not known. Subbottom profile and piston core data may give us some more information on these questions.

The size of the hummocky hills regularly decreases with increasing distance from Oahu. Hummocky hills, whose diameter exceeds 50 km, are distributed mostly within an area 130 km northeast from the current coast of Oahu. Hummocks, smaller than 50 km in diameter, are distributed beyond 130 km distance. Size of the hummocks gradually decreases to 1 km in diameter and the number becomes sparse until 230 km distance from the shore. No hummocks were detected on a seabeam map beyond 230 km distance.

Profile 8 started at point A (23deg0'46"N 155deg51'18"W), 10 km south of an unnamed Cretaceous seamount, and sailed southwestward. Simple and sub-parallel reflection planes were detected at least 45 km from point A. Depth of the strongest reflection plane is 6 ms from the sea floor at point A. The plane becomes gradually deeper, 20 ms from the sea floor at 25 km from point A, and 30 ms at 45 km away. On the other hand, depth of the plane becomes shallower towards the northeast from point A, and finally merges to sea floor. The depth of another deeper reflection plane exists 8 ms deep at point A, 35 ms at 25 km and 60 ms at 45 km away. The signal of the deeper plane becomes weaker towards the southwest. Other 2 shallower and weaker reflection planes appear gradually above the strongest plane. Small mound-like reflections interrupt these parallel planes approximately at 35 and 45 km away from point A. This means that emplacement of the small hummocks occurred later than that of the strong reflection plane.

Profile 13 started at point B (22deg50'48"N 156deg39'14"W), and sailed towards the ENE. Hummocks are concentrated until point C (22deg51'26"N 156deg 33'30"W). These hummocks are not mantled with subparallel reflection planes. Then, the subparallel planes suddenly appeared and continued until the end of the profile (point D, 23deg53'07"N 156deg17'29"W) where piston core (P-3) penetrated. The strongest reflection plane is 7 ms beneath the sea floor at point D. Smaller and sparsely distributed hills were detected between point C and D. These hills are covered with the strongest reflection plane, but are not covered with the second and deeper reflection planes. P-3 piston core data suggests that upper and strong reflection planes are correlated with a surface of volcaniclastic layer 60 cm in thickness.

Profile 19 started at point E (22deg31'56.8"N, 156deg57.6'W) towards the northeast. KAIKO turned to ENE at point F (22deg45'50.9"N, 156deg41'59.6"W) and terminated at point G (22deg47'45.0"N, 156deg15'18.4"W). Later half of the profile is parallel to the profile 13 locating approximately 10 km closer to Oahu. Sea floor is uphilling during the section EF. None of clear reflection plane is identified on the surface of hummmocks at the earlier half of the EF section. On the other hand, sea floor becomes flat and clear reflection plane, similar to the profile 13, was appeared at the later half of the section EF. Hummocky topography without any sharp reflection plane was appeared again at the earlier half of the section FG. Then, sharp reflection plane was appeared but occasionally interrupted by hummocks without any reflection plane. Near the final part of the record, a few number of hummocks which covered with sharp reflection plane were appeared.

Two layers of distal facies debris avalanche deposits distribute at the area covered with profiles 8,13 and 19. Upper stronger reflection plane may correlate with Nuuanu debris avalanche deposit derived from Koolau volcano. The reflection plane is younger than smaller and sparsely distributed hummocky hills which source is not known.

4-4. Subbottom profiler report for KR9809, Hilina slump and Loihi seamount

During the KR98-09 cruise, we used the subbottom profiler mostly for selection of the piston core, dredge, and Kaiko dive sites. Several long lines using the subbottom profiler were run away from the island in the direction of the landslide debris pattern. The purpose was to trace turbidite layers far out to sea and attempt to observe when they pinched out. We hope that correlation could be made with turbidite layers observed in the piston cores taken along and near the end of these tracks.

4-5. Dredged rock samples

We have carried out 10 dredges in order to characterize the variety of rock types of Koolau and Molokai volcanoes. Rock samples were recovered from 8 dredge sites and the following lines of observations were made.

1) In most sites on the land slide blocks, we recovered rocks of sedimentary origin; siltsone, conglomerate, and volcanic breccias. The origin of such sedimentary rocks are still unclear. The ROV dive (K90) conducted at the SE corner of the Tuscaloosa seamount provided a clue. The ROV observations suggest that much of the surface of the giant landslide blocks are covered by layers of sediments (siltsone, conglomerate) with various size of clastics. They may have formed during or soon after the landslide. Alternatively, these sediments might have formed and consolidated in shallow water environment prior to the land slide.
2) In the conglomerate and volcanic breccia, numerous blocks of basalt are included. These basalts show large variation in vesicultion, modal

abundance of olivine phenocryst and the degree of oxidation. Most basalt blocks recovered from the landslide blocks show very high vesicularity and their outer margin has no quench rim (D-3, D-4, D-5). Accordingly, it is concluded that much of the landslide materials were derived from subaerial portion of Koolau volcano.

3) Preliminary petrologic analysis of the basaltic rocks recovered from the land slide blocks suggest that some of them (D-6) were derived from East Molokai volcano rather than Koolau because they contain Ca-rich clinopyroxene phenocryst instead of Ca-poor orthopyroxene. If indeed the landslide blocks are mixed in the central part of the studied area, this proves our prediction that Nuuanu slide is younger than Wailau slide. More detailed petrologic analysis combined with geochemical work is necessary to verify this point.

4) In the dredge site (D-4) we recovered volcanic breccia with euhedral hornblende megacryst which may have crystallized from a post-erosional alkalic magma (Honolulu series). Origin of the breccia and its possible link with Nuuanu land slide is still a matter of open question. Because there is a possibility that the Honolulu series magma activity is triggered by the landslide or vice versa, detail study of the volcanic breccia and the D-4 site may be important.

5) We have recovered pillow lava and glassy fragments which indicate submarine lava sequences in the dredge sites D-7 and D-8. The rocks from the D-7 site are olivine basalt and picrite with various amount of olivine, while the rocks from D-8 site are olivine basalt with clinopyroxene and plagiocalse phenocrysts. This petrologic character implies that the D-8 site belongs to West Molokai volcano rather than Koolau. Geochemical study on the recovered rock specimen is needed to confirm this conclusion.

6) Overall, the submarine portion of the volcanoes are rich in olivine and this observation is common to those in the modern counterparts (Kilauea and Mauna Loa). However, it is in contrast to the lithology of subaerial part of Koolau volcano, represented by aphyric tholeiite with high-silica composition.

5. DREDGE

During the Leg-1 in JAMSTEC-98 cruise in Hawaii, we carried out 10 dredges with a standard cylindrical dredger (0.6 m in diameter) and a teeth wall small bucket type dredger (0.25 m in diameter). No sample was recovered from D-2 and D-10. Summary of the dredge report follows. List of the recovered rock specimen and their descriptions are in Appendix.

5-1. D-1

locality: SW corner of the Tuscaloosa seamount, bottom of the slope
date: Aug.25, 1998
starting point: 21 ° 59.4070 ' N, 157 ° 7.3975 ' W
water depth = 4000 m
end point : 21 ° 59.7474 ' N , 157 ° 6.9649 ' W
water depth = 3690 m
recovery: five pieces of rocks (up to 15 cm)
rock type: volcanic breccia, volcanic silt stone

5-2. D-2

locality: north east end of the cruise (next to the PC-2 site)
date: Aug.26, 1998
starting point: 23 ° 25.9423 ' N, 155 ° 34.9904 ' W
water depth = 4086 m
end point : 23 ° 26.3776 ' N , 155 ° 34.6397 ' W
water depth = 4092 m
recovery: none

5-3. D-3

locality: at the NE slope of the landslide block closest to Oahu island
date: Aug.27, 1998
starting point: 21 ° 46.7880 ' N , 157 ° 29.6780 ' W
water depth = 3799 m
end point : 21 ° 46.1790 ' N , 157 ° 30.1138 ' W
water depth = 3464 m
recovery: only small fragments
rock type: picritic basalt, aphyric basalt, glassy olivine basalt
5 samples described

5-4. D-4

locality: at the NE slope of the landslide block closest to Oahu island (same as D-3)
date: Aug.27, 1998
starting point: 21 ° 46.3516 ' N , 157 ° 30.0859 ' W
water depth = 3596 m

end point : 21 ° 45.8531 ' N , 157 ° 30.5051 ' W
water depth = 3215 m
recovery: a piece of volcanic breccia and rock fragments with the matrix of breccia up to 25 cm, 16 samples described
rock type: volcanic breccia with hornblende megacryst and fresh glass
breccia: olivine basalt, aphyric basalt (all vesicular subaerial lava)

5-5. D-5
locality: at the SE corner of the Tuscaloosa seamount, near the top of the slope
date: Aug.28, 1986
starting point: 21 ° 59.9650 ' N, 157 ° 2.6654 ' W
water depth = 3711m
end point : 22 ° 0.4224 ' N, 157 ° 2.7999 ' W
water depth = 3377m
recovery: many large piece of rocks (up to 33 cm)
21 samples described
rock type: majority of the recovered samples are volcaniclastic siltstone with Mn-coated upper pebble-cobble surface, with fewer amount of angular basalts of various variety vesicular olivine basalt, aphyric basalt may be dike rock origin, all looks like subaerial products

5-6. D-6
locality: unnamed seamount in NE of the Tuscaloosa (with oblique orientation)
date: Aug.28, 1998
starting point: 22 ° 16.6000 ' N, 156 ° 52.6659 ' W
water depth = 4646 m
end point : 22 ° 16.0650 ' N , 156 ° 52.3719 ' W water depth = 4431 m
recovery: some volcanic rock and sedimentary rock (up to 22 cm)
8 samples are described
rock type: one piece of picrite basalt (22 cm) and several pieces of conglomerate with basalt block

5-7. D-7
locality: near the north corner of Oahu island, away from the landslide area
date: Aug.30, 1986
starting point: 21 ° 50.9700 ' N, 157 ° 46.0093 ' W
water depth = 2809 m
end point : 21 ° 50.4299 ' N , 157 ° 45.8357 ' W
water depth = 2580 m

recovery: only one piece of rock (11 cm) and some small fragments in the small dredge 17 specimen were described

rock type: olivine basalt, part of pillow basalt with 5 mm thick Mn-coating glassy picrite, olivine basalt with various quench texture all rock specimens show submarine features

5-8. D-8

locality: at the SE end of Oahu island, could be extension of a rift zone from W-Molokai

date: Aug.30, 1998

starting point: 21 ° 31.3752 ' N, 157 ° 25.2428 ' W
water depth = 2680 m

end point : 21 ° 30.6285 ' N, 157 ° 25.1154 ' W
water depth = 2284 m

recovery: one piece of pillow lava (30 cm) and two smaller rocks
13 samples were described

rock type: picrite with pyroxene and plagioclase (ankaramite?)

5-9. D-9

locality: on the north slope of a landslide block from Molokai, close to PC-4 point

date: Aug.31, 1998

starting point: 21 ° 37.7709 ' N, 156 ° 56.6836 ' W
water depth = 4163 m

end point : 21 ° 36.8998 ' N, 156 ° 56.3651 ' W
water depth = 3618 m

recovery: one piece of rock (11 cm) and some small fragments
7 samples were described

rock type: aphyric basalt, one specimen has a glassy rim, possibly submarine origin

5-10. D-10

locality: same as D-7

date: Sept.1, 1998

starting point: 21 ° 52.46 ' N, 157 ° 46.16 ' W
water depth = 3455 m

end point : 21 ° 51.60 ' N, 157 ° 46.16 ' W
water depth = 2915 m

recovery: none

remarks: changed position of the weight (closer to the dredge), removed the small dredge, three large bites (up to 6 ton).

5-11. Dredged rock samples

We have carried out 10 dredges in order to characterize the variety of rock types of Koolau and Molokai volcanoes. Rock samples were recovered from 8 dredge sites and the following lines of observations were made.

1) In most sites on the land slide blocks, we recovered rocks of sedimentary origin; siltsone, conglomerate, and volcanic breccias. The origin of such sedimentary rocks are still unclear. The ROV dive (K90) conducted at the SE corner of the Tuscaloosa seamount provided a clue. The ROV observations suggest that much of the surface of the giant landslide blocks are covered by layers of sediments (siltsone, conglomerate) with various size of clastics. They may have formed during or soon after the landslide. Alternatively, these sediments might have formed and consolidated in shallow water environment prior to the land slide.
2) In the conglomerate and volcanic breccia, numerous blocks of basalt are included. These basalts show large variation in vesicultion, modal abundance of olivine phenocryst and the degree of oxidation. Most basalt blocks recovered from the landslide blocks show very high vesicularity and their outer margin has no quench rim (D-3, D-4, D-5). Accordingly, it is concluded that much of the landslide materials were derived from subaerial portion of Koolau volcano.
3) Preliminary petrologic analysis of the basaltic rocks recovered from the land slide blocks suggest that some of them (D-6) were derived from East Molokai volcano rather than Koolau because they contain Ca-rich clinopyroxene phenocryst instead of Ca-poor orthopyroxene. If indeed the landslide blocks are mixed in the central part of the studied area, this proves our prediction that Nuuanu slide is younger than Wailau slide. More detailed petrologic analysis combined with geochemical work is necessary to verify this point.
4) In the dredge site (D-4) we recovered volcanic breccia with euhedral hornblende megacryst which may have crystallized from a post-erosional alkalic magma (Honolulu series). Origin of the breccia and its possible link with Nuuanu land slide is still a matter of open question. Because there is a possibility that the Honolulu series magma activity is triggered by the landslide or vice versa, detail study of the volcanic breccia and the D-4 site may be important.
5) We have recovered pillow lava and glassy fragments which indicate submarine lava sequences in the dredge sites D-7 and D-8. The rocks from the D-7 site are olivine basalt and picrite with various amount of olivine, while the rocks from D-8 site are olivine basalt with clinopyroxene and plagiocalse phenocrysts. This petrologic character implies that the D-8 site belongs to West Molokai volcano rather than Koolau. Geochemical study on the recovered rock specimen is needed to confirm this conclusion.
6) Overall, the submarine portion of the volcanoes are rich in olivine and this observation is common to those in the modern counterparts (Kilauea and Mauna Loa). However, it is in contrast to the lithology of

subaerial part of Koolau volcano, represented by aphyric tholeiite with high-silica composition.

6. PISTON CORE

To understand the timing and emplacement processes of giant Hawaiian submarine land slides, piston corings were performed on the top of large detached slide block and on the abyssal plain in the front of Nuuanu slide. We recovered foraminifera ooze with distinct, 60-cm thick turbidite composed of graded volcanic sandy-silt on the top of a detached large block, Tasculoosa Seamount (P-1). P-3 was recovered at 100 km in front of the slide blocks. Another similar turbidite at 5.5-m depth in pelagic red clay may represent the Nuuanu slide event. P-2 recovered on the abyssal plain shows massive red clay and brown clay, they are bounded with a sharp contact at 6.2 m depth. Turbidite-rich carbonate ooze was recovered from the top of the large detached block off Molokai, which includes more than 20 turbidites.

6-1. Summary of piston core sediments

Sediments collected by piston corer were pushed out of the barrel using an oil pressure extruder. They were cut into 1 m lengths for the convenience of analyses. The cores were then vertically split into two halves; a working half and an archive half. On this cruise, visual description, making of smear slides, and color and magnetic susceptibility scans were routinely performed. Sediments of the working half were distributed to interested scientists on board for future post-cruise analyses.

KR98-08 P-1
Date: 25 Aug. 1998: time 08:20 - 11:00
Location: on the Tuscaloosa
Position: 22°04.7846N, 157°07.676W (WGS84)
Water depth: 3012 m
Device used: 10 m long Aluminum barrel without inner tube.
Total length recovered: 638 cm
Major Lithology: Calcareous ooze

A total length of recovered sediments in P-1 core is 692.5 cm. The principal lithology recovered is moderately yellowish-brown calcareous clay which is composed of brownish mud that contains abundant brown glass fragments and bioclasts such as nannofossils, foraminifera, radiolarians, diatoms, etc. The calcareous clay shows massive and sometimes faint mottled structures in visual inspection.

A thick black sand layer is intercalated in the interval between 62.5 to 81.7 cm of section 6 (see the next section in detail) showing size gradings

On-board magnetic susceptibility scan on P-1 core shows positive spikes (~600 10^6 SI) in several horizons. But just below the sand layer of section 6, the magnetic susceptibility becomes constant. This fact suggest that sediments below the sand may have occurred from flow-in. Lightness (L*) of color and magnetic susceptibility show distinctive values in the interval of the black sand.

Despite L* values not showing distinctive signals at 40 cm of sec. 1 and 20 cm of sec. 2, magnetic susceptibility shows a similar value as black sand. This suggests that these horizons include as much magnetic minerals as the black sand.

KR98-08 P-2

Date: 26 Aug. 1998: time 09:30 - 13:05

Location: north off Oahu

Position: 23°20.2083N, 155°36.7835W (WGS84)

Water depth: 4199.5 m

Device used: 15 m long Aluminum barrel without inner tube.

Total length recovered: 725 cm

Major Lithology: Red clay

A total length of recovered sediments in P-2 is 725 cm. The principal lithology recovered is moderately yellowish-brown clay which is composed of brownish mud that contains abundant brown glass fragments and siliceous bioclasts such as radiolarians, diatoms, etc. The clay shows massive and sometimes faint mottled structures in visual inspection. Consolidated dark brown clays appear in horizons between 620 - 725 cm with a sharp boundary. On-board magnetic susceptibility scans on P-2 core show a higher value in the 620 to 725 cm zone than 0- 620 cm. The trend of L* value shows a similar behavior to magnetic susceptibility. Consolidation and sudden changes in the physical properties of P-2 core at 620 cm suggest a major hiatus there.

KR98-08 P-3

Date: 29 Aug. 1998: time 09:25 - 12:32

Location:

Position: 22°53.0600N, 156°17.4915W (WGS84)

Water depth: 4323 m

Device used: 10 m long Aluminum barrel without inner tube.

Total length recovered: 717 cm

Major Lithology: Red clay

A total length of recovered sediments in P-3 is 717 cm. The principal lithology recovered is moderately yellowish-brown clay which is composed of brownish mud that contains abundant brown glass fragments and siliceous bioclasts such as radiolarians, diatoms, etc. The clay shows massive and sometimes faint mottled structures in visual inspection. A thick black sand layer is intercalated in the interval from 43.5 cm of section 7 to 60 cm of section 8 (see next section in detail). On-board magnetic susceptibility scans on P-3 core shows a huge value (~1400 10^6 SI) in this interval.

KR98-08 P-4

Date: 31 Aug. 1998: time 9:23 - 10:04

Location: detached slide block off Molokai

Position: 21°32.3200N, 156°56.2120W (WGS84)

Water depth: 3282 m

Device used: 10 m long Aluminum barrel without inner tube.

Total length recovered: 726 cm
Major Lithology: A turbidite rich carbonate ooze

A total length of recovered sediments in P-4 is 726 cm. The principal lithology recovered is moderately yellowish-brown calcareous ooze accompanied by abundant turbidites. The calcareous ooze contains glass fragments and bioclasts such as nannofossils, foraminifera, radiolarians, diatoms, etc. Values of magnetic susceptibility and L* fluctuate with most lithologic changes. Magnetic susceptibility scans show positive spikes and L* spikes on the darkness side in the turbidite horizons

KR98-08 P-5
Date: 12 Sep. 1998: time 09:38 - 13:04
Location: south-east off Hawaii Is.
Position: 17°33.0361N, 153°32.0253W (WGS84)
Water depth: 4932 m
Device used: 10 m long Aluminum barrel without inner tube.
Total length recovered: 7.14 m
Major Lithology: Red clay

The site of P-5 is located in the distance of 255 km, south-east off Hawaii Island. The purpose of piston coring in this site, was to recover turbidites as a proxy of the Hilina land-slide events in the distal setting from the Hilina block. P-5 recovered 714 cm length red clay with visible 4 sand layers. The lithology below the horizon of 68 cm of sec. 8 show a obvious flow-in structure. The principal lithology is light brown massive clay which is composed of abundant glasses, rock fragments and bioclasts such as radiolaria, diatoms and sponges. The red clay appear massive or faintly mottled in visual inspection. Black sand layers are intercalated in the interval between 86 to 87 cm of sec. 1, 71.5 to 90 cm of sec.6, 47 to 60 cm of sec. 7 and 47 to 68 cm of sec. 8 (see next section in detail).

Three characteristic patterns are recognized in the magnetic susceptibility profile. The lowest domain (from sec. 6 to sec. 8) showing positive spikes (~800 10^6 SI unit) in three horizons, can be correlated to turbidite occurrences. The middle interval showing low magnetic susceptibility (~100 10^6 SI unit), the value is very similar to that of red clay of ODP site 842, off Oahu Is. Sedimentation rate can be regarded as very slow and homogeneous due to no turbidite occurrence. This interval might be estimated to be 300 kyr, applying a average sedimentation rate of red clay (4 mm/kyr). The upper domain has a higher value but no visible turbidite. However L* value does not show distinctive signals at sec. 1, magnetic susceptibility in this interval show similar value as black sand suggesting that these horizons include much volcanic materials. This suggests that original sand layers were probably disrupted and materials scattered by bioturbation.

KR98-08 P-6
Date: 12 Sep. 1998: time 08:05 - 11:46
Location: south-east off Hawaii Is.

Position: 18°27.1344N, 154°22.3194W (WGS84)
Water depth: 5204 m
Device used: 10 m long Aluminum barrel without inner tube.
Total length recovered: 7.37 m
Major Lithology: alternation of red clay and sand

The site of P-6 is located in the distance of 100 km, south-east off Hawaii Island. The purpose of piston corering in this area, was to recover turbidites as proxy of the Hilina slump. We recovered 737 cm alternation of red clay and volcanic sands. light brown massive clay consists of abundant glasses and rock fragments and bioclast such as radiolarian, diatom and sponges. Clay shows massive and sometimes faint mottled structures in visual inspection.

Several ten cm thickness sand layers are intercalated in the sections between sections 2 and 4, frequently (see next section in detail). They show sedimentary structure such as grading. A huge thick sand layer appears from sec. 5 to sec.8 . The lower portion of the sand is including mud crusts chaotically and such feature suggests corering disturbance or flow-in structure. But the boundary between disturbed and coherent portion is unclear. The soft-x ray photographic study is required to understand the effect of artificial disturbance on the cores. The magnetic susceptibility profile consists of two major domains, upper and lower intervals. The upper interval has much sand layers but does not show so higher value. The lower interval has a thick sand (more than 1 m) and shows huge high values in the magnetic susceptibility profile. The origin of difference between lower and upper intervals in magnetic susceptibility value in sand layers is unknown, although smear slide observations suggest material variation in sand layers (see next section in detail)

6-2. Sample description of the volcaniclastic layers in P-1 and P-3 cores

Black-colored volcaniclastic sand layers are found in P-1 (Section 6, 625-817 mm) and P-3 (Section 7, 435 mm to Section 8, 60 mm) piston cores. Constituent materials through the entire layers in both cores are essentially same except for some microfossil existence from 705 mm to 715 mm in P-1 core. Grain sizes and the modal compositions of constituents change variously through the two cores. Main constituent materials can be categorized into three, brown glass, free crystal and lithic fragment. The brief descriptions of constituent materials are as follows.

Internal structure of the layers

Volcaniclastic layers recovered from two piston cores are made of alternated volcanic sand to silt sub-layers. Each sub-layers are moderately sorted showing massive, normally graded or reversely graded structure. More details are shown as follows.

P-1 core

640-705 mm: moderately sorted fine-grained volcanic silt. Black in color. Massive but silty patches of overriding sediment are found.

705-715 mm: moderately sorted fine-grained volcanic silt with abundant micro-fossils. Most of the fossils are fragmented. Black in color.
715-812 mm: moderately sorted fine-grained volcanic sand. Black in color. Upper part is massive and finer-grained. Lower part is poorly laminated.
812-829 mm: reversely graded volcanic sand. Black in color. Maximum grain size is 0.2-0.3 mm.
829-855 mm: reversely graded volcanic sand. Black in color. Maximum grain size is 0.2-0.3 mm.
855-897 mm: reversely graded volcanic sand. Black in color. Maximum grain size is 1.0 mm at the top, and 0.1-0.2 mm at the bottom.

P-3 core

435-540 mm: normally graded volcanic sand. Black in color. Bioturbation is clearly developed in the top 10 mm.
540-710 mm: massive volcanic silt, normally graded at the lower part. Black in color. Maximum grain size is 0.1-0.2 mm at the bottom.
710-980 mm: massive volcanic silt, normally graded at the lower 70 mm interval. Black in color. Maximum grain size is 0.1-0.2 mm at the bottom.
980-1020 mm: Reversely graded volcanic sand. Black in color. Maximum grain size is 0.1-0.2 mm at the top.
1020-1050 mm: Black sand. Maximum grain size is 0.2-0.3 mm.

Description of constituent materials

Samples for smear slides were collected from the following depth.
P-1: 610, 684, 715 and 890 mm from the top of section 6.
P-3: 535, 960, 990 and 1025 mm from the top of section 7.
Grain sizes and the modal compositions of constituents change variously through the two cores. Main constituent materials can be categorized into three, brown glass, free crystal and lithic fragment. The brief descriptions of constituent materials are as follows.

Brown glass

Glass fragments are brown in color and clearly transparent. Size of the fragments is various from less than 0.1 mm to up to 1 mm. In the coarsest part of the deposit, some fragments are bigger than 1 mm in diameter. Most of the glass fragments have rectangular granular to wedge shape with relatively flat and smooth surface with sharp edges, suggesting the shattered origin. Some have concave edges formed by the vesiculation of volatiles. Confined vesicles 20-50 m in diameter are sporadically found, and most of them have spherical shape but some have elongated oval shape. More than half of the fragments are free from crystals but some contain micro-crystals. Olivine seems to be dominant but there are few pyroxene and plagioclase. There are some elongated crystals possibly be olivine, suggesting the quenched origin.

Free crystal

Crystal grains free from any lithic or glassy materials are abundant. All are transparent and almost colorless. Size are various from less than 0.1 mm to 0.6 mm in diameter. Few of them have euhedral shape, and almost all are broken fragments with shape edges and corners. No crystals with rounded shape is so far recognized. Almost all of crystals seem to be olivine. Plagioclase or pyroxene have not been so far identified.

Lithic fragment

Various kinds of lithic fragments are recognized. They have various shapes from subanguler to angler, about 0.1 mm to more than 1 mm in diameter. Half of them are reddish colored fragments, either oxidized volcanics or hydro-oxidized lithics. Next abundant fragments are relatively fresh crystalline volcanics, gray to dark brown in color. Typical groudmass texture of lavas with elongated pyroxene and plagioclase are recognized. There are some fragments with 10-20% amount of interstitial brown-glass.

6-3. Sample description of the volcaniclastic layers in P-4 core

Twenty two layers of gray to black-colored volcaniclastic sand layers are found in P-4 piston core. Constituent materials through these layers in this core are different from each other. Grain sizes and the modal compositions of constituents change variously through the core. Observation of the main constituent materials were made at four positions at the core. The brief descriptions of constituent materials are as follows.

Internal structure of the layers

Layer 1 (sec.1 630-790 mm): black coarse-grained sand with some white fossil fragments. Maximum grain size is 2 mm.

Layer 2 (sec.1 950-960 mm): dark gray fine-grained sand. Rich in fossil fragments. Maximum grain size is 0.5 mm.

Layer 3 (sec.1 970-975 mm): dark gray fine-grained sand. Lens-shape. Maximum grain size is 0.5 mm.

Layer 4 (sec.1 980 mm): dark gray fine-grained sand. Lens-shape. Maximum grain size is 0.5 mm.

Layer 5 (sec.1 1009- sec.2 5 mm): black medium-grained sand. Maximum grain size is 1 mm.

Layer 6 (sec.2 14-40 mm): black coarse-grained sand with some fossil fragments. Maximum grain size is 2 mm.

Layer 7 (sec.2 48-55 mm): dark-gray fine-grained sand.

Layer 8 (sec.2 66-70 mm): dark-gray fine-grained sand. Lens-shape.

Layer 9 (sec.2 481-502 mm): black medium-grained sand with some fossil fragments.

Layer 10 (sec.2 810-829 mm): dark-gray fine-grained sand. Lens-shape.

Layer 11 (sec.2 980- sec.3 210 mm): black and white medium-coarse grained sand in the upper half with normal grading, while black coarse-medium grained sand in the lower half with reversed grading. Abundant fossil-fragments (max. 3 mm).

Layer 12 (sec.3 550-592 mm): dark-gray medium-grained sand with some fossil fragments. Maximum grain-size is 0.5 mm.

Layer 13 (sec.3 870-875 mm): gray volcanic silt.

Layer 14 (sec.3 931-935 mm): gray volcanic silt. Lens-shape.

Layer 15 (sec.4 198-235 mm): dark-gray fine-grained sand in the upper half (198-215 mm), while black fine-medium grained sand in the lower half(215-235 mm). Fossil fragments concentrate in the middle of the layer. One shell fragment (13 mm x 15 mm) is found in the middle.

Layer 16 (sec.4 355-382 mm): black fine-grained sand with some fossil fragments.

Layer 17 (sec.4 665-712 mm): black fine-grained sand. Normal grading. Abundant fossil fragments in the lower 70 mm.

Layer 18 (sec.5 317-434 mm): black fine-medium grained sand. Normal grading.

Layer 19 (sec.5 661-672 mm): black fine-grained sand. Lens-shape.

Layer 20 (sec.6 200-258 mm): black medium-grained sand with abundant fossil fragments in the lower 20 mm. Poor sorting. Two large rounded pebbles are found, one is about 16 mm in diameter and the other is about 6 mm in diameter.

Layer 21 (sec.6 415-425 mm): dark-gray fine-grained sand.

Layer 22 (sec.6 910-963 mm): dark-gray medium-grained sand. Maximum grain-size is 1 mm.

Description of constituent materials

Samples for smear slides were collected from the following depth.

Sec.1 700 mm, sec.3 100 mm, sec.5 430 mm and sec.6 950 mm.

Sec.1 700 mm (Layer 1): constituent components are glass, micro-fossils, broken crystals and lithic fragments. Glasses are pale-brown to dark-brown in color, 0.3-1 mm in diameter, and contain abundant vesicles. Having wedge shape with flat surface and frequently with concave edge due to the raptured vesicles. Olivine(?) crystals are occasionally found in glass. Micro-fossils, mostly be foraminifera(?), are white in color, 0.3-0.5 mm in diameter and have oval shape. Broken crystals, probably be olivine, are 0.2-0.3 mm in diameter. Lithic fragments are relatively smaller in amount, and are subrounded to subangular in shape, 0.3-0.5 mm in diameter. Various from hydro-altered fragments with oxidized reddish brown color to crystalline ones with dark to light gray in color.

Sec.3 100 mm (Layer 11): This layer contain fragments of lithics, fossils and broken crystals along with abundant white powder-like fine grains, probably are crushed fossils. No brown glass are so far observed. Lithic fragments are subangular to angular in shape. Most of them are reddish brown in color and some are gray-colored and crystalline. Maximum grain-size is 1.2 mm. Some fossils are oval in shape but many are broken fragments less than 0.8 mm in diameter. Crystals are colorless to pale brown in color. Most of them are probably olivine. Some have fluid inclusions. Grain size is 0.2-0.5 mm.

Sec.5 430 mm (Layer 18): Constituents are mostly the same with Layer 11, but are finer in grain size. Maximum is 0.8 mm, and most are 0.2-0.5 mm in diameter. Clinopyroxene crystals are recognized.

Sec.6 950 mm (Layer 22): Main constituents of this layer are lithic fragments and crystals. No fossils and brown glass are so far observed. Lithic fragments are similar with those in Layer 11. Maximum grain-size is 0.8 mm. Plagioclase, pyroxene and olivine crystals are recognized. Plagioclase is colorless and pyroxene and olivine are pale brown in color. They are 0.3-0.5 mm in diameter.

6-4. Description of volcaniclastic layers in P5 and P6 piston cores

Two pisoton cores, P5 and P6, were recovered from sites approximately 200 and 100 km southeastward from the shore of Hawaii Island. Major target of this coring was to recover volcaniclastic layers which emplaced as turbidites. The following is a brief description of recovered volcaniclastic layers by means of visual inspections of the core and smear slide observations.

P5 core

Total length of the core recovered was 7.18 m including 4 volcaniclastic layers. Columnal section is shown in the attached figure.

Layer 1 (Section 2 860-870 mm): This layer consists of black fine-grained sand. Smear slide was made from a sample collected at the bottom (870 mm) of this layer. Constituent materials are glass, olivine and altered volcanics. Many grains show angular shape, but subangular grains are also commonly included. Glass grains show flake shape. Some glass includes vesicles. Altered volcanics are more abundant than the other 3 layers in this core. Degree of alteration is variable.

Layer 2 (Section 6 715-900mm):: Two cycles of normal grading are identified in this layer. The lower one is between 830-900 mm level. Maximum grain size is 0.2 mm at the bottom (900 mm). The other graded cycle is between 770-830 mm level. Cross bedding is identified between 800-830 mm level. Altenation of very fine-grained black ash and brownish clay is identified at 715-770 mm level. Smear slide was made from a sample collected at the bottom (900 mm) of this layer. Constituent materials are glass, olivine and altered volcanics. Glass is fresh and shows flake shape with angular rim. Glass includes a few amount of vesicle.

Layer 3 (Section 7 470-600 mm): Lower part of the layer 3 (500-600 mm) consists of black fine-grained sand. Remaining shallower part cnsists of brownish-gray silt. Smear slide was made from a sample collected at the bottom (600 mm) of this layer. Constituent materials are glass, olivine and altered volcanics. Glass is fresh and shows flake shape with angular rim including a few amount of vesicle. Hydrated glass grains are rarely included.

Layer 4 (Section 8 470-680 mm): The lower part of this layer (630-680 mm) consists of cross-laminated fine-grained sand. Color is black. The middle part (560-630 mm) consists of black fine-grained sand but without cross lamina. The upper part (470-560 mm) consists of interbedded very fine-grained black ash and brownish clay. Smear slide was made from a sample collected at the bottom of this layer. Constituent materials are the same as the above layer, but a few amount of subangular grains are included.

P6 core

Total length of the core was 7.01 meter including 10 volcaniclastic layers. Columnal section is shown in the attached figure.

Layer 1 (Section 2 805-850 mm): This layer consists of black fine-grained sand with cross bedding. Normally graded at bottom 15 mm interval. Maximum grain size at the bottom is 0.1 mm. Bioturbation is common above this layer. Smear slide was made from a sample collected at the bottom (850 mm) of this layer. Constituent materials are glass, olivine and altered volcanics. All of the grains are angular. Glass shows flake shape with angular rim. Glass includes a few vesicles.

Layer 2 (Section 2 900-917 mm): The same as layer 1 but lacking cross lamina.

Layer 3 (Section 3 50-60 mm): This layer consists of black fine-grained sand. Thickness is not uniform. No smear slide was made for inspection.

Layer 4 (Section 3 130-270 mm): This layer consists of black fine-grained sand at lower 240-270 mm level. The layer is normally graded. Maximum grain size at the bottom (270 mm) is 1 mm. Upper part of this layer (130-240 mm) is dark brown-gray volcanic silt. Smear slide was made from a sample collected at the bottom (270 mm) of this layer. Constituent materials are glass, olivine and rock fragments. Glass shows flake shape with opaque inclusion. Most of the grains are subangular.

Layer 5 (Section 3 365-405 mm): This layer consists of black fine-grained sand. The layer is normally graded. Maximum grain size is 0.2 mm at the bottom. Smear slide was made from a sample collected at the bottom of this layer. Constituent materials are glass, olivine and altered volcanics. All of the grains shows angular rim. Glass shows flake shape and includes a few vesicles.

Layer 6 (Section 4 40-50 mm): Lower 10 mm interval of this layer consists of black fine-grained sand. Bottom contact is undulated. Upper part of this unit is made of dark brown-gray volcanic silt. Smear slide was made from a sample collected at the bottom of this layer. Constituent materials are glass flake, olivine and altered volcanics. Vesicles are common in glass. Minor amount of fibrous glass grains are also identified. Degree of alteration is generally less than the other upper layers.

Layer 7 (Section 4 270-280 mm): This layer consists of black ash. No smear slide was made for inspection.

Layer 8 (Section 4 295-310 mm): This layer consists of lack fine-grained sand. Maximum grain size is 0.1 mm.

Layer 9 (Section 4 560-645 mm): Lower 20 mm interval of this layer consists of black fine-grained sand. The layer is normally graded. Upper part of this layer (560-625 mm) is dark brown-gray volcanic silt. No smear slide was made for inspection.

Layer 10 (Section 5 45 mm-section 6 360 mm): All of this layer consists of black fine-grained sand. Maximum grain size is 0.2 mm at the bottom. Normally graded at the interval of sec.5 640-670 mm. White ash or clay layer only 2 mm in thickness is identified at sec.5 640 mm. Layer 10 includes abundant water when recovered. Smear slide was made for a sample collected from the bottom. Constituent materials are glass, olivine and altered volcanics. Abundance of glass fragment is less than the other 9 layers. Also, most of glass grains show subangular rim. Altered volcanics are abundant compared with the other layers.

Fibrous glass fragment is identified.

Summary

Petrographic textures of P5 layer 1 and P6 layer 10 are similar each other and clearly different from the other layers. Abundance of altered volcanic fragment and subrounded clast morphology suggest that this layer might be derived as a turbidite associated with major landslide-debris avalanche.

6-5. Summary of piston core

To understand the timing and emplacement processes of giant Hawaiian submarine land slides, piston corerings were performed on the top of large detached slide block (Tuscaloosa seamount, P-1) and on the abyssal plain in the front of Nuuanu slide. We recovered foraminifera ooze with distinct, 60-cm thick turbidite composed of graded volcanic sandy-silt on the top of a detached large block, Tuscaloosa Seamount (P-1). P-3 was recovered at 100 km in front of the slide blocks. Another similar turbidite at 5.5-m depth in pelagic red clay may represent the Nuuanu slide event. P-2 recovered on the abyssal plain shows massive red clay and brown clay, they are bounded with a sharp contact at 6.2 m depth. Turbidite-rich carbonate ooze was recovered from the top of the large detached block off Molokai (P-4), which includes more than 20 turbidaites. Stratigraphic study on these cores will aid in determining their origin and in calculating the frequency of turbidite deposition that continues to the present offshore of their islands.

7. KAIKO DIVE REPORT

7-1. Dive No. 89

Date: 1998 Sept. 5

Authors: Eiichi Takahashi, Michael Garcia, Jiro Naka, Tadahide Ui, Frank Trusdell, Julia Morgan, and Osamu Ishizuka

Purpose

To determine the internal structure of Koolau volcano and to take the rock specimen from deep interior of the volcano.

Dive location

21 ° 51.00 ′ N, 157 ° 46.00 ′ W starting at water depth of 2813m, ending at 2540m following a ridge towards South.

Samples collected

Nine rock specimen were collected. They are:

KR98-09-K89-1 (Depth: 2807 m) olivine basalt, small fragment of pillow lava

KR98-09-K89-2 (Depth: 2808 m) picrite basalt, fragment of pillow lava

KR98-09-K89-3 (Depth: 2794 m) composite breccia, hyaloclastite in conglomerate,

KR98-09-K89-4 (Depth: 2735 m) picrite basalt, fragment of pillow lava

KR98-09-K89-5 (Depth: 2632 m) picrite basalt, fragment of pillow lava

KR98-09-K89-6 (Depth: 2603 m) picritic basalt with modal layering of olivine, fragment of pillow lava with glassy rim

KR98-09-K89-7 (Depth: 2565 m) layered silt/sand stone with fresh glass, an elongated boulder

KR98-09-K89-8 (Depth: 2565m) olivine basalt, fragment of pillow lava with thin glassy rim

KR98-09-K89-9 (Depth: 2562 m) olivine basalt, small fragment of pillow lava with reddish surface

Geologic observations

The studied slope is steeper in the first 0.5 km where good outcrops of pillow lava and volcanic breccia were observed. Some of the lava shows smooth surface and massive interior and can be said as sheet flow. In the latter 0.7 km, the KAIKO traveled along a gentle slope covered with soft sediment. Boulders of sedimentary rocks were seen on this slope along with sporadic exposure of pillow lava. For more detail information as a function of depth, see Video log.

Highlights of the dive

Thanks to the effort of the KAIREI captain and the KAIKO team, we were able to cover 1.2 km slope of the Koolau volcano near its north corner. The studied area consists essentially of continuous pillow lava outcrop. Covered sediments are thin and the recovered rock specimens are very fresh. These information and the Sea Beam data on the north flank of Oahu island indicate a possibility to sample continuous stratification of the lava sequence in the early stage of Koolau volcano by submersible dives.

7-2. Dive No. 90
Date: 1998 Sept. 6
Authors: Michael Garcia, Tadahide Ui, Susumu Umino, Frank Trusdell, Julia Morgan, and Osamu Ishizuka

Purpose

To determine the internal structure and rock types of Tuscaloosa Seamount. The internal structure will allow us test a hypothesis that this feature was emplaced as a coherent mass with little or no rotation. The rock types will allow us to evaluate models for where within Koolau volcano that this mass was derived, especially whether it was from the subaerial portion of the volcano (or at least whether the rocks were formed under subaerial conditions).

Dive location

21° 59.47' N, 157° 02.86' W starting at 3718 m, ending at 3040 m following a ridge at 310° direction.

Samples collected

Three rocks and two push cores collected. The rocks were:

KR98-09-K90-1 (Depth: 3683 m): Near the beginning of the dive, we collected a rock sample from the base of a small outcrop (~ 1.5 m) of bedded sediments. We were unable to collect an 'in place' sample, so a loose block was collected.

KR98-09--K90-2 (Depth: 3645 m)

KR98-09--K90-3 (Depth: 3147 m) Collected from the top of a massive cliff section of boulders and cobbles. This sample was protruding from the sediment among a pile of debris.

KR98-09-K90-1 (Depth: 3041m) The two push cores were both taken of the muds at the top of the southern slope of Tuscaloosa, depth 3041 m. The cores were taken within a few tens of cm's of each other and the material was very soft, foram-bearing mud. Only short, 5-7 cm cores could be taken, probably because the mud was underlain by hard material.

Geologic Observations

3682 m: Near the start of the dive, a ledge of bedded sediments was observed. This unit consistent of at least 4 distinct layers all sloping parallel to the hillside.

3645 m: Massive cliff composed of loose boulders chaotically arranged without no apparent bedding. The unit is overlain by bedded sediments.

3589 m: Contact between massive and bedded sediments.

3564 m: Possible lava outcrop with numerous fractures; could not collect a sample.

3505 m: Layered rocks dipping into hillside. Unable to stop and examine these rocks more closely because of launcher cable problems. Had to move to east to ridge to be in position with launcher.

3443 m: As we moved up the ridge, we found the bedded sediments again, which seem to mantle the more gentle slopes to the east of the ridge target.
3440 m: Fractured rocks.
3291 m: Cliff of massive conglomerate.
3170 m: Base of another cliff section of massive conglomerate.
3142 m: Top of cliff.
3045 m: More bedded sediments.
3041 m: Top of southeastern slope of Tuscaloosa Seamount.

For more details on the dive, the reader is referred to the video log for this dive.

Highlights of the Dive

Thanks to the efforts of the KAIREI Captain and the KAIKO dive team, we were able to cover ~1.6 km along the middle to upper southern slope of Tuscaloosa Seamount, from depths of 3718 to 3040 m (total for dive 678 m ascent). These are new records for a KAIKO dive.

We were able to achieve our objectives of observing part of the internal structure of Tuscaloosa Seamount and to collect some rocks from it. Our most significant observation was noticing bedded sediments dipping at moderate angles into the seamount. We also noted that the massive conglomerate was chaotically fractured. Another important observation is that all of the volcanic samples collected appear to have a subaerial origin. These observations lead us to conclude that the seamount was transported in a debris avalanche from what was the subaerial portion of Koolau volcano. These lavas may have subsided up to 1 km after their deposition, so it is possible that the slide came from either the shallow marine or subaerial portions of the volcano.

7-3. Dive No. 91
Date: 1998 Sept. 9
Authors: Peter W.Lipman, Dave Sherrod and Tadahide Ui
Dive location: SW margin Hilina slump

This dive traversed to the NNE, from a depth of 4,180 m to a break in slope at about 3,240 m, going up the most prominent slope-failure embayment along the NW-trending tear-fault that heads toward Papa'u Seamount. Major goals were to: (1) determine the stratigraphy and volcanic emplacement features of the lower southwest margin of the deep Hilina slump block and develop evidence for coherent versus chaotic slumping, back tilting, and/or compressional folding; (2) search for features that might be related to the transverse structure that bounds the Hilina slump; and (3) collect lava samples that could be used to evaluate whether lower parts of the Hilina slump might involve the old south flank of Mauna Loa versus consisting entirely of Kilauea rocks.

During dive #91, the most impressive geologic feature was the dominance of sedimentary rocks, probably well indurated sandstone, as controlled by two samples collected collected by visual comparison with known sedimentary outcrops viewed in later dives. All outcrops were strongly fractured and locally brecciated, commonly without obvious bedding or shear structures. Some transported breccia is likely also interbedded with the sandstone, but identification of such breccia is difficult because of visual similarly to widespread exposure of fractured sandstone, partly covered by angular talus. A few interlayers of well-bedded finer-grained sedimentary rock, that are part of a primary depositional sequence, dipping nearly homoclinally to the west and northwest, probably record back-tilting during deep-level Hilina slump events. No shearing or severe deformation was observed that could readily be related to the NW transverse bathymetric-structural feature trending toward Papa'u Seamount.

The dominance of sedimentary rocks differs from our expectation that the flanking submarine volcanic edifice would be dominated either by a pedestal of primary volcanic hyaloclastite breccia or by abundant pillow lava as seen close to rift zones. The thick sandstone section along the lower Hilina scarp, if derived solely from Kilauea, would suggest that flanking aprons of fine-grained volcanic sedimentary rocks may constitute substantial proportions of the total volume of some Hawaiian volcanoes.

Dive #91 notes

KAIKO descends at up to 75m/min; by 1040 is down to 3200 m. Separation of the vehicle from launcher was at 1100.

1110 hr., 4165 depth: vehicle reached bottom. Sloping seafloor, with scattered talus blocks. ROV heads N25E, staying a few m above surface. Fragments are mostly highly angular, but some rounded small pillow-like fragments appear to have rolled downslope, staying more or less intact.

1114: Round boulder: possible pillow?

1116: Group of rounded boulders: possible pillows

1130, 4125 m: not much change.

1140, 4100 m: similar

1200, 4000 m: similar

1210, 3940 m: many rounded pillow-like boulders. Cliff reported ahead, based on sonar, but turns out to be a downslope ridge of talus debris

1215, 3920 m: finally an outcrop, or near outcrop of highly fractured dense lava-like rock. But also closely resembles outcrops of indurated sandstone seen in dive #93. Two joint sets intersect at acute angles. Probable bedding plunges 32o@130o. Prolonged attempt to sample, probably by 2nd crew (in training).

1224: Possible pillow-like cross-section in cliff

1227: change operators, then immediately lift off, apparently because launcher has caught up with ROV (or other problem).

1228: Two possible hollow pillows, seen in cross-section in cliff face

1234, 3850: back at bottom, in lots of talus, including dominant angular fragments but also lots of rounded pillow-like pieces. Conspicuous downslope "trains" of debris.
1240, 3790 m: In large talus field
1245, 3740 m: Bedded massive debris and finer sedimentary material (at 3735 m) has a strong tilt (to SW, rather than NW--but possibility that this is detached local slump block?). Old slope deposit, or tilted interbed? Too steep to land and sample.
1253, 3670 m: Steep irregular cliffs of cemented clastic debris (primarily pillow hyaloclastite?). A couple probable hollow pillows.
1300, 3575 m: Cliffs of angular breccia (check images to see if pillows clearly present?--not obvious). Massive, without bedding or lava layers. Then, a finer-grained well bedded zone (25@305), with white patches (zeolite, Mg sulfate?). Clearly back tilted to NW.
1305, 3472 m: Top of cliffs; thin weakly indurated cap of light colored sediment that overlies hyaloclastite? breccia
1310: Samples of angular proximal talus (two small fragments of indurated sandstone).
1318: After completion of sampling, traverse along edge of drop-off
1326, 3414: Concentration of angular & fairly well sorted talus blocks on lip of drop-off. Collect large angular block of well indurated sandstone, representative of large area.
1335, 3375: Fragmented closely jointed sandstone?, partly covered by talus (resembles breccia) makes weak outcrops over sizable area. Getting lots of red-light and automated audible warnings at this point. No obvious pillow fragments here; rather some massive areas look much like the sources for the angular well sorted talus that is volcaniclastic sediment.
1337, 3371: Vague bedding within fragmented sandstone?, 25@290
1340, 3355: Fairly massive brecciated sandstone? here, with vague layering perhaps dipping to the east. Much of this is well sorted
1345, 3334: Possible vague bedding, 18@288?
1350, 3310: Bottom becomes flatter; no outcrops
1400, 3260: Only scattered talus
1410, 3230: Similar, dive terminated.

7-4. Dive No. 92
Date: 1998 Sept. 9
Authors: Tsugio Shibata
Objective of the dive

The main objectives of this survey are,

1. Obtain size, distribution, structure, precipitation (growth) rate of hydrothermal deposits
2. Identify the hydrothermal precipitates and determine their chemical characteristics

3. Estimate the extent of hydrothermal activity and measure the phisical and chemical properties of the efluent
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 from the hydrothermal system and investigate the addition and removal of elements due to hydrothermal alteration

We will explore the characteristics of deep portion of the Loihi hydrothermal system during this survey. We will condust 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 dependance 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 the differences (e.g. host rock chemistry, magamtic gas input, etc.).

Proposed survey site for ROV Kaiko

Th hydrothermal site at a water deoth of approximately 4800m, located in the southeastern slope of the Loihi seamount, where Dr. Alexander Malahoff found hydothremal deposits during the Russian submersible MIR dive in 1990. This site is located in the area where the slope of the Loihi Seamount intersects a 200m high NE-SW trending ridge. The survey track was designed to follow the contour where the slope of Loihi and the ridge intersect.

Dive summary

The ROV Kaiko landed on the relatively smooth-surfaced seafloor covered with light-colored sediment. We located the cliff along the slope of the NE-SW trending ridge using forward-looking sonar. It was proposed that this discontinuity has served as the conduit for hydrothermal solutions. We found several lines of NE-SW to ENE-WSW trending cliffs. Pairs of cliffs running parallel to each other were often observed and formed steps on the slope of the NE-SW trending ridge. Most of the outcrops were highly fractured. Some of the cliffs showed fairly smooth surfaces and had joints. We mainly observed the foot of the cliffs to search for hydrothermal vents. Although no hydrothermal deposits were found, the morphology of these cliffs might contribute to the understanding of the origin and geologic setting of the NE-SW trending ridge. Another important observation is the occurrence of rounded pillow-like boulders on the slope of the NE-SW trending ridge. Since these boulders seemed to lie on the sediment covering the slope, they are thought to have originated from the upper part of the ridge.

Sample description

a) Rock sample

K98-09 K92-1: This sample was collected from the ENE-WSW slope. I is olive to gray-colored mudstone with no Mn-oxide crust. This mudstone is not completely solidified and easily broken. No internal structure or stratification can be recognized. Under the microscope, fragments of transparent glass and plagioclase are abundant and minor amount of pyroxene(?) and organic material are also observed.

b) Push core

K98-09 K92-P1: Yellowish gray mud partly bearing black color. This sample was collected from the E-W trending slope of the ridge, dipping north. The mud is mainly composed of transparent glass, dark brown-colored glass and fragments of plagioclase. Minor amounts of Mn-oxides and radiolaria were also observed.

3)Shore-based research plan

The shore-based study of the hydrothermal precipitates and altered rocks will include microscopic observation, XRD, major and trace element analysis (XRF), selected REE elements (INAA), stable isotope analysis and fluid inclusion analysis. These analyses will be conducted to estimate the physicochemical condition of formation of hydrothermal deposits, the source of some elements and the spatial and temporal variation of hydrothermal activity. The bulk chemical analysis of altered rocks is conducted to reveal the flux of elements combined with the chemistry of the hydrothermal solutions. If evidence of microbial activity (remnants of bacteria, filamentous texture, etc.) is found, SEM observation, spot chemical analysis, FTIR analysis and other related analysis will be done to estimate the contribution of microbial activity to the concentration of elements.

7-5. Dive No. 93

Date: Sept. 10, 1998

Authors: Peter Lipman and Tadahide Ui

Dive location: Large NE-trending ridge seaward of Hilina slump

This dive traversed NNW, from a depth of 5260 m, up a prominent rib of the largest of several NE-trending linear ridges about 10 km seaward of the main Hilina slump toe. These enigmatic ridges 3-8 km long, rise several hundred meters above the seafloor and are oriented subparallel to the base of the Hilina slump. They have alternatively been interpreted as partially buried thrust-related folds involving abyssal sediments of the oceanic crust (Borgia et al., 1990) or slide blocks generated during early flank failures of Hawaii Island (Moore et al. 1989). The purpose of this dive was to provide information about the stratigraphy, depositional processes, composition, source, and structure of the rocks making up these linear ridges. Dive #93 was planned to traverse up the outer (SE) flank of the ridge, because this side provided a longer section than the NW side, and also because the previously proposed hypotheses for origin of the ridge predict dominant stratal dips to the NW. Priority was placed on collecting multiple representative samples, rather than maximizing traverse distance, but the dive traversed the steepest and best exposed lower two-thirds of the ridge.

The most impressive features observed during this dive were: (1) the dominance of sedimentary material, most of it fine grained, and absence of primary volcanic deposits, indicating distal original depositional environment; (2) a general upward decrease in degree of induration and diagenetic alteration, suggesting a coherent stratigraphic sequence; (3) the prevalence of breccia containing blocks of sandstone low in the section (below 5,215 m), indicating fragmentation and transportation of this material, presumably downslope during an early landsliding event; (4) well developed bedding in many sedimentary outcrops, varying from near horizontal to perhaps as much as 30 degrees in southwesterly to northeasterly directions that suggest an overall tilt to the NW, with modest folding, large-scale block rotation, or other mild disruption to account for the dip variations, but neither fine-scale internal brecciation nor other intense deformation of the elongate ridge. Three samples from lower parts of the traverse are all densely indurated volcanic sandstone. The highest sample (#4) is a less indurated coarse bedded volcanic sandstone; it contains apparently unaltered volcanic material (glass, olivine phenocrysts) that could provide information on the source volcano and eruptive depth (subaerial vs. deep water).

The ridge is thus tentatively interpreted as a slump block, distal to the main Hilina slump, that slid to the southeast as a fairly coherent mass, but it is not a structurally simple back-tilted mass. Its dominantly fine-grained sedimentary rocks are clearly is derived from Hawaii Island, rather than consisting of an upthrust seafloor sequence.

Dive #93 notes

1124 hr., 5249 m, heading 330o: On bottom, with angular pillow-like fragments covered by thin ooze (much less than typical during previous dive.

1131, 528 m: Good outcrops of breccia, consisting of angular pillow(?) fragments. Coll. small sample #1 @1138, 2nd larger sample #2 @1141, both breccia clasts collected from the outcrop. These are bedded well-indurated volcaniclastic sediments, consisting of coarse sandstone, in which basaltic grains are abundant.

1143, 5243 , 330: Large blocks of breccia on steep outcropping slope

1147, 5238: : Apparent cross section through pillow (look again)

1149, 5232, 300: More similar appearing breccia. Try to collect breccia fragments. No success (have to leave, because of launcher position)

1156, 5230: Similar breccia, moving up rib.
1159, 5216: Massive large outcrop on steep slope, with steep fractures
1201, 5200: Steep sedimented slope, but quite sandy without thick ooze
1204, 5184, 330: Big outcrops again
1209, 5174, 328: Large outcrop, with NW-dipping bedding
1218, 5135, 330: Similar outcrops; Large reddish sample of massive rocks (sedimentary?)
1220, 5130: Massive bedded? outcrops on steep slope
1218, 5118: Joints (bedding) dip to left (NW); still steep
1226, 5050: Breccia outcrop; first in long distance
1228, 5019: Lose bottom
1229, 5018: Bottom again; breccia on steep slope
1233, 5002, 330: Steep sedimented slope
1236, 4997, 328: Outcrops of pillow-like breccia; try for sample but no luck
1247, 4889: Move short distance; further sample attempt on apparent soft material (mud?); try to put small sample in left basket (washed out)
1255, 4987: Sediments dip to left
1256, 4985: Small area of breccia, between more massive outcrops and covered slopes with ripple marks
1301, 4945: Lose bottom, then descend
1304, 4975: Bottom again; slabby sedimentary rock
1307, 4968: Outcrop of breccia on steep slope
1309, 4966, 336: Subhorizontal sedimentary outcrops
1313, 4945, 338: Small outcrops of gently dipping platy sedimentary rocks; problems with launcher position.
1326, 4944: Moving again, crossing gully and traversing covered slope
1334, 4938, 337: Stop again, to wait for launcher. Collect push core in sandy sediment; limited penetration.
1339, 4937: Move short distance to fine-grained sedimentary outcrop, with fluted cross-bedded surface (etched by currents?). Attempt to collect this fairly well indurated but friable rock; small sample put in right rear basket, but lost during ascent.
1348, 4920: Outcrop with odd lenticular fabric. Probably not pillow fragments: no talus, and looks only weakly indurated--perhaps sheared mudstone?
1355, 4895: Small outcrops of indurated fine-grained sedimentary rock, with nearly flat bedding.
1359, 4875, 340: Resistant layer, with small cauliflower-like fragments on slope where less resistant layers are covered by ooze.
At 1408, succeed in collecting sample #4, from this layer is coarse bedded sandstone, containing unaltered volcanic fragments: large glass fragments, abundant olivine grains, and a porous open texture (in contrast to densely indurated sandstone from deeper levels).
1410, 4870: Leave bottom

7-6. Dive No. 94

Date: 1998 Sept. 13

Authors: Tsugio Shibata (Okayama University)

Purpose

Loihi Volcano shows overall topography with an elongated appearence, stretching approximately north-south over 35 km, and its rift zone runs parallel to this north-south elongation. In contrast to the shallower portions of the rift zone, its deeper parts are relatively less explored and very few submersible dives were made over the water depth of 2000m. So, we had chosen this particular site on the Loihi South Rift at the water depth of 4000m for the second KAIKO dive in order to explore and sample its deeper parts.

The main purpose of this dive was as follows:

1. to collect several rock samples along the survey line;
2. to record visual images and information on lava morphologies, its relative ages, tectonic features, sediment types and distributions;
3. to attempt finding new hydrothermal venting sites and, if any, to measure fluid temperatures and to set a marker for another KAIKO dive; and
4. to obtain continuous temperature and pH measurements along the survey line.

Dive location

Loihi South Rift: Start at ca.18°46.1'N, 155°10.85'W, Water Depth: 4020m. End at ca.18°46.73'N, 155°11.05'W, Water Depth: 3900m

Geologic observations

We landed on the south-dipping slope about 80m off the intended landing point that is located at the southern end of Loihi South Rift. From there, we started surveying northward, climbing the slope up to the crest of small, protruding ridge. We then took a heading of ca.335° and surveyed along this small ridge crest. Whenever we found bright reflections in the forward looking sonar image, we changed the heading to see what occurs there; thus, taking a slight zigzag path, we continued surveying along the small ridge crest until the survey time ran out. The total distance surveyed during this dive was about 1.4 km.

Generally, the lava morphologies we encountered during this dive are represented by pillow lavas or lava tubes on steep escarpments and nearly vertical cliffs, and they are represented by lobate pillows and/or lobate sheets on gentle slopes and nearly flat areas. Thus, the lava types are predominantly pillow lavas along the ca. 300m length of observed route right north of the landing site and 200m route south of the point where we concluded the survey. Particularly remarkable is the draping, elongated lava tubes that occur on the steep slope about 100-200m north from the landing site. These lava tubes elongate north-south, pointing southward; apparently, this suggests that molten magma was supplied from north and flowed down the slope southward. However, the lavas become more flattened and the flow directions become more variable as we approach the top of the slope. Also, we come across a very rugged area located ca. 300m north of the landing site, where blocky, jumbled sheet flows are accumulated.

During the dive, we observed several open fissures with several tens of centimeters to over one meter wide at the crest regions of the small ridge. These fissures run nearly parallel to each other and trend north-south. This north-south trend is slightly oblique to the trend of the ridge crest and the overall, general trend of the South Rift. The fault-generated, nearly vertical scarps occur at a few places. These fault scarps trend roughly either north-south or east-west. The lava types exposed on the scarps are predominantly intact pillow lavas and the truncated pillows are rare, suggesting that fracturing or displacement took place along the boundaries between individual pillow lavas and not through them. About 400m south of the site where we ended the survey, we observed a topographic depression, forming a saddle off of the ridge crest where it is liekly that a eruption center was once located.

On the south-dipping slope located at the landing site, the pockets and spaces in between pillow lavas were empty and no significant amount of sediments occur. Along the rest of the survey line, however, we observed thin patches of sediment cover (black sands) on the top of pillow lavas or lobate pillows and also, we found that the pockets and spaces in between pillow lavas are filled with the sediments. Neither did we come across any active hydrothermal area, nor dead chimneys or other remnants of hydrothermal activity. Along the way, we spotted a couple of red shrimps and deep-sea fishes; organisms not indicative of hydrothermal areas, however.

This dive achieved the following objectives:

1. Observed and videotaped volcanic constructions, tectonic features, and sediment distributions on the protoruding, small ridge at the water depth of ca. 4000m in the Loihi south rift zone in order to obtain information for geological mapping of the region.
2. Collected rock specimens at 7 sites for further petrological and geochemical studies on shore. The seven sites are spaced less than 300m intervals along the survey line.
3. Obtained continuous temperature and pH measurements along the survey line

刧刧刧7-7. Dive No. 95
Date: Sept. 14, 1998
Location: Eastern Hilina slump, basal Kilauea marine slope
Authors: Tadahide Ui and Peter Lipman

This dive traversed NNW, from a depth of 3,430 m, up a steep rib between two slump scars in the basal part of the marine slope that rises to shoreline near the eastern limit of the on-land Hilina faults (Figure). The main goals of the dive were to determine the lithology and structure of the submarine platform along the southeast flank of Kilauea, to sample deep underwater deposits that are confidently derived from Kilauea, and to make comparisons with the volcanic sandstone and mudstone that constitute the dominant rock types along deeper submarine scarps of the Hilina slump, at least near its southwest margin as determined during dives # 91 and 93. We anticipated that coarse volcaniclastic rocks, either pillow hyaloclastites or slumped debris from subaerial eruptions that entered the sea, would be abundant along the Kilauea marine slope, in contrast to their scarcity at great depths along the basal scarps of the Hilina slump. Dive #95 was positioned to traverse the steepest deep ridge that projects through the smooth 3,000-m-high slope that is probably largely or entirely veneered by volcaniclastic debris derived from the present Kilauea coastline. Samples should provide evidence on early eruptive history along the Kilauea east rift zone, and would permit determination of submarine vs. subaerial eruption. Only 25 km to the NE, the bathymetric data indicate that this smoothly sedimented slope changes abruptly to a hummocky terrain interpreted as being pillow lava erupted along the underwater continuation of the east rift.

Major results from this dive include: (1) Because the surveyed ridge lies between two large slump scars, excellent exposures were found of the deepest primary volcanic deposits likely anywhere on Kilauea's slope, without cover by recent lava deposits from the highly active east rift zone (other than abundant basaltic black glass, derived from shoreline processes, as a component of the surficial sandy ooze). (2) Large dense whole and broken pillows are spectacularly exposed in cross section along the entire outcropping segment of this dive; these display textbook examples of the predicted dominant submarine volcanic platform of an oceanic volcanic island. (3) The pillows lack hollow cores, contain only sparse small vesicles, and have thick prismatic joints. Seven sampled pillow fragments are dense nearly aphyric basalt, most preserving thin glass rinds. (4) Especially importantly, there is a complete contrast with the sandstone and mudstone sections seen at greater depths along the lower Hilina bench and blocks slumped from it (dives #91 & 93).

The pillow breccias observed in this dive are inferred to be representative of the entire steep marine slope of Kilauea, which is heavily mantled by sediment, down to the prominent lower bench of the Hilina slump. The dense pillows may have erupted subaerially and flowed across the shoreline to deposit in deep water; subaerial vs. submarine eruption could be determined from S contents of the glassy pillow rinds. The contrast between the pillow breccias of this dive and the sandstone-mudstone sections exposed along the lower Hilina bench disproves a widely proposed prior interpretation that the bench deposits are a downfaulted part of the primary volcanic pedestal of Kilauea that subsided along slump faults similar to those exposed along the subaerial Hilina slump system. Instead, the sedimentary rocks must completely underlie the Kilauea pillow-breccia platform, interfinger with its lower distal parts, or (least likely) lap out against it.

Dive #95 notes

Kaiko descends to bottom by 1104, separates vehicle 1111.

1120, 3371 m depth. Mud on the seafloor, ripple mark.

1130, 3356 m, scattered angular blocks on the seafloor. Sampled K95-1.

1148, 3351 m, massive and fractured outcrop covered with mud.

1150, 3336 m, mud on the sea floor, scattered blocks.

1154, 3296 m, fractured outcrop covered with mud.

1158, 3275 m, outcrop of pillow breccia. We sampled K95-2 from the surface of a pillow.

1205, 3256 m, pillow breccia partially covered with mud.

1211, 3219 m, we sampled K95-3 from a surface of pillow.

1226, 3162 m, relatively gentle slope covered with mud.

1229, 3153 m, we sampled K95-4 and 5 from a surface of pillow.

1244, sampled push core (K95-P1) from the seafloor near the site K95-4 and 5.

1259, 3087 m, excellent pillow breccia outcrop, but failed to make a sampling due to 2nd cable length problem.

1306, 3002 m, mud on the sea floor.

(Change video cassete)

1311, 2981 m, outcrop of pillow breccia, sampled K95-6 from a chilled surface of pillow.

1323, 2943 m, mud on the sea floor, ripple mark.

1340, ---- m, bedding plane-like image, but we could not stop vehicle.

1346, 2868 m, outcrop completely buried with mud.

1350, 2868 m, blocks scattered on the muddy seafloor. K95-7 was sampled from a cluster of blocks. Sampled push core K95-P2.

1357, 2856 m, small outcrop? in the muddy sea floor.

Continued muddy sea floor by the end of dive.

1430, 2765 m, leave bottom.

Total distance traversed was about 2 km.

7-8. Dive No. 96

Date: September 15, 1998

Authors: Tsugio Shibata

Dive location

Loihi Basal Lava Field, ca.18°43.2'N, 155°11.15'W, start at 4915m, ending at ca.18°43.65'N, 155°11.35'W,3865m

Purpose

Previous studies indicate that the ratio of alkalic to tholeiitic lava at Loihi varies systematically with depth from predominantly alkalic at the base to tholeiitic at the top. However, most of the rock samples collected from the basal parts of Loihi Volcano are not so well located as very few submersible dives were made over the water depth of 2000m. Thus, this dive primarily aimed at collecting rock samples from the deeper, basal parts of Loihi in order to better define the petrologic and geochemical characteristics of magma that formed the Loihi basal lavas. Also, it is suggested that this area might be the site where lavas could have extruded during the 1996 summit collapse of Loihi (A. Malahoff, personal communication).

The main purpose of this dive was as follows:
1. To collect several rock samples along the survey line;
2. To record visual images and information on lava morphologies, its relative ages, tectonic features, sediment types and distributions;
3. To attempt finding new hydrothermal venting sites and, if any, to measure fluid temperatures and to set a marker for another KAIKO dive; and to obtain continuous temperature and pH measurements along the survey line.

Results

We landed at the proposed site with the water depth of ca. 4900m on the southern basal flank of Loihi Volcano as we planned. From there, we started surveying with a heading of north-northwest. The dive area is a part of the southern basal apron of Loihi and is generally characterized by south-dipping slopes; however, we found that topographically it is a very rugged, bumpy area with several deep depressions and numerous, minor ups and downs. For this rugged topography, it was difficult to keep KAIKO always close to the bottom, so that at many instants we lost sight of the bottom. As in the case of Dive #94, whenever we found bright reflections in the forward looking sonar image, we changed the heading to see what occurs there; thus, taking a slight zigzag path, we continued surveying with a general heading of 340° until the survey time ran out. The total distance surveyed during this dive was about 1.0 km.

Kaiko landed at the rim of a large collapsed lava lake several tens of meters across. The lava morphologies we encountered during this dive are represented by pillow lavas, lava tubes, lobate pillows, and lobate sheets; in addition to these standard lava morphologies observed underseas, we encountered lava flows that are more like subareal, shelly pahoehoe. Also, in addition to numerous collapsed pits, hollow lava tubes and hollow lobate flows with many cracks and fractures are very common; these are the outer quenched rinds of lava flows formed after the magma that was still molten inside had been drained out. Unlike dive #94, the distributions of these morphological types are complicated and are not well correlated with local topography, although flattened pillows, lobate sheets or shelly pahoehoe tend to occur in flat areas or on gentle slopes. On two occasions, we noted that one morphological type of lava flow overlies another type of lava flow;

e.g., pillow lavas and lava tubes overlies lobate sheet flows with distinct boundaries.

As indicated previously, we came across several deep depressions or valley during the course of this dive. We, however, could not observe the structural details of these depressions; they could be either collapsed large lava lakes or fault-bounded depressions. Numerous open cracks and fractures with irregular, variable trends were commonly observed on the surfaces of lava flows. Throughout the area surveyed during this dive, we noted no significant amount of sediment on the top of lava flows, suggesting that these lava flows were derived from relatively recent eruptions and all were formed in a short time span. From the visual observation of TV images and handspecimen inspection on the collected rock samples, however, it is apparent that the lava flows encountered during this dive are not so young as those erupted several years ago. As in the case of dive #94, neither did we come across any active hydrothermal area, nor dead chimneys or other remnants of hydrothermal activity. Along the way, we spotted a large white sea anemone.

This dive achieved the following objectives:
1. Observed and videotaped volcanic constructions and tectonic features on the southern basal flank of Loihi Volcano at the water depth of ca. 5000m in order to obtain information for geological mapping of the region.
2. Collected rock specimens at 7 sites for further petrological and geochemical studies on shore. The seven sites are spaced less than 200m intervals along the survey line.
3. Obtained continuous temperature and pH measurements along the survey line.

7-9. Dive No. 97
Date: Sept. 17, 1998
Authors: Bryan Midson and Osamu Ishizuka
Purpose

The main objectives of this survey are,
1. Obtain size, distribution, structure, precipitation (growth) rate of hydrothermal deposits
2. Identify the hydrothermal precipitates and determine their chemical characteristics
3. Estimate the extent of hydrothermal activity and measure the phisical and chemical properties of the efluent
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 from the hydrothermal system and investigate the addition and removal of elements due to hydrothermal alteration

We will explore the characteristics of deep portion of the Loihi hydrothermal system during this survey. We will condust 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 dpendance 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 the differences (e.g. host rock chemistry, magamtic gas input, etc.).

Proposed survey site for ROV Kaiko

Th hydrothermal site at a water deoth of approximately 4815m, located in the southeastern slope of the Loihi seamount, where Dr. Alexander Malahoff found hydothremal deposits during the Russian submersible MIR dive in 1990. This site is located in the area where the slope of the Loihi Seamount intersects a 200m high NE-SW trending ridge. The survey track was designed to follow the contour where the slope of Loihi and the ridge intersect.

Dive summary

The ROV Kaiko landed on the relatively smooth-surfaced seafloor covered with light-colored sediment in 4813 meters of water. We located the cliff along the slope of the NE-SW trending ridge using forward-looking sonar. It was proposed that this discontinuity has served as the conduit for hydrothermal solutions. We then followed the 4815 meter depth contour to the east and south. Most of the cliffs and rock outcrops were massive with some fractures and joints. The cliffs were of the sedimentary type of mudstone or sandstone that had been observed and sampled during Kaiko dive # 92. We mainly observed the foot of the cliffs to search for hydrothermal vents. The dive track covered the entire arcuate section of the ridge that was suspected to be the location of the hydrothermal chimneys observed in 1990. Although no hydrothermal deposits were found, the morphology of these cliffs might contribute to the understanding of the origin and geologic setting of the NE-SW trending ridge.

Sample description

KR98-09 K97-E1 (Eckman Grab sampler): light borwn to dark brown-colored mud. Dark brown-colored part is mainly composed of coarser-grained and dark-colored fresh glass and subordinate amount of transparent glass and olivine crystals. Lighter colored part is mainly composed of finer-grained transparent glass.

KR98-09 K97-p1 (Push core)

Only very small amount of dark brown-colored glass was recovered.

Shore-based research plan

The shore-based study of the hydrothermal precipitates and altered rocks will include microscopic observation, XRD, major and trace element analysis (XRF), selected REE elements (INAA), stable isotope analysis and fluid inclusion analysis. These analyses will be conducted to estimate the physicochemical condition of formation of hydrothermal deposits, the source of some elements and the spatial and temporal variation of hydrothermal activity. The bulk chemical analysis of altered rocks is conducted to reveal the flux of elements combined with the chemistry of the hydrothermal solutions. If evidence of microbial activity (remnants of bacteria, filamentous texture, etc.) is found, SEM observation, spot chemical analysis, FTIR analysis and other related analysis will be done to estimate the contribution of microbial activity to the concentration of elements.

7-10. Dive No. 98

Date: Sept. 18, 1998

Authors: Tadahide Ui and Peter Lipman

Dive location: Southwestern Hilina slump, scarp of midslope bench

This dive traversed NW, from a depth of 3,771 m, up the eastern margin of a large slump scar in the 2-km-high scarp that bounds the seaward margin of the Hilina midslope bench (Figure). This site bounds the largest steep secondary landslide scarp along upper parts of the Hilina boundary scarp, and it provides a transitional location, both in vertical stratigraphic position and in map location between the earlier 1998 dives. The main goals of the dive were: to determine the lithology and structure of upper parts of the great bounding scarp of the Hilina slump, to make comparisons with the well indurated volcanic sandstone and mudstone that constitute the dominant rock types deeper along the submarine scarp (dive #91) and in the elongate ridges seaward of the scarp (dives #93 & 97), to look for evidence of compressional folding or other structures that could indicate active uplift of the midslope bench, and to search for primary volcanic deposits (pillow lava or breccia) within the upper scarp section and obtain samples of rocks that directly underlie the midslope bench. These might include glassy volcanic sand or coarser fragments that could be used to identify the source volcano(s) for the sedimentary deposits. Time permitting, late in the dive we would explore the gently sloping edge of the midslope bench, to evaluate whether exposures are sufficient for more extensive diving observations in a future year.

Major results from this dive include: (1) The entire sequence of rocks traversed in this dive, over a vertical distance of 630 m, consists of variably bedded volcaniclastic sedimentary rocks; these included unstratified breccia containing basaltic clasts (seemingly most common low in the sequence), coarse to fine grained indurated sandstone containing small fragments of basaltic glass, and massive to finely bedded weakly indurated siltstone and mudstone. (2) No primary volcanic deposits, such as pillow lava or hyaloclastite pillow breccia were identified. (3) The overall lithologic assemblage contained more coarse volcanic debris than identified during the two previous dive traverses on lower Hilina scarps (#91 & 93); eight samples were collected during this dive. (4) Dips in well bedded units were mostly gentle, especially high in the sequence, but were more variable at lower levels. (5) Recent deformation of this area is indicated by the presence of young talus deposits, lacking any surficial sedimentary mantle (perhaps resulting from the 1975 Kalapana earthquake?), and by the presence of probable small ground cracks with a geometry indicative of expansion in a seaward direction. (6) Continuous cover of all low-relief surfaces by a blanket of muddy ooze makes it doubtful that much useful information could be gained through future traverses over the crest of the midslope bench.

Along with the prior dive #91, it has becom clear that the entire 2-km section exposed on the frontal scarp of the Hilina slump seaward of the midslope bench is sedimentary volcaniclastic material. The general similarity of the sedimentary section traversed during this dive to that observed on the elongate ridge seaward of the Hilina basal scarp during dive #93 supports interpretation of this elongate ridge as having slumped essentially intact from the Hilina scarp. The many other blocks seaward of the main Hilina scarp have an overall geometry broadly similar to blocks on more distal portions of the Tuscaloosa landslide deposit north of Oahu, and likely were emplaced by a comparable mechanism involving extensional separation of semi-coherent masses. In contrast, the indications of young deformation along the upper Hilina scarp traversed during this dive suggest that the midslope bench, which seems likely a compressional structure, remains tectonically active. Petrologic study of the excellent sample suited collected during this dive, which contain fresh basaltic material, may help identify the source volcano(es) for the sedimentary debris that forms the entire frontal scarp of the Hilina slump.

Dive #98 notes

1056 3771 m on bottom.

1111 3755 m, breccia sample #1 collected from an outcrop.

Then continuously muddy slope. Vehicle forced to wait launcher.

1134 3742 m, fresh talus.

1156 3735 m, fresh talus.

1158 3728 m, fresh talus.

1208 3706 m, white mineral (zeolite?) fills crack. Sampled #2, but might be crushed and lost when put into basket.

1216 3698 m, a breccia with white mineral (sample #3) was collected the same outcrop.

1223 3638 m, highly fractured outcrop. Ascending steep cliff.

1230 3572 m, sampled massive and dense rock (sample #4) from an outcrop.

1255 3427 m, bedded outcrop, sampling by a manupilater was failed, but

two small pieces were fallen into the basket. These are sample #5 and 6.
1257 3416 m, sampled from fresh talus deposit. This is sample #7.
1301 3391 m, fractured outcrop, probably sandstone.
1306 3350 m, relatively gentle slope covered with mud.
Then continuously muddy slope.
1330 3312 m, sampled push core.
1345 3277 m, excellent bedded outcrop, soft and sampling was failed.
Indurated sandstone on top of bedded layers.
1404 3184 m, gentle slope with thick mud.
1409 3159 m, pick up a boulder (sample #8) on a muddy deposit.
1420 3140 m, off bottom.
Brief description of samples
#1: Aphyric and slightly vesiculated basalt block
#2: Unidentified rock with zeolite (?) vein
#3: Picrite boulder
#4: Poorly sorted volcanogenic sandstone
#5: Loose mud
#6: Several pieces of basalt fragment, one is the same as #1
#7: Lapilli tuff, most of lapilli is quenched basalt
#8: Poorly sorted volcanogenic sandstone

7-11. Summary of KAIKO dives

LOIHI DIVE RESULTS

Loihi Submarine Volcano, located 34 kilometers south of the Island of Hawaii, shows overall topography with an elongated appearence, stretching approximately north-south over 35 kilometers, and its rift zone runs parallel to this north-south elongation. The summit is located at a water depth of 960 meters, and its basal apron extends to the sea floor as deep as over 5000 meters water depth. In contrast to the shallower portions of Loihi Volcano, its deeper parts are so far less explored and very few submersible dives were made over the water depth of 2000 meters. In addtion, during the Russian submersible MIR dive in 1990, a hydrothermal site was found on the southeastern slope of Loihi Seamount at a water depth of approximately 4800 meters, which is the world's deepest hydrothermal site so far known. Thus, four KAIKO dives at Loihi site were devoted to exploring the geology of the deeper, basal parts of Loihi Volcano and revisiting the hydrothermal site.

Two KAIKO dives (#94 and #96) were successfully conducted on the south rift zone at a water depth of ca. 4000 meters and on the southern basal flank at a water depth of ca. 4900 meters. During these dives, we found that fairly young lava flows with various lava morphologies occur in these surveyed areas. The lava morphologies provide us with valuable information to define flow directions; in the ridge crest zone observed during dive #94, we could trace the eruption center from which magma was possibly supplied. Besides pillow lavas, lava tubes, and lobate pillows commonly observed underseas, we encountered lava flows that are more like subareal, shelly pahoehoe. Also, collapsed pits and hollow lava flows are ubiquitously present. The local topography is dominantly due to volcanic constructions, but we came across the deep depressions with possible tectonic origin during dive #96. It is also worthwhile to note that we observed several open fissures with several tens of centimeters to over one meter wide at the #94 dive site; these fissures run nearly parallel to each other and trend north-south. This north-south trend is slightly oblique to the trend of the ridge crest and the overall, general trend of the South Rift.

During these two dives, we successfully collected rock samples at 14 localities. Cursory handspecimen inspections suggest that these rocks are mostly olivine phyric to picritic basalt with glassy selvage generally less than a few milimeters in thickness. It is most remarkable that some of these specimens are extremely vesicular, having as much as 30 vol.% vesicles in visual estimates. Petrological and geochemical studies on the collected samples are to be carried out in attempts to reveal magma genesis at Loihi Volcano.

The entire two KAIKO dives (#92 and 97) were devoted to finding and revisiting the hydrothermal site that Dr. Alexander Malahoff of the University of Hawaii encountered during the Russian submersible MIR dive in 1990. This site is supposed to be located on the southeastern slope of Loihi Seamount at a water depth of approximately 4800m. More specifically, it is supposed to be found at the foot of the 200m high, NE-SW trending small ridge, located ca.19km southeast of the summit of Loihi. Despite our devoted effort, however, we were unable to locate the world's deepest hydrothermal site during these two dives.

8. SUMMARY

8-1. Nuuanu landslide and adjacent area, northeast of Oahu

(1) We made a bathymetric map of the Nuuanu and Wailau slide areas, northeast of Oahu. The Nuuanu slide is the largest landslide around the Hawaiian Islands, having flowed as much as 150 miles across the sea floor; it is thought to derive from the northern part of Kooalu volcano, northern Oahu. The Wailau slide originated from Molokai.

(2) We collected subaerially erupted samples of basaltic lava from Tuscalusa Seamount, which is the largest block in the Nuuanu landslide (10 x 15 miles across, rising 6,000 ft from the seafloor). Therefore, this seamount was once part of the Koolau volcano and slid into its present position. On the eastern flank of the seamount, we also observed fractured outcrops which are characteristics of debris avalanches.

(3) We observed and collected basaltic pillow lava, which is characteristic of submarine eruptions, on the northern underwater slope of Oahu. This pillow lava seems to be the lower flank of Koolau Volcano.

(4) We collected volcaniclastic turbidite sand layers, which include beach deposits, on the top of Tuscalusa Seamout and at other sites in the Nuuanu and Wailau slide area, by piston coring.

8-2. Hilina Slump and adjacent areas, south of Hawaii Island

(1) We conducted 4 KAIKO dives on steep underwater slopes of the Hilina slump area on the south side of Kilauea volcano. During these dives, we observed pillow-lava fragments on the upper steep marine slope of Kilauea, and observed sandstone and consolidated breccia layers which derived from basaltic volcanism on lower slopes.

(2) Elongate ridges as much as 8 miles long and 2,500 ft high, on the deep ocean floor 3-6 miles seaward of the Hilina slump, have slid from the steep frontal slope of the Hilina slump. On the largest of these ridges, we observed sandstone and breccia layers, which are similar to rocks on the Hilina frontal scarp.

(3) By piston coring of the deep seafloor 60-125 miles southeast of Hawaii Island, we obtained volcaniclastic turbidite sand which was derived from the volcanoes of Hawaii Island.

8-3. Loihi Seamount, south of Hawaii Island

(1) We conducted 2 KAIKO ROV dives at depths of 13,000-16,000 ft on the south volcanic rift zone of Loihi Seamount, the newest volcano of the Hawaiian chain. During these dives, we observed and collected samples from submarine lava flows, containing lava channels similar to those that form on land.

(2) We attempted to revisit the world deepest known hydrothermal site (16,000 ft), which was discovered by Russian submersible "Mir" in 1990, but were unable to locate hydrothermal features at the reported site south

of Loihi Seamount.

9. RESEARCH AND PUBLICATION PLAN

During this cruise we discussed research plan using these cruises result. The identified research plans are follows:

Nuuanu Slide area

1. Sedimentilogical study for piston cores (Kanamatsu and Naka)
2. SBP, SSS Sea Beam and KAIKO images study on avalanche (Ui, Smith, Tsuboyama and Satake)
3. K-Ar, Ar40/39 dating on volcanic glass & pillow basalt from Koolau(Uto)
4. U-Th C14 dating and paleomagnetic study (McMurtry, Herero-Bervera and Kanamatsu)
5. Petrology of landslide rocks, Petrology & Geochemistry of pillow basalt from Koolau (Trusdell, Takahashi, Garcia, Nakajima and Shinozaki)
6. Picrite from Koolau, comparison between subareal and submarine (Garcia and Takahashi)
7. Compositional hetroginities of volcanic sands (Garcia)
8. Morphological study of submarine lava lobes (Umino)

Hilina Slump area

1. Origin of deep sea cliff (Ui, Lipman and Smith)
2. Study on volcaniclastic rocks from Hilina Slump (Umino)
3. Tsunami generation (Satake and Smith)
4. Volcanic geochemistry (Sission)
5. Sedimentological and stratigraphic study on core and rock samples (Naka, Kanamatsu and Sission)

Loihi Seamount area

1. Petrology and Geochemistry (Shibata, Naka, Sission, Malahoff and Kaneoka)
2. Volcanic geology (Umino, Shibata and Naka)
3. Morphological study on lava (Umino)
4. Morphologic time series (Smith)
5. Geochemical characteristics of hydrothermal deposit (Ishizuka and Malahoff)
6. Deep sea hydrothermal venting (Midson and Ishibashi)
7. Microbiology of hydrothermal fluid (Naganuma)