United States Department of the Interior
Geological Survey

Shipboard Report For Hawaii GLORIA Ground-Truth Cruise F11-88-HW, 25 Oct.-7 Nov., 1988

David A. Clague[1], Robin Holcomb[2], Michael Torresan[1], and Stephanie Ross[1]

OPEN-FILE REPORT
89-109

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U. S. G. S.

[1]U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

[2]U.S. Geological Survey
Dept. of Oceanography
University of Washington
Seattle, WA 98195

Introduction

GLORIA side-scan imagery of the region north of Oahu was collected during two cruises in the spring of 1988. These cruises, F4-88-HW and F6-88-HW, discovered an extensive lava flow field on the Hawaiian Arch and extensive landslide deposits that moved down through the Hawaiian Moat and up onto the Hawaiian Arch. These landslide deposits were apparently derived from two separate submarine failures on the north side of Molokai and the northeast side of Oahu. The cruise reports for these cruises will be released as USGS Open-File Reports in 1989.

This report summarizes the results of a subsequent cruise, F11-88-HW on the R/V Farnella, to sample some of the features discovered during the prior GLORIA surveys. Cruise F11-88-HW began in Honolulu on Oct. 25, 1988 and ended in Honolulu on Nov. 7, 1988. The major objectives of the cruise were to sample the giant lava field north of Oahu (Figure 1), to sample an apparently young flow between Oahu and Kauai (Figure 2) , to do some preliminary sampling of the deposits of the Nuuanu giant landslide north-northeast of Oahu, and to determine the thickness of sediment on flows in this lava field to compare to the acoustic backscatter variations observed in the GLORIA imagery of the flow field.

These objectives were modified during the cruise due to rough seas which limited the deployment of the camera sled and to problems with the coring equipment which limited us to collecting 10 ft gravity cores. In particular, we did not complete any work aimed directly at the Nuuanu landslide deposits. The comparison of sediment thickness on the flows to observed acoustic backscatter on the GLORIA images was not completed because flows with intermediate backscatter were found to have thicker sediment than we could sample. The other objectives were achieved and lava samples of the flows and vents of the flow field were recovered from 23 locations. Gravity cores on top of the flows also determined the sediment thickness at 12 locations. The flow between Oahu and Kauai was sampled and photographed and found to be young, but clearly not historic in age.

Scientific Crew List

David Clague	Chief Scientist-USGS
Robin Holcomb	Co-chief Scientist-USGS
Stephanie Ross	Watch Chief-USGS
Mike Torresan	Watch Chief-USGS
Corky Ozanne	Marine Technician-USGS
Hal Williams	Marine Technician-USGS
Jim Vaughan	Electrical Engineer-USGS
Mike Boyle	Electronics Technician-USGS
Kaye Kinoshita	Navigator-USGS
Chuck Heywood	Navigator-USGS
Leda Beth Pickthorn	Watchstander/DAFE-USGS
Marilyn DeRosa	Watchstander-USGS
Lynn Ingram	Watchstander-Stanford graduate student/USGS
Tom Juster	Watchstander-MIT graduate student
Suzanne Smaglik	Watchstander-Univ. Hawaii graduate student
Steve Wessells	Watchstander-USGS

Cruise Narrative

During the cruise we occupied 39 stations including 2 camera stations, 13 gravity core stations, and 24 dredge stations. The locations, depths, and a brief description of the recovery are summarized in Table 1 and the rough shiptrack and station locations are shown schematically on Figure 3.

<u>The Oahu-Kauai Lava Flow</u>

We departed Honolulu at 1752 GMT (0752 Hawaiian Time) on Tuesday October 25, 1988 and began to steam to our first work area, the high-backscatter flow in the channel between Oahu and Kauai. After a fire and boat drill at 1900z, we had a brief meeting of the scientific crew, Captain John Cannan, and First Mate Albert Fuller to discuss the planned operations for the cruise.

At about 0400z we began dredge station 1D on the western part of the flow. The flow slopes downward from west to east and is quite rough. The high backscatter is not caused by a smooth flat lava surface like that seen at the South Arch flow. The profile collected on F4-88-HW shows the flow to be quite flat near the margins but to contain a central high rising about 120 m above the margins; this high may have been produced by inflation of the flow interior or by accumulation of a pillowed ridge along the axis of the flow. The survey line (Line 1) prior to the dredge was mislocated due to an incorrectly plotted navigation point.

The dredge (station 1D) was lowered about 0.5 nm (nautical miles) west of the flow and hit bottom in the sediment adjacent to the flow. The dredge course was changed from northerly to northeasterly to correct for this mislocation. No true bites occurred, apparently because the dredge pulled through mud. Dredging was stopped at 0739z after the pinger trailed the ship so far that we lost the trace on the recorder. The dredge was almost empty, but three small fragments of Mn-encrusted sediment and lava(?) were recovered along with a nearly full minidredge of sandy mud. Comparison of GLORIA images from 3 successive legs (F4-, F5-, and F6-88-HW) showed that mapped locations of the flow field differed by as much as 2 nm, and when GPS came up again at 1210 we found that our location was off by about 1.5 nm; dredge 1D could have missed the target owing to various errors.

Meanwhile, we put the dredge backinto the water at 0921; station 2D was on the bottom in the same general area (near the northwest, upper end of the flow, where we dredged in a direction slightly south of east near the margin of the flow at its upper end) from 1033z to 1204z and back on deck at 1331z. This dredge came up with ~40 kg of rock, including one small-boulder-sized, several cobble-sized, and many pebble-sized fragments. The cloth bag that we used in the minidredge was torn out; thus we recovered no fine material. All of the lava fragments appeared to come from the same flow, which (contrary to our favored hypothesis) did not appear young, being coated by about 1.5 mm of palagonite and 1-2 mm of Mn-oxides. Most of the fragments formed surprisingly thin fingers only a few to several centimeters thick, and several of the cobble-sized pieces fit together end-to-end to comprise sinuous chains more than 30 cm long but less than 10 cm thick. Some of the pieces appeared to be clots of thin fingers resembling subaerial lava driblets. Contrary to our expectation of high viscosity, based on the apparently great thickness of the flow, the thinness and intricacy of these samples suggest unusually low viscosity. This dredge was close to a small cone with low acoustic backscatter located at the west end of the flow; the samples may be from this cone rather than from the high-backscatter flow.

As soon as the dredge was back on deck, we began running a bathymetric survey of the flow field, following a zigzag course toward its distal SE end. When this survey was complete we began to deploy the camera sled but, owing to several problems, had to reset the timers on the sled. We finally got the sled into the water after about a 2-hr delay. When the sled reached the seafloor, some overly conservative estimates of when to start the cameras had us waiting for nearly another hour until the cameras were activated. The new altimeter on the sled posed some unexpected difficulties, as we had to calculate the time delay and scale expansion. We ran the first 1.5 hours over mud to the southwest of the flow, then came over an area where the 3.5 kHz record showed about 7 m of transparent sediment, and finally traversed onto the young flow, which showed no sediment on the 3.5 kHz. We crossed the flow field for the remaining 2.5 hours of the camera tow. The station was run for 1/2 hour after the video shut off in order to photograph the flow front with the still camera. The videotape shows that most of this high- backscatter flow has continuous sediment cover, punctuated by small areas where lava forms protrude through the sediment. Where the lava protrudes, it appears to have 1-2 m of relief and consists of rounded, pillow-like forms that lack striations and are heaved open along cracks. Small tumuli are common, and at 01:40 Z we crossed a larger crack that may represent the marginal crack of a broad plateau.

We completed our work on the Oahu-Kauai flow with one final dredge to make sure that we had sampled the flow and not just an older cone that was located near the dredge track of station 2D. Dredge station 4D recovered about 10 kg of glassy basalt fragments that have about 0.5 mm palagonite and 2 mm of Mn-oxide on the rims. The fragments appear to be lobate flow fragments of dense sparsely olivine phyric basalt. The lithology and apparent age of the samples from dredges 2D and 4D are distinct, but neither is historic in age and neither appears to be sheet flows. The work in this target area was completed about 1200z Thursday.

Southern North Arch Flow Field

We used 9 hours of Thursday, Oct. 27, to complete a transit to the southern part of the North Arch flow field. We subsequently sampled three flows with distinct acoustic backscatter in this area. Station 5G, a gravity core, recovered 1.5 m of medium brown mud and must have penetrated to the flow surface, since the nose cone on the corer was damaged. We then proceeded to a dredge target on the western margin of the same flow. This short transit was complicated by a mismatch of the location of the GLORIA image and our navigation by nearly 2 nm. We began dredge station 6D shortly after 0030z and had the dredge on board at 0506z. The dredge was smeared with brown mud, but was otherwise empty. The minidredge contained about 10 gms of the same brown mud. The target was the flow front on one of the largest lobes of the southward flowing arch flows. The flow front at the dredge site was about 5 m high, but no bites occurred as the dredge moved over the flow front.

Examination of the seismic records from F4-88-HW GLORIA leg indicates considerably more topographic relief on the eastern edge of the flow, so we moved and attempted a second dredge (7D). Again there were no bites, and the tension on the wire indicated that the dredge was pulling through mud. On recovery, there were 30-40 small flat chips of Mn-encrusted basalt in the dredge and some medium brown mud and additional small basalt chips. We steamed to the north to another target south of an east-west trending ridge.

Gravity core 8G was attempted in a region of high acoustic backscatter and low topographic relief; the core bounced and fell over. There was no core but the barrel was smeared with brown mud to the top, and a fist sized blob of cohesive mud with one flat 5-cm-sized basalt fragment and several smaller chips was perched on the top of the weightstand.

We crossed the east-west ridge and began dredge station 9D in an area having higher acoustic backscatter than the area where gravity core 8G bounced. The dredge had a few small bites and recovered about 2 kg of small thin chips of basalt. These chips are quite distinctive in that they are flat and commonly only 2-4 mm thick. They appear to be spalled glassy margins of flat sheetflows and are similar to all the samples recovered up to this point from the north Arch flows on this cruise.

Gravity core 10G was attempted on an area of lower backscatter just north of the dredge 9D site. The recovered core is 1.7 m of brown mud; a single 2-cm basalt chip was caught in the core catcher, but the nose cone of the core was undamaged.

East-west Trending Ridge

Dredge 11D was attempted on a continuous ridge between the sites of dredge 9D and gravity core 8G. The ridge is probably a Cretaceous feature because it is parallel to the trend of the Molokai Fracture Zone. The dredge arrived on deck at about 1130z on Saturday, and it contained about 40-50 kg of consolidated mud and Mn-oxide-encrusted mud and basalt. Approximately 20% of the rock was broken from outcrop, with substrate lithologies consisting of volcaniclastic breccia, claystone, and siltstone. The remainder of the dredge consisted of Mn-oxide crust material detached from its substrate.

Most of the substrate rocks were partially phosphoritized. Several of the basalt clasts in the volcaniclastic breccia were covered with 10-30 mm of Mn-oxide prior to lithification. Two basalt clasts had glassy, palagonitized rinds which may provide an age of the formation of the ridge. Twenty-five percent of the claystone was porous because of worm borings. The thickness of the ferromanganese crusts ranged between 2mm and 45mm, with an average of 20mm. Many of the thicker crusts (30-42 mm) contained a mottled, Fe-oxide zone in the center, with a laminated to botryoidal zone at the top. The remainder of the crusts were massive to layered. All of the crusts had botryoidal surfaces.

Small Volcano with Summit Caldera

After the dredge came on deck, we transited NW toward a low, flat-topped dome or shield west of the young flow field, near the axis of the Hawaiian Arch at 24°2' N, 158°40'W. This dome is slightly elongate and contains a doublet crater or caldera about 1 km wide and 2 km long. We had planned to cross obliquely the NE flank of the dome, and then traverse southward across the caldera to confirm its location before dredging northward up its north wall. However, our navigated track was offset to the west of the dome as located on the mosaic, and although we crossed the crater during our initial approach from the SE we missed the crater during our southward traverse, crossing instead the flat area fringing the top west of the crater. In order to dredge the crater wall, we turned eastward and made a NNE dredge run (station 12D) about 2 km east of our southward traverse, up the NE wall of the crater. Our 3 traverses across this dome showed that the crater floor and top outside of the crater are both quite flat.

The dredge (station 12D) brought up 50 kg of Mn-oxide encrusted claystone, siltstone, and very altered basalt. The Mn-oxide crusts ranged in thickness from 0.3 mm to 20 mm, with an average of 10 mm. Ten to fifteen Mn nodules were also present in the dredge. The siltstone contained alternating light and dark layers of clay and silt. The claystone had cross-bedding and extensive worm-boring features . Many of the worm boreholes, which ranged from 2 mm to 12 mm in diameter, were lined with Mn-oxide. Most of the holes were parallel to the surface. Approximately 50% of the claystone samples contained clasts of phosphorite and basalt, some of which were coated by 4-6 mm of Mn oxide prior to deposition. The presence of these clasts produced a knobby, irregular surface expression in overlying Mn crust. The Mn crusts themselves contained small (2-5mm) clasts of basalt, phosphorite, and chert(?). Three sharks teeth were embedded in three separate Mn-oxide crusts, and may provide ages of these crusts by measuring their 87Sr/86Sr ratios. One very large specimen contained 2 generations of Mn-oxide crusts; the older is on an altered basalt substrate, overlain by laminated siltstone, that is, in turn, overlain by an outer, younger crust.

West-central North Arch Flow Field

We next transited about 10 nm eastward to the margin of another lobe along the western edge of the large young flow field, crossing en route an elliptical 3x5 nm hill having low backscatter and bordered on only its east side by a flat-floored moat. We crossed the flow margin going east, then turned and recrossed it going SW, then turned again and began dredging (station 13D) toward the NE onto the flow. Once again, however, a jump in the loran navigation caused us to misjudge our location, and we ended up with the dredge in a kipuka; we spent about 1.5 hr getting the dredge back onto the flow. When the dredge was recovered, it had about 1 kg of basalt with relatively thin rinds of palagonite and Mn-oxide. In addition to the usual flakes of surficial glass, this haul included one finely crystalline fragment from deeper within the lava flow; it had abundant microphenocrysts of olivine and pyroxene(?).

We then took a gravity core (station 14G) from a point about 4 nm away on the same flow lobe. We experienced no extra pull-out tension on the wire when beginning to recover the core, leading us to think that there was very little sediment at this site. But when the core barrel came on deck, it contained 115 cm of moderate yellow-brown mud. The mud was featureless except for some slight mottling and worm burrows, but on its top we found 2 chips of palagonitized basaltic glass. Furthermore, when the core was split, another chip was found inside the core about 20 cm from the top. How these chips arrived in the upper part of the core is a puzzle.

Nothwest North Arch Flow Field

Our next target was the very long, narrow flow extending almost due north, probably along a sediment-mantled graben of Cretaceous abyssal-hill topography NW of the large young flow field. Suspecting that this narrow flow begins farther south than is apparent on the GLORIA mosaic, we followed a zigzag course aimed at using the 3.5 kHz profiler to locate the flow along its suspected proximal segment. These crossings, however, showed that our suspicion was wrong; we found no sign of the lava flow where expected. The flow must originate very near the end shown on the GLORIA image. In order to learn more about the vent area, we drove in a clockwise loop over a small seamount, partially surrounded by young lava, near the end of the long flow. Although our loop was planned to cross all the way over the seamount and a fringe of lava along its eastern base, we actually turned above the summit of the seamount; this suggests that the GLORIA image is displaced about 1 nm east of its correct position. Our navigation at this time was under GPS, and should have been reliable. The crossings of the lava flow suggest that the flow surface is higher (by only 1-3 m) around the base of the seamount and that the eruptive vent is therefore on the seamount or along its base.

Dredge station 15D attempted to sample this narrow flow. There were only a few small bites and the dredge was smeared with mud on recovery. The dredge contained only one 6x16 cm basalt fragment and 8 smaller fragments. All the pieces were thin (2-7 mm thick) flat chips. The large piece is a thin blister with lava stalactites on the bottom. The lava is aphyric and has about 0.5 mm of palagonite and 1 mm of Mn-oxides on its surface. The minidredge recovered a small amount of brown mud.

We proceeded to survey this flow towards the north. At a point near 24°46'N, 158°24'W, the GLORIA images suggest that the narrow flow divides into two lobes; one continues to the north and the other floods a broad area to the east. Our survey shows that the flooded area to the east actually flowed towards the west and that the narrow flow continues past the end of the more easterly flow. A step down in the 3.5 kHz record from the western flow onto the eastern flow suggests that the western overlies the eastern. We moved up the eastern flow and conducted dredge station 16D in a hilly area that may mark a low lava shield and a vent for the flow. The dredge had numerous bites to 5.8 T and recovered 1/4 dredge bag of mudstone, basalt, sandstone, and Mn-oxides. The mudstone and sandstone pieces and blocks have a thin (1 mm) rind of Mn-oxides. The sandstone contains apparently fresh basaltic glass grains and may be genetically related to the eruption of the young flow. The basalt fragments are glassy aphyric sheetflow and near-vent spatter-like fragments. The GLORIA image shows no areas of low acoustic backscatter near the dredge site that might be kipukas surrounded by the flow. The bedded mudstone and siltstone may be related to the voluminous eruption of the young flows as distal parts of hyaloclastite deposits or they may be from a Cretaceous hill that is too small for the GLORIA system to resolve. Many of the rocks were embedded in a soft brown mud in the dredge bag.

Following a 28 nm transit to the east, dredge station 17D sampled another high acoustic backscatter flow. The dredge recovered about 5 kg of thin glassy aphyric basalt fragments with about 1 mm palagonite and <1 mm Mn oxides.

Another 24 nm transit to the south brought us to the area surveyed in detail by Normark and Shor (1968) and Spiess et al. (1969). Our dredge station 18D was located on the margin of the flow in the northern part of their survey area. This location is the site of the photograph in the Spiess et al. (1969) paper that shows abundant basalt fragments on the surface. We recovered about 3 kg of thin glassy aphyric basalt fragments and a few small pieces of Mn-oxide encrusted light brown mud. The basalt had moderate palagonite and Mn oxide on the glassy rinds.

We then moved about 6 nm to the southeast and did a gravity core, station 19G, in the area described by Spiess et al. (1969) as having 190 m of sediment cover. The core overpenetrated and at least 30 cm of mud was lost during recovery from the top of the core. The 3 m barrel was completely full. The loss of the top section of mud makes the utility of the core uncertain since the objective was to determine the amount of sediment that had accumulated since the Bruhnes-Matayama geomagnetic polarity boundary at 740 ka. This thickness of sediment could have been used to determine the rate of sediment accumulation in the area, and therefore the ages of some of the flows. Gravity core 20G was taken on the young bright flow south of the area described by Spiess et al. (1969); it recovered 95 cm of brown mud and two flat chips of basalt at the top and another at the bottom of the core.

East-Central North Arch Volcanic Field

Upon leaving the area of previous detailed studies, we transited southeastward to the suspected major vent area for the young flows on the axis of the Hawaiian Arch, the general area where dredging and Seabeam surveys had been done earlier in the year by Robert Detrick. We focused on the area around 23°50'N, 157°40'W, a short distance west of the surveyed Seabeam grid. We began the work with bathymetric profiles. Approaching initially from the northwest, we turned and ran the first profile 22 nm southward along 157°31'W. We crossed the axis of the Arch and encountered a step upward of about 120 m, with lava flows on the south side of the axis standing higher than the adjacent flows to the north. At 23°51'N, 157°31'W we crossed a broad swell that may be a small lava shield. We then zigzagged to the west, northeast, and west in order to investigate a few other small features that show up as subtle tonal variations in the GLORIA images. The first of these, a faint pattern of concentric circles 3 nm wide at 23°52'N, 157°39'W, turned out to be a low shield surmounted by a steep-sided knoll that almost certainly accumulated around a volcanic central vent. A patch of finely lineated or corrugated pattern about 3 km wide at 23°55', 157°35'W also may be a cluster of vents. A circular, crater-like depression at 23°57', 157°41'W, however, does not occupy a topographic high; instead it appears to represent a small kipuka of low-backscatter material, perhaps in the form of a very low hill.

Had the crater-form depression been the crater of a lava shield, we would have dredged it; but since our profile suggested that it was not a vent, we returned to the first pattern of concentric circles for dredging (station 21D). We had considered making a camera run across this vent area or at the step in the lava field along the axis of the Arch, but we abandoned this idea when the ship began to roll in a swell from the northeast, making it hazardous to deploy the camera sled. From this vent area we recovered a large haul that included a huge 100-kg block from the interior of a lava flow. After searching this block for glass, finding none, and removing about 20 kg for archiving, we threw the remainder overboard. We then transited 5 nm south and dredged a different low hill (station 22D, another vent area indicated by a small irregularity in the GLORIA image), where we again recovered a large sample, this one consisting of delicately knobby pillow lava. The rocks at both of these dredge stations were plagioclase-bearing and coated with Mn oxide. Frequent large bites during dredging (as heavy as 6.9 Tons), thick Mn coatings, and lack of mud in the micro-dredge indicated that the protruding vent areas at 21D and 22D had each accumulated little sediment cover, probably because bottom currents had swept them clean. Consequently we decided to attempt a camera run across the site of 22D later if the swell subsided. Meanwhile, we went on to dredge at two other sites.

Station 23D was executed at another hill about 5 nm ESE of 22D. This area is characterized by numerous small hills. The dredge recovered highly-vesicular plagioclase-phyric pillow-basalt fragments. Many of the samples contain 30-40% round vesicles. The pillows have thin glass rinds and discontinuous palagonite and Mn oxides. Much of the vesicular glass has spalled off the samples. Camera station 25C returned to this vent area to determine the physical characteristics of these near vent vesicular lavas, rather than to the 22D site.

Station 24D sampled another vent structure located 8 nm further to the southeast. The dredge recovered abundant pillow fragments of moderately vesicular pillow basalt. The lava contains about 5% plagioclase phenocrysts, and rare small clots of clinopyroxene and plagioclase. The pillow fragments have glassy rinds and discontinuous palagonite and Mn oxides.

These small vents appear to consist of alkalic or transitional basalts that are moderately fractionated and have vesiculated to varying degrees. Several important questions arise, including: have the dense lavas degassed at some point in their history? Where are these apparently large volumes of magma stored so that they can fractionate? Are these identifiable vents the sources for the extensive sheet flows that make up most of the lava field, or are they some late phase small volume magmas that are differentiated from the voluminous sheet flows? Most of these vent lavas contain plagioclase that may be large enough and abundant enough to separate for K-Ar dating. This may provide the ultimate method to calibrate the formation rate of the palagonite and thereby date the other sampled flows.

Camera station 25C returned to the site of dredge 22D and was intended to determine the morphology of the near-vent vesicular flows. The camera system malfunctioned (the flood lights did not turn on, the video camera did not turn on, and the still camera did not advance any film), and no stills or video were obtained. Moreover, at the completion of this station the signal was lost from the 12 kHz altimeter because of a bad transistor in the Mufax recorder; no 10 kHz bathymetry was collected for the next 12 hours until the recorder was repaired.

Dredge station 26D was located about 15 nm SW of station 25C. Here again the dredge target was a 2-nm wide cluster of inconspicuous mounds forming a "pebbly" pattern on the GLORIA images, a pattern which we now recognize as characterizing some vents for the young lava flows. Here again we dredged up vesicular aphyric lava; a new wrinkle was the occurrence of a crudely bedded hyaloclastite deposit about 3 cm thick on top of the lava flow. This deposit must have been produced by vigorous effervescence of gases during the eruption, a surprising occurrence for such a great depth (4300 m).

We then transited about 20 nm NNE in order to dredge station 27D, a patch of peculiar, subtly corrugated seafloor that we had passed over 2 days earlier. When making our preparatory survey over this locality, the 10 kHz depth sounder was still not operating because of the malfunction in the Mufax recorder, and as we came over the target the 3.5 kHz signal faded away. We therefore had no bathymetric information to guide the dredge and had to feel our way slowly onto the seafloor using the cable tensiometer. Despite these problems the station was successful; the dredge had several substantial bites, and once again it brought up a heavy load of rocks, this time including large parts of several massive pillows. In addition, there were a few more pieces of hyaloclastite including one piece of breccia that apparently accumulated atop the mud on an old, probably Cretaceous, hill adjacent to the younger target vent.

Flow field north of East-west Ridge

We crossed the east-west Cretaceous ridge and surveyed around a small vent-like hill identified on the GLORIA imagery. Due in part to a navigational shift between the GLORIA image and our survey and to a complete crash of the onboard navigational system during the survey, we failed to locate the inferred vent. We changed from the planned dredge to a gravity core station (28G), which recovered 120 cm of brown mud. No rock chips were present, although the nose cone on the core barrel was severely damaged by the impact of the corer onto a hard surface, presumably consisting of lava, beneath the mud.

We then ran a survey line to the east and began a detailed survey of the final dredge target on the main part of the North Arch lava field. Here again, we failed to find a vent at the site of a small irregularity indicated on the GLORIA images. We continued with the planned deployment of the dredge, however (station 29D). Despite a lack of bites--which were replaced by a "chattering" behavior of the dredge, as if it were bouncing over a flat rocky surface lacking sediment cover--we succeeded in recovering a few pebble-sized pieces of Mn-oxides that we hope contain cores of basalt. To obtain a better determination of sediment cover , we then tried a gravity core (station 30G) at the same site. Except for a little trouble handling the coring assembly in the choppy seas, wind, and lightning, the operation went well and we recovered a core 270 cm long. The barrel did not overflow, but there was no evidence that the core penetrated all of the way to lava; the nose cone had no new dents, and the core catcher contained no basalt. The catcher did contain several pieces of partially indurated silty-sandy mud; the core may have bottomed in a layer of volcanic ash instead of a basaltic lava flow. We may have cored from a small kipuka instead of the lava flow.

Having finished our sampling attempts on the north side of the central ridge of the large lava field, we then ran a short survey to determine ground slopes and probable flow directions for the flow lobes scattered around the east end of the ridge. We wanted to know if the the lava had been vented from the ridge (or its base) or from low vent areas separated from the ridge. We began by transiting south across the east end of the ridge; we found that the lava-flow surface north of the ridge sloped slightly southward toward the ridge, indicating a separate vent area to the north unless the flow has been tilted since its eruption. The GLORIA images show that this lobe narrows greatly toward its southern end, so we were not surprised when we crossed from it onto older seafloor a short distance before reaching the base of the ridge. This seafloor was initially level and the 3.5 kHz profiler recorded subbottom reflectors below it, but these reflectors faded as the seafloor descended slightly into the shallow moat of low sedimentation surrounding the ridge.

We crossed from the south flank of the ridge directly onto a lava flow surface sloping slightly northward. This slope toward the ridge suggests that here too the lava was not erupted from this part of the ridge or its base. The acoustic profiles indicate that a shallow moat, less than 5 m deep, also occurs on this side of the ridge. This moat could represent a marginal band of uninflated lava around an inflated lava field; the 3.5 kHz recorder shows, however, that its surface reflects less strongly than the rest of the flow, suggesting that the moat may lack a thin skin of sediment. Instead of being an uninflated lava surface, the moat could be entirely a product of reduced sedimentation and the lava flow nearly bare of sediment.

In order to completely determine the slope of the lava surface, we turned and transited northeast to obtain the slope component in that direction. Although we passed over the edge of the flow after only a short distance, it appeared that the flow surface sloped slightly northeastward. We then turned and transited eastward through 30-knot winds toward the site of station 31G, crossing sediment mantled abyssal-hill faults visible on the 3.5 kHz profile that had not been seen on the GLORIA images.

<u>Older Flow Field East of the Giant Flow Field</u>

Windspeed had dropped to 10-20 kt by the time we reached the site of station 31G, and we went ahead with the coring operation. The core was deployed over a flat area of the flow field and recovered in heavy seas and rain. The core had overpenetrated and we recovered a full 10 ft barrel plus about 50 cm that were inside the weight stand.

The next station was a dredge that attempted to sample the lava of this flow field in a central region having moderate relief. The survey line showed no detectable sediment on the 3.5 kHz record, but the dredge recovered no rock and had only a few small bites. The rolling of the ship in the continuing heavy seas made it difficult to identify bites with the dredge. A single 4-cm piece of mudstone encrusted with Mn-oxides was recovered in dredge 32D. The minidredge, having been newly fitted with a custom liner fabricated from the leg of a pair of jeans, was 3/4 full of brown mud and a few small fragments of Mn-oxides.

In order to evaluate whether the sediment cover is uniform in thickness above a flow unit, we deployed a second gravity core on this same flow. Station 33G recovered only 20 cm of indurated sandy-silty mud. This material may be the distal part of the Nuuanu landslide. The cored site is either a site of non-deposition or erosion postdating the deposition of the landslide debris. The recovery does not confirm that this flow is covered by >10 ft of mud, but suggests that the sediment cover on these flows is highly variable due to sediment reworking and redeposition.

<u>South-Central Giant Flow Field</u>

As the weather continued to deteriorate, we steamed back towards the main flow field to the west to complete the cruise. We abandoned our plans to core on the other flows to the east of the big flow because we could not deploy a corer longer than 10 ft. Likewise, the inability to deploy long cores made it unlikely that we would penetrate to the sediment horizon representing the Nuuanu landslide; thus we abandoned that part of the workplan as well. In the east-central part of the North Arch flow field we had identified a feature in the GLORIA imagery that we had interpreted as a lava shield and the possible source of the extensive flows that pour southward into the Hawaiian Deep. We surveyed this feature and discovered that it was not a shield, but rather a deep hole within the flowfield. We deployed dredge 34D to sample the inflated flow margins bounding this deep hole. The dredge had few noticable bites but recovered about 3 kg of flat aphyric basalt sheetflow fragments 3-10 mm thick and a few small, highly altered pillow basalt fragments. The altered pillow fragments are probably from a small Cretaceous hill in the kipuka. The denim minidredge was 2/3 full of brown mud.

We continued to the west to a rough patch on the GLORIA images that has high acoustic backscatter and appears to be a vent. After a brief survey which showed the hill to rise about 400 m above the surrounding lava plain, we deployed dredge 35D to sample this apparent vent. The hill is surrounded by a shallow moat. The dredge recovered about 20 kg of glassy flat basalt chips with thin Mn-oxide and palagonite rims, altered Mn-oxide encrusted pillow fragments and pillow breccia, and mudstone. The pillow fragments and mudstone are probably from the hill and the flat glassy basalt fragments from the surrounding young sheetflows. Apparently, neither this nor the previous site sampled vents of the young volcanic field. The glassy lava is sparsely plagioclase phyric and coated by about 0.5 mm palagonite and 1 mm Mn-oxides.

We then continued to the northwest to another bright rough patch on the GLORIA imagery that we infer to be the source vent for the flow sampled at station 8G. The survey of this area was complicated by the complete crash of the shipboard navigation system due to lightning associated with local thunderstorms. We finally located ourselves after having determined that the inferred vent was in a deep part of the flow and was therefore not a vent for the main flow. We deployed dredge 36D to sample the eastern part of this flow and to compare to the composition of the basalt chips recovered in gravity core 8G. The dredge recovered about 0.5 kg of thin Mn-encrusted basalt chips, several pieces of pumice, and a 2.5

cm shark's tooth. The flow sampled does not appear to have thinner Mn-oxides or palagonite than the other sampled flows; it is unclear if the western part of the flow, where gravity core 8G recovered no sediment, is a separate younger flow or if the sediment cover is highly variable. If the compositions of basalt from 8G and 36D are the same, we can conclude that the sediment cover on this flow must be highly variable.

The southeast North Arch flow field

We finished the cruise with a series of three gravity cores on and adjacent to the southeast lobe of the North Arch lava field. The first core (37G) was on the highest backscatter portion of the flow; it recovered 215 cm of brown mud and a single 2-cm chip of basalt part-way up the core. The second core (38G) was located just east of the flow in thick sediment; it was a full barrel that overpenetrated. Total recovery was 348 cm with a silty layer at the base. The final station was on the flows, but in a slightly lower backscatter area. Station 39G recovered 210 cm of brown mud. The similarity in sediment thickness recovered at stations 37G and 39G suggests that some of the subtle distinctions in backscatter on the flows are due to some factor other than sediment thickness. This unknown factor could be a surface texture on the flows, or sediment with distinct physical properties on the two flow lobes.

Summary of Results

A first order conclusion is that the flow field consists of many flows with varying mineralogy, and presumably composition, that are young. All the sampled flows have 0.5 to perhaps 1.5 mm of palagonite and 0.5-1.5 mm of Mn oxides; these thicknesses imply ages on the order of perhaps 0.5-1 Ma. Some of the flows with lower acoustic backscatter (thicker sediment cover) may be older, but probably the entire flow field is Pleistocene to perhaps Late Pliocene in age.

The sediment cover on flows with high acoustic backscatter ranges from no recovery, which could indicate as much as 30 cm (the core catcher and cutter are designed to recover sediment only thicker than 20 cm and any sediment layer thinner than perhaps 10 cm would wash out of the barrel) to a maximum of 2.35 m recovery (again including 20 cm for the catcher and nose-cone). The results are summarized in Table 2. Several flows with distinctly lower acoustic backscatter were also cored; recovery ranges from >50 to >370 cm. Since we did not core any of the lowest backscatter flows we can only infer that the sediment thickness overlying these flows is considerably more than 3.7 m and that the GLORIA system penetrates through this sediment and thereby images the underlying sediment.

The flows are dominantly inflated sheetflows and the samples recovered from them are commonly thin (2-5 mm thick) dense slabs of basaltic glass with palagonite rims and Mn-oxide encrustations. These flat lava fragments represent the outer glassy rinds of sheetflows that have spalled off the flow top. Many of the flow samples are aphyric, others are sparsely olivine phyric, and a few are sparsely plagioclase phyric. None of the observed crystals are larger than about 0.5 mm and none of the lavas appear to have accumulated phenocrysts of any kind. The presence of plagioclase in some of the sheetflows indicates that the lavas are moderately differentiated. The sheetflow fragments are dense; only very rare round vesicles were observed.

The sampled vent lavas from the central part of the flow field are distinct from the sheetflow fragments in that they are pillow fragments, are commonly highly vesicular, and contain more abundant crystals, primarily of plagioclase. Several of the dredges on vents also recovered glassy hyaloclastite to volcanic breccia. Fragmental rocks produced at depths as great as 4200 m were previously unknown. Similarly, vesiculation of lavas at such great pressure requires that the magmas were extremely gas-rich.

Most, if not all, of these lavas are fractionated which implies that the magmas collected in a magma storage zone at some depth and cooled and partially crystallized prior to eruption. The presence of plagioclase indicates that this magma storage zone is at depths less than about 20 km. The base of the ocean crust seems a likely place for these magmas to accumulate and fractionate. The lavas on the islands that are thought to be chemically similar to these lavas, the alkalic rejuvenated stage lavas, are generally near-primary melts that commonly contain mantle xenoliths. The distinction in degree of fractionation between the arch lavas and the rejuvenated stage lavas is an unresolved problem. Likewise, the relationship between the gas-rich vent lavas and the dense undegassed sheetflow lavas is unresolved. One possibility is that the vent lavas represent lavas derived from the voluminous sheetflow lavas by fractionation which enriched the magmas in gases to the point that the vent lavas were supersaturated and vesiculated as they migrated to the surface. If this is the case, we expect the vent lavas to be systematically more fractionated than the sheetflow lavas.

The Nuuanu giant landslide apparently occurred after the eruption of the older flows on the north Arch. Several cores bottomed in a silty-sandy indurated mud layer that may represent the distal fines of the landslide deposit. It is possible that the entire flow field was erupted during a relatively short time period that was punctuated by the Nuuanu landslide. If this is the case, then the older flows have much thicker sediment cover, but may not really be much older than the less-sedimented flows that postdate the landslide.

The small flow between Oahu and Kauai is at the location of a reported submarine eruption in 1956. The samples and photographs of this flow demonstrate that it is a young flow, but on the order of tens to hundreds of thousands of years rather than historic. The flow is probably related to rejuvenated stage of volcanic activity on Kauai and Oahu that spans the time interval from 3.65 Ma to perhaps tens of thousands of years ago. The recovered lava is dense, sparsely olivine-phyric sheet or lobate flow fragments.

During the cruise we sampled a volcanic ridge, a small cratered seamount, and several small hills within the flow field that are probably Cretaceous in age. We recovered Mn-encrusted pillow basalt and pillow breccia, and Mn-encrusted mudstone. None of the Mn-oxide crusts are thicker than about 1 cm. These features have a distinctive scalloped pattern on the GLORIA images that appears to be diagnostic of older seamounts. One of these dredges recovered fresh basalt glass rinds that should provide a rough age of the ridge using fission-track dating, and may provide an important datum for regional isotopic studies.

Table 1. Station Summary F11-88-HW

Sta.	Loc.	Depth, m	N. Lat.	W. Long.	Type	Description
1D	Young flow near Oahu	S 3838 E 3813	21°36.6' 21°37.7'	159°04.0' 159°03.8'	Dredge 30 gms	3 Mn-encrusted pebbles, sock full of sandy mud
2D	Young flow near Oahu	S 3803 E 3805	21°38.1' 21°38.1'	159°02.5' 159°01.7'	Dredge 40 kg	tubular aphyric basalt with 1+mm palagonite and 1-2 mm Mn-oxides
3C	Young flow near Oahu	S 4077 E 4125	21°34.1' 21°36.5'	159°00.8' 158°57.5'	Camera	much of the flow is sediment covered, pillow basalt is exposed in 15% of images
4D	Young flow near Oahu	S 4000 E 3963	21°39.9' 21°38.0'	158°59.3' 158°59.1'	Dredge 3 kg	lobate or sheet? flow frags of sparsely olivine-phyric basalt. Palagonite 0.5 mm, Mn 2mm. Sock 2/3 full of brown mud
5G	Southwestern N. Arch flows	4781	22°48.1'	158°17.6'	Gravity core	1.5 m of medium brown mud nose cone damaged by underlying basalt flow
6D	Southwestern N. Arch flows	S 4759 E 4746	22°52.6' 22°53.4	158°20.4' 158°19.7'	Dredge empty	no bites, no rocks, 15 gms of mud in minidredge
7D	Southwestern N. Arch flows	S 4750 E 4718	22°52.7' 22°54.5'	158°20.3' 158°18.4'	Dredge 0.3 kg	no bites but recovered small chips of Mn-coated basalt glass, 100 gms of brown mud in the minidredge
8G	West-central N. Arch flows	4615	23°29.2'	158°24.6'	Gravity core	core empty, nose cone badly damaged, 75 gms of mud and several small basalt fragments (15 gms)stuck to top of weightstand
9D	West-central N Arch flows	S 4631 E 4615	23°37.3' 23°38.3'	158°27.0' 158°25.6'	Dredge 1 kg	only a few small bites but recovered numerous thin glassy chips of basalt and 1/4 of minidredge of mud
10G	West-central N Arch flows	4636	23°41.4'	158°27.3'	Gravity core	1.7 m of brown mud, one 2 cm chip of basalt in the core catcher, no damage to nose cone

Table 1. (continued)

11D	East-west ridge	S 4518 E 4008	23°32.2' 23°33.5'	158°21.7' 158°21.6'	Dredge 40 kg	many bites to 6.0 T, mud and Mn-encrusted (to 4.5 cm) mudstone and basalt breccia with glassy pillow rinds
12D	crater wall small seamount	S 4205 E 4158	24°02.0' 24°02.3'	158°41.5' 158°42.5'	Dredge 50 kg	many bites to 6.3 T, bedded mudstone and siltstone with Mn-crusts to 2.0 cm thick, rare small basalt pebbles in breccia
13D	West-central N Arch flows	S 4620 E 4625	24°04.2' 24°05.9'	158°31.8' 158°30.3'	Dredge 1 kg	about 25 2-5 mm thick basalt fragments with glassy rims and 0.5 mm palagonite and about 1 mm Mn-oxide
14G	West-central N Arch flows	4615	24°06.2'	158°28.2'	Gravity core	no pull-out, but recovered 115 cm of 10Y/R 4/2 mud; 2 chips of palagonitized glass from top of core, and another 20 cm from top
15D	Narrow north-west N Arch flow	S 4660 E 4670	24°34.4' 24°36.2'	158°23.7' 158°24.0'	Dredge 0.25 kg	dredge smeared with mud, 8 small and 1 6x16 cm piece of 4-5 mm thick basalt. The large piece is a blister. 50 g mud in minidredge
16D	Northwest N Arch flows	S 4700 E 4705	24°49.6' 24°50.8	158°11.8' 158°10.5'	Dredge 125 kg	1/4 bag mudstone, basalt, sandstone, and massive Mn-oxides. Basalt is sheet flow and near-vent spatter-like fragments. Palagonite is 1+ mm on some pieces.
17D	Northwest N Arch flows	S 4705 E 4515	24°49.2' 24°50.9'	157°41.4' 157°40.6'	Dredge 3 kg	many small to 15 cm pieces of glassy thin basalt sheet-flow fragments. Palagonite about 1 mm, Mn-oxides thin
18D	North-central N Arch flows	S 4555 E 4540	24°27.1' 24°28.4'	157°42.1' 157°42.9'	Dredge 3 kg	many small to medium sized flat fragments of aphyric basalt with moderate Mn and palagonite
19G	North-central N Arch flows	4450	24°21.4'	157°38.6'	Gravity core	a full 10 ft barrel, roughly the top 30 cm of the core lost due to overpenetration

Table 1. (continued)

20G	North-central N Arch flows	4445	24°12.4'	157°38.5'	Gravity core	a 95 cm long core of brown homogeneous mud with 2 small chips of basalt at the top and one at the bottom
21D	Vent in central N Arch flows	S 4372 E 4329	23°49.6' 23°52.4'	157°39.2' 157°39.7'	Dredge 120 kg	one huge massive basalt block with sparse plagioclase, one glassy pillow, and many small flat sheetflow fragments
22D	Vent in central N Arch flows	S 4340 E 4330	23°43.7' 23°44.1'	157°38.7' 157°39.0'	Dredge 100 kg	many sparsely plagioclase phyric pillows with delicate ornamentation, 0.5 mm palagonite and 1 mm Mn-oxides
23D	Vent in central N Arch flows	S 4300 E 4291	23°42.8' 23°45.3'	157°34.9' 157°33.7'	Dredge 350 kg	many large pillow fragments of highly vesicular pillow basalt. Basalt is olivine and plagioclase phyric and has glassy rims with palagonite and Mn-oxides.
24D	Vent in central N Arch flows	S 4360 E 4305	23°38.6' 23°40.9'	157°27.3' 157°27.3'	Dredge 175 kg	many large pillow fragments of vesicular basalt. Basalt is plagioclase phyric and has glassy rims with palagonite but little Mn-oxides.
25C	Vent in central N Arch flows	S 4309 E 4322	23°42.6' 23°45.4'	157°35.0' 157°33.1'	Camera	same site as dredge 23D. No stills or video, because still camera , floods , and video camera did not turn on.
26D	Vent in central N Arch flows	S 4335 E 4270	23°34.1' 23°36.1'	157°42.4' 157°42.1'	Dredge 150 kg	fragments of vesicular, aphyric pillow and sheet lava under ~3 cm of bedded hyaloclastite
27D	Vent in central N Arch flows	S 4187 E 3900	23°53.9' 23°54.6'	157°34.9' 157°34.9'	Dredge 150 kg	Many large fragments of striated, recurved pillows. A few pieces of hyaloclastite; one accumulated atop mud on Cretaceous hill.
28G	Vent in central N Arch flows	4380	23°02.6'	157°21.3'	Gravity core	120 cm of homogeneous brown mud, nose cone badly damaged

Table 1. (continued)

29D	Vent in east-central N Arch	S 4375 E 4370	24°05.5' 24°05.7'	157°02.9' 157°02.6'	Dredge ~30 g	11 lapilli-sized flat pieces of Mn oxide, hopefully with cores of basalt
30G	East-central N Arch flows	4375	24°04.9'	157°04.7	Gravity core	270 cm of brown mud, homogeneous except for a gritty ash(?) at the bottom; no new dents in nose cone
31G	Smaller flow field E of big flow field	4295	23°50.5'	156°40.9'	Gravity core	350 cm of brown mud, no damage to the nose cone, core overpenetrated
32D	Smaller flow field E of big flow field	S 4230 E 4245	23°48.4' 23°49.5'	156°35.0' 156°33.2	Dredge 20 g	1 angular Mn-encrusted mudstone, minidredge 3/4 full of brown mud
33G	Smaller flow field E of big flow field	4290	23°42.1'	156°40.7'	Gravity core	30 cm of mud, nose cone packed with consolidated gritty mud
34D	South-central N Arch flows	S 4450 E 4440	23°21.6' 23°23.0'	157°45.8' 157°45.0'	Dredge 3 kg	many small flat chips of Mn-encrusted basalt, a few small altered old pillow fragments, minidredge 2/3 full of brown mud
35D	South-central N Arch flows	S 4465 E 4465	23°21.7' 23°23.5'	157°50.2' 157°49.6'	Dredge 20 kg	many flat chips of young glassy basalt, old altered Mn-encrusted pillow fragments, mudstone
36D	South-west N Arch flows	S 4512 E 4280	23°31.2' 23°33.6'	158°03.5' 158°03.5'	Dredge 0.5 kg	small flat aphyric glassy basalt fragments, some mud in minidredge
37G	Southeast lobe of N Arch flows	4505	22°51.8'	157°25.3'	Gravity core	215 cm of brown mud, firm at the bottom, one 2 cm flat chip of basalt at 50 cm depth
38G	Off the southeast lobe of N Arch flows	4505	22°51.7'	157°24.0'	Gravity core	348 cm of brown mud, core overpenetrated, silty layer near the bottom
39G	Southeast lobe of N Arch flows	4545	22°47.7'	157°26.1'	Gravity core	210 cm of brown mud, firm at the bottom, soupy at top

Table 2. Sediment Thickness on Flows

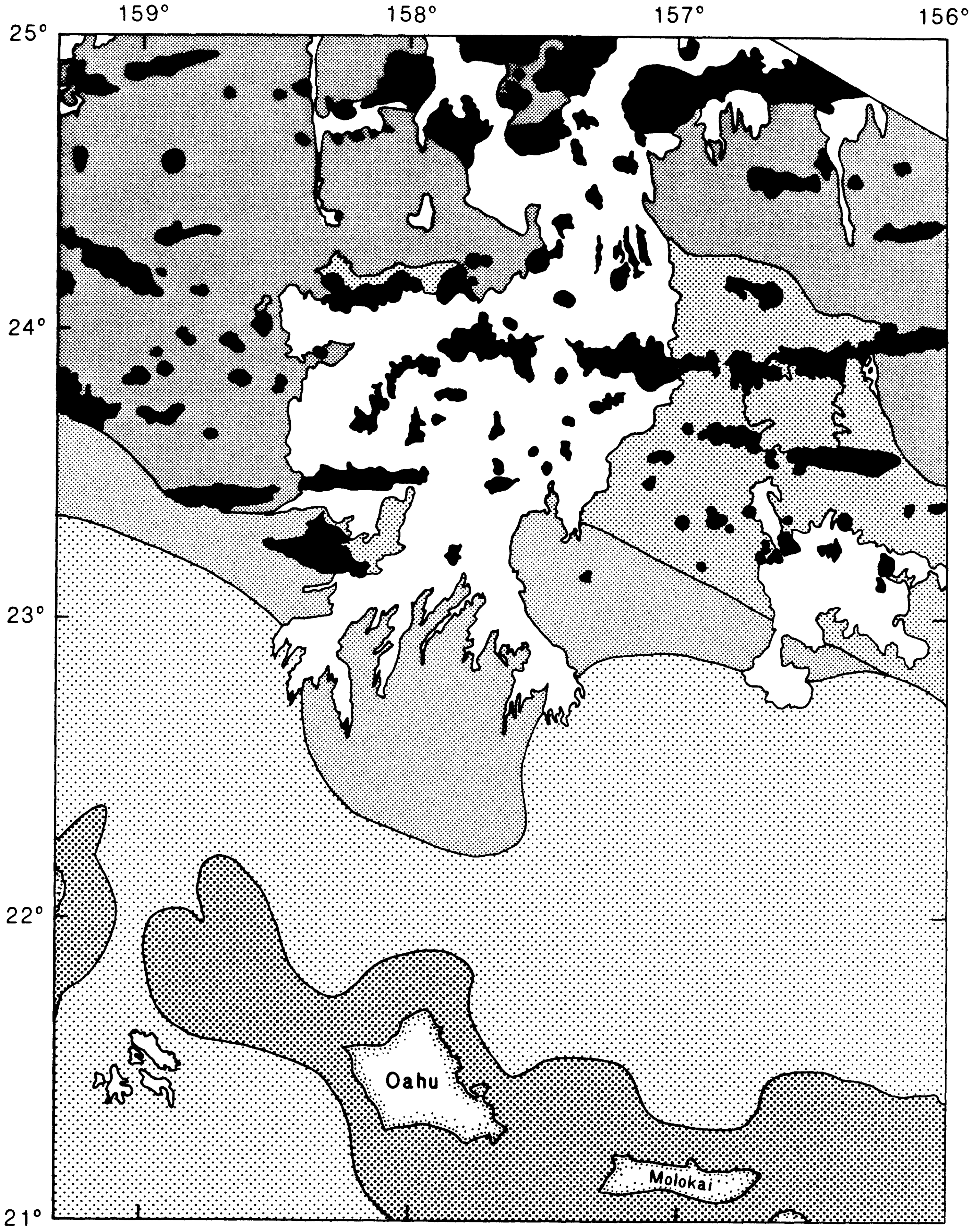
Station	Recovery	Nose Cone +Catcher	Total Sediment Thickness	Location
5G	150 cm	20 cm	170 cm	high backscatter flow
8G	none	20 cm	<30 cm	high backscatter flow
10G	170 cm	20 cm	190 cm	high backscatter flow
14G	≥115 cm	20 cm	≥135 cm	high backscatter flow
20G	95 cm	20 cm	115 cm	high backscatter flow
28G	120 cm	20 cm	140 cm	high backscatter flow
30G	≥270 cm	20 cm	≥290 cm	moderate backscatter kipuka (?) in high backscatter flow
31G	≥350 cm	20 cm	≥370 cm	low-moderate backscatter flow
33G	≥30 cm	20 cm	≥50 cm	low-moderate backscatter flow
37G	≥215 cm	20 cm	≥235 cm	high backscatter flow
39G	≥210 cm	20 cm	≥230 cm	high backscatter flow

> indicates no nose cone damage and no rock chips at the bottom of core, and that sediment could be thicker than recovered
< indicates the catcher + nose cone + arbitrary 10 cm washout

Figure 1. Location map showing the North Arch lava field and the regional geology of the GLORIA surveys conducted north of Oahu on legs F4-88-HW and F6-88-HW.

EXPLANATION

- Submarine flanks of the island
- Landslide deposits
- Clastic sediment cover
- Older lava field
- Younger lava flows
- Cretaceous seafloor with horst and graben fabric
- Cretaceous volcanic ridges and cones


159°
158°
157°
156°
25°
24°
23°
22°
21°
Oahu
Molokai

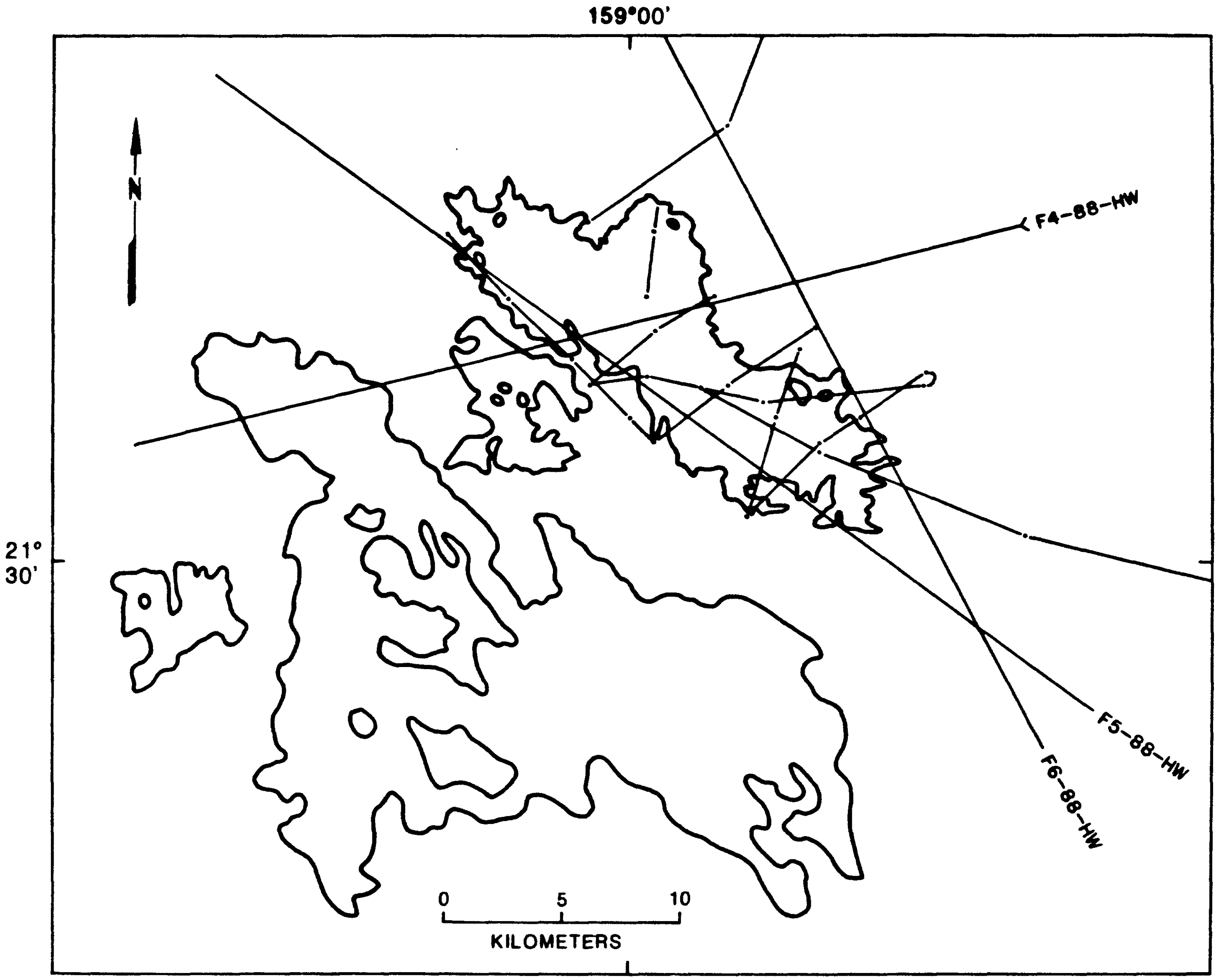


Figure 2. Map of the young flows between Oahu and Kauai. The northernmost of the flows has extremely bright backscatter and is inferred to be the youngest of these flows. The survey lines on this flow are shown.

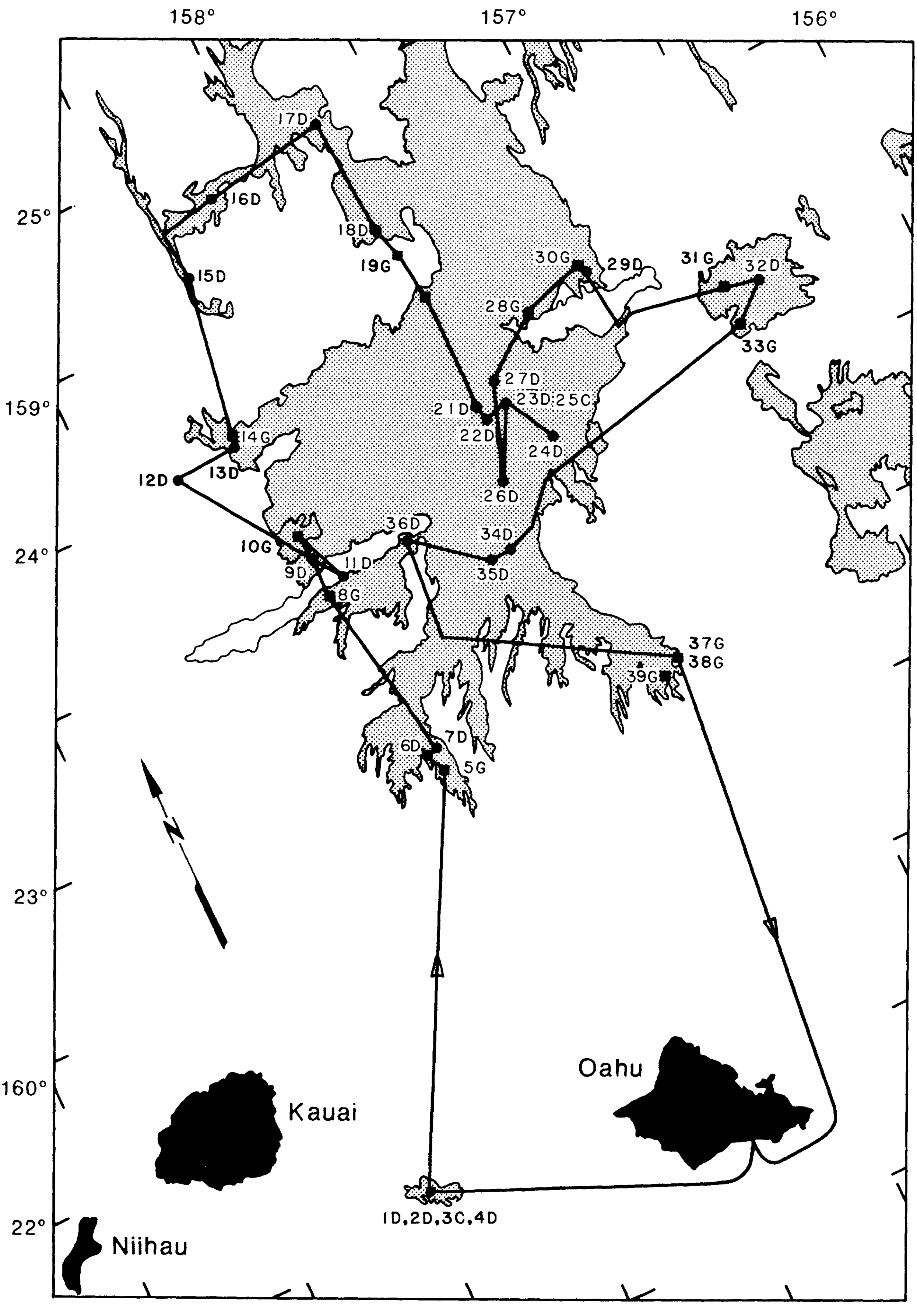


Figure 3. Simplified map showing the north Arch lava flow field and the approximate shiptracks and station locations for the F11-88-HW cruise. The stations are described in more detail in Table 1. D=dredge, G=gravity core, C=camera.

Appendix 1: Camera Station 3C, JD 300.

Altitudes taken from pinger trace on 10 kHz record.

Time	Altitude	Notes
21:18	21.5	
21:24	19.5	
21:30	2.8	
21:33:44		The seafloor is coming into view; it has a cobbly-textured surface.
21:34:30		The sled hits bottom, and the screen goes dark.
21:36:00	2.5	
21:36:28		No rocks are in view, only mud with worm tracks.
21:37:00		The seafloor is out of view, probably because the camera is too low.
21:39:55		Close-up views of mud.
21:41:00		The seafloor is still in view but is entirely mud, and clots are falling from the sled.
21:42:00	7	The camera is at a good height and the circle of illumination nearly fills the field of view.
21:42		Holothurians.
21:45:00		The camera is flying a little too high
21:46:45		Possible small rocks are seen from a good height; then we have nice close-ups.
21:47:30		The screen is dark; the camera is too low.
21:48:00	1.5	
21:49:50		We are getting occasional glimpses of mud.
21:51:12		Straight fecal track.
21:51:35		The screen is dark; the camera is too low.
21:51:55+		Close-up views of softened circular imprints.
21:52:00	11	
21:52:30		The sled hits the seafloor, and clouds of sediment roil up.
21:52:49		Circular imprint.
21:53:37		Crooked fecal track.
21:54:00	1.5	
21:54:18		Nice views of mud, with fecal tracks, etc.
21:54:49		From a good height, the camera records scattered bottom dwellers and one swimmer.
21:55:59		Fish?
21:58		The camera is flying at a nice height, a few meters above the seafloor.
21:59		The camera is still high, and clots of mud are falling from it.
22:00:00	3	
22:02		The camera is still flying high, with a good view of the circle of illumination.
22:04:08		Peculiar pair of small white anchor-shaped objects on the mud.
22:06:00	10	
22:10		Flying high, good view of circle of illumination.
22:12:00	7.5	
22:13:30		The camera is a little too high now.
22:14:00		The camera is at a very nice height.
22:17:00		The camera is a little too high.
22:18:00	11	The camera is still a little too high.
22:20:00		The camera is at a good height.

22:22:00		The camera is a little too high; the mud on the seafloor is featureless.
22:24:00	9	The camera is still a little too high.
22:26:00		The camera is a little high, but not bad; sediment clots are still falling from the sled.
22:27:05		The camera is at a good height; a white fish is motionless above the sediment.
22:29:12		A big cloud of sediment falls from the sled, followed by more ~30 sec later.
22:30:00	8	The camera is high, but the view is pretty good; now the camera is descending slightly.
22:30:30		The camera has a good view now, fairly close-up.
22:30:56+		Holothurian, fecal tracks, etc.
22:32:20		Nice fecal tracks.
22:33:30		Nice close-up view of faint hummocks.
22:34:00		Nice view of bottom, with holothurian, etc; then the camera rises higher.
22:36:00	10	Nice view of fecal tracks, etc.
22:36:55		White object, shaped like a femur.
22:39:00		The camera is a bit high.
22:42:00	8	The camera is still a bit high but has a good view of the illuminated circle. We pass a fish, and clots of mud fall from the sled.
22:45		The camera is a little too high.
22:48:00	8.5	The camera is too high, and the seafloor is seen only vaguely.
22:50:15+		Nice close-up views of fecal tracks, etc.
22:51		The camera is too high again.
22:54:00	10	The camera is still too high; clots of mud are falling from it.
23:04:00+	14	Nice views of tracks etc. in the sediment.
23:06:00	5	
23:12:00	5.5	
23:18:00	7	
23:24:00	5	Nice views of fecal tracks, etc.
23:25:40		Nice holothurian.
23:27:00		Much detail in the mud can be seen from this height.
Outcrops		
23:28:06		Recurved pillow-like forms have have come into view, to the right.
23:28:08		Start of duplicate tape #2.
23:28:25		A heaved or knobby pillow.
23:28:55		Many pillows now, with 1-2 m of relief, protruding from 15-20 cm of sediment.
23:29:36		End of duplicate tape #1.
23:29:30		Sediment pond behind wall of rocks. Are we above the lava flow now?
23:30:00	6	Featureless sediment, then more rocks 10 seconds later. Heaved pillows?
23:35:40		Some pillows or fragments, then featureless sediment.
Sediment-covered stretch		
23:36:00	8?	Still featureless sediment.
23:42:00	5	Still featureless sediment.
23:45:12		Small white object on sediment.
23:45:56		Holothurian.
23:47:00		Still featureless sediment with rocks, but many tracks and imprints.
23:48:00	6	Still sediment, featureless in fairly high views.
23:54:00	6	Still sediment.
23:56:40		The view goes dark; the camera is too low.
23:58:12		Occasional crashing noises, but not often or loud.
Scattered outcrops		

23:59:00		Glimpses of rock having ~1 m of relief, then more darkness and crashing noises.
23:59:39		More rock, pillows having 1-2 m of relief; then rock with 40-60% sediment ponds perhaps 10-20 cm thick.
00:00:00	6	The view is dark again; the camera is too low, but no crashing noises are heard.
00:01:13		Knobby pillow clusters in view.
00:01:30		Knobby pillow clusters go out of view.
00:01:50		The view goes dark, and brief crashing noises are heard for the next few minutes.
00:04:10		Brief view of rocks scattered among 80% sediment ponds; the rocks are rounded pillow-like forms, but no striations are resolved.
00:04:50		Another brief view of pillows and sediment; then the view goes dark.
00:05:30		The camera is flying very low over rubble(?) in sediment.
00:06:00	3	The camera is now flying over cracked pillows, having 1+ m of relief, in sediment.
00:06:40		Only occasional cracked pillows are seen now; mostly sediment.
00:07:19		It looks like these highs are tumuli or mounds of pillows that protrude from the sediment; they must rise >1-2 m above the general surface of the flow.
00:08		Nice fecal tracks; we still see some scattered pillows or fragments.
Outcrops	**rare**	
00:10:00		Fairly high view of scattered pillows in sediment.
00:10:45		Close-up views of many fecal tracks in a tortuous spaghetti-like pattern.
00:14:00		Still just sediment; views are fairly high, and no more fecal tracks are seen.
00:12:00	~6	
00:16:00		Still just sediment.
Outcrops	**common**	
00:16:37		We cross onto a peculiar smoothly curviplanar lava surface; it still looks like heaved tumuli, but perhaps not pillows.
00:17:50		Still this same heaved-looking surface.
00:18:00	8?	
Outcrops	**rare**	
00:18:12		Now we seem to cross back onto sediment; the view is pretty high.
00:19:30		Fecal tracks are common occasional close views, but mostly flying high; no rocks.
Outcrops		
00:21:00		More scattered rounded, pillow-like flow forms are in view.
00:21:50		Mostly lava now, with ~30% sediment ponds that appear to be 10-15 cm thick.
Sediment		
00:22:40		Now the camera is flying high over sediment again.
00:24:00		Just sediment seen in fairly high views.
00:25:35		Coming in close onto spaghetti of old fecal tracks.
00:27:05		Appear to be a few cobble-sized fragments lying around loose on the sediment.
00:27:50		Just sediment again.
00:28:20		Dark view, too low.
00:29:36		Brief glimpses of rounded flow forms and sounds of crashing.
00:30:00	3	Still low over rounded, heaved forms with no striations resolved.
00:31:00		Back over sediment again.
00:33:00		A few scattered rocks; thin it gets dark again as the camera flies too low.

00:34:40		Glimpses of rounded flow forms again, with ~1 m of relief, then dark and crashing.
00:35:00	3	
00:35:45		More glimpses of outcrops--mounds of rounded forms having some heaving or cracking but no striations.
00:36:30		Back over sediment again.
00:37:34		Fecal spaghetti again, and no rocks; the camera is flying low, and the screen is often dark.
00:38:36		Glimpse of rounded cobbles in sediment
00:39:16+		Glimpses of pillowed(?) mounds protruding.
00:40:00		Sediment ponds 30% among mounds.
00:40:30		Mostly sediment again.
00:41:00		Just sediment
00:41:24		Fairly high; one cobble, then just sediment.
00:42:00	7	Just sediment in slightly high views.
00:43:36		Isolated mounds of smooth but heaved flow forms protrude from ~90% sediment ponds.
00:43:50		Ditto.
00:44:40		Fecal tracks common again; no rocks.
00:46:00	7	
00:46:01		Small cobble in expanse of sediment.
00:48:00		Just sediment still; flying fairly high.
00:49:00		Waves drop the camera low enough to resolve fecal tracks.
00:51:00		Still just sediment.
00:52:49		Odd white objects occur in irregular depressions.
00:55:01		Rocks again, the same cracked forms having ~2 m of relief, with 30% sediment ponds.
00:56:44		One small mound of heaved, rounded lava forms.
00:57:55		More cracked flow forms again, some resembling striated pillows, among 30-50% sediment ponds.
00:58:45		Back onto sediment again.
01:00:00		Still just sediment.
01:01:07		A round hump in the sediment may be flow form veneered by sediment.
01:03:00		Still just sediment; low swings reveal fecal tracks.
01:04:00	~7	
01:05:00		Sediment; a holothurian is recorded.
01:12:00		Still just sediment; the camera is flying pretty high now, but sometimes it gets low enough to resolve tracks, etc.
00:14:26		Rocks appear again.
01:14:35	approx	Good view of a cracked, heaved mound.
01:15:00		The camera is back over sediment again.
01:15:57		A small squid?
01:16:17		More heaved, rounded lobes that lack striations.
01:16:46		Nice view of a heaved mound, with small white fish or squid nearby.
01:17:14		Starfish, the first recorded in this lowering; then the camera goes back over sediment.
01:18:00	3	
01:19:00		Still sediment.
01:20:33		Tumulus, with odd white "web", only visible ~5-10 seconds, then sediment again. Is there a photograph of this?
01:22:00		Still just sediment; holothurian at 15 sec.
01:26:00	5	Still just sediment; this is a good height for the camera.
01:27:26		Clump of heaved rocks with a "balloon" (white organism with a long stem) rising from it; then sediment again.

01:29:00		Just sediment; the view is a bit too high.
01:31:41		It is possible that dark rocks are scattered in the sediment, but the camera is too high to say for sure.
01:33:00		Just sediment; the camera is still a bit too high.
01:33:51		End of duplicate tape #2.
01:34		Still just sediment.
01:38:32		One cracked rock, with a rattail fish nearby, seen from a good height of about 6 m.
01:39:00	6	
01:40:01		A steeply heaved rock comes into view; it is cut by a shallow fissure ~1 m wide and 1-2 m deep. It might be the margin of a pressure plateau, though it could be just a local tumulus. Hope for a photograph of this.
01:41:00		Back in just sediment.
01:42:28		Fresh-looking fecal tracks, nearly straight.
01:45:00		Still just sediment; fairly high view.
01:45:50		Descending for a close look at fecal tracks.
01:47:30		Still just sediment, and
01:49:00		It is possible that some tilted plates of rock barely protrude from the sediment.
01:50:50		The camera is too low; the view is mostly dark.
01:53:00		Still just sediment, flying a litle too high most of the time.
01:57:00		Still just sediment
01:58:00		Too high
02:00:00		Too high; strobes still flashing.
02:01:19		Just sediment, with fecal tracks.
02:03:00		Too high
02:05:20+		The bottom comes into view again, briefly; it is still just sediment.
02:05:30 approx.		End of duplicate tape #3.