OCEAN DRILLING PROGRAM LEG 169
PRELIMINARY REPORT
SEDIMENTED RIDGES II

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SCIENTIFIC REPORT

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ABSTRACT

Leg 169 had the ambitious goal of drilling into two active seafloor hydrothermal systems to understand mass and energy transfer between the ocean and the oceanic crust. Of particular emphasis was investigation of the genesis and evolution of Fe-Cu-Zn deposits formed at sediment-covered spreading centers in Middle Valley on the Northern Juan de Fuca Ridge, and at Escanaba Trough on the Southern Gorda Ridge.

The Bent Hill Massive Sulfide (BHMS) in the Middle Valley comprises three major mineralized parts: (1) a 100-m-thick conical mound of massive sulfide formed at the seafloor and then partly buried by sediment; (2) an underlying 100-m-thick feeder zone which consists of subvertical crosscutting veins filled with Cu-Fe sulfide and pyrrhotite, and where the intensity of veining decreases with depth and the style of mineralization changes to predominantly subhorizontal impregnation and replacement of sediment; and (3) the surprising discovery at the base of the feeder zone of a 4-m-thick, strongly silicified horizon underlain by a 13-m-thick zone of intense alteration and replacement of the host sandstones by Cu-Fe sulfides and chlorite (Deep Copper Zone). This zone of high grade (up to 16% Cu) stratiform copper mineralization may represent an aquifer of hydrothermal fluid flowing laterally into a permeable sedimentary horizon. This aquifer is capped and isolated by an impermeable silicification front. Pore fluid derived from below this horizon is distinct from that sampled above and, has the low chlorinity signal typical of the only vent known in the area prior to Leg 169. Hole 1038F penetrated this horizon and was vigorously venting hydrothermal fluid after drilling ceased.

The metal zonation observed in ancient massive sulfide deposits is also present in the BHMS. Continued hydrothermal circulation through the massive sulfide after its initial deposition converted much of the primary pyrrhotite to pyrite ± magnetite and has remobilized metals like zinc which were reprecipitated at the top and on the sides of the mound at lower temperatures. Much of the copper transported in the hydrothermal fluid was deposited below the seafloor in the stockwork zone and in the Deep Copper Zone.

A second mound, the Ore Drilling Program massive sulfide (ODPMS) mound, occurs 350 m south of the BHMS. A single hole was drilled near the top of the mound, 50 m south of the only known natural active vent. The results were nothing less than spectacular. Hole 1035H penetrated three stacked zones of massive and semi-massive sulfide mineralization along with their feeder zones. Metal grades are much higher than those encountered at BHMS with some samples exceeding 40% Zn and 15% Cu. Most explorationists in the mining industry will never have the experience of drilling a hole that intersects as much high-grade ore as at Hole 1035H. However, the true value of this deposit is in the complex record of deposition, recrystallization, and remobilization of metal recorded through the multiple hydrothermal stages that remained focused beneath this mound throughout its history. We were not able to test the continuity of mineralization between the ODPMS and BHMS mounds, but a zone of high-grade stratiform copper mineralization was intersected at approximately the same stratigraphic horizon as the zone under BHMS. Hole 1035H is also now the third known hydrothermal vent in the Bent Hill area.

Although creating new vents in the Bent Hill area was not part of the pre-cruise plans, conducting active hydrological experiments in the Dead Dog vent field, which occurs 4 km to the northwest, was a high-priority objective of Leg 169. We successfully removed the existing CORK from Hole 858G, recovering the first CORK-hosted hydrothermal chimney deposits in the process, and sampled 272˚C hydrothermal fluids from the borehole. The borehole was then reinstrumented with a new temperature string and pressure transducer and a new CORK was installed. The damaged CORK in Hole 857D was recovered and replaced with an 898-m-long thermistor string and a new CORK in a technologically difficult operation that was efficiently executed by the Ocean Drilling Program (ODP) engineering group and the Sedco staff. Rapid downflow of cold bottom water into this hole was confirmed. This may lead to a pressure pulse that is potentially detectable in Hole 858G, 1.6 km to the north, and may lead to induced seismicity, which was being monitored by an array of Ocean Bottom Seismometers deployed prior to drilling. A transect of short holes across the Dead Dog active hydrothermal mound demonstrated that the mound is young and was formed by build-up and collapse of anhydrite chimneys, rather than by subsurface deposition and internal inflation.

A high priority objective was to establish the differences between the mature hydrothermal system developed at Bent Hill and the young hydrothermal system in Escanaba Trough. These systems differ in more than their state of evolution. Metals in the Middle Valley sulfide deposits seem to be dominantly derived from basaltic rocks, whereas in Escanaba Trough, the composition of the deposits shows extensive contribution of metals from the sediment. Massive sulfide recovered from Central Hill suggests that the thickness of massive sulfide differs little from the amount exposed above the seafloor (5-15 m). The absence of a well-developed veined feeder zone indicates pervasive diffuse venting of hot fluid over a short period of time rather, than long-lived, focused high temperature discharge, as it was the case at Bent Hill.

A hydrothermal component in the pore fluid from Escanaba Trough indicates that hydrothermal fluid flow was relatively recent. Both low and high-salinity fluids are present indicating phase separation, followed by segregation of most of the low-salinity fluids into an unconsolidated sand unit in the interval from 70 to120 mbsf. Concentration of alkalies and other elements indicates that the hydrothermal fluids have interacted extensively with sediment, even though most of the recovered sediment is not extensively altered. Organic matter maturation confirms that the sediments have seen at least a brief pulse of high temperature.

The sedimentary fill of the Escanaba Trough records some of the highest sedimentation rates observed in the deep sea. The sparsity of biostratigraphic control, however, makes it difficult to quantify the rates of deposition. A change of provenance from older sediment derived predominantly from the Klamath Mountains to more recent sediment derived predominantly from the Columbia River drainage was indicated by spot coring on Deep Sea Drilling Project (DSDP) Leg 5. Leg 169 obtained a nearly continuous record of the 500 m of sediment fill at the reference hole at Site 1037 which was drilled into basaltic basement.

Most of the sediment is derived from turbidity currents that enter the southern end of Escanaba Trough and flow northward along the ridge axis. The unique “box canyon” setting of Escanaba Trough traps even the thickest turbidite flows leading to both high sedimentation rates and unusually thick deposits of muddy turbidites. An acoustically transparent layer that is traceable in seismic records throughout Escanaba Trough was determined to be a 45-m-thick depositional package containing abundant well sorted fine- to medium-grained sand with little admixed clay and silt. We hope that radiocarbon dating of pristine looking wood fragments in this unit will supplement sparse paleontological data.

SCIENTIFIC RESULTS

Introduction

Leg 169 was the second leg of a planned two-leg program to investigate the geological, geophysical, geochemical, and biological processes at sediment-covered spreading centers in the northeast Pacific Ocean (Fig.1). Building on the highly successful Leg 139 drilling (Davis, Mottl, Fisher, et al., 1992) our primary goal was to investigate the genesis of massive sulfide deposits by drilling two deposits at different stages of maturity; Middle Valley at the northern end of the Juan de Fuca Ridge and Escanaba Trough at the southern end of the Gorda Ridge. The four primary topics investigated on this leg were 1) the mechanism of formation of massive sulfide deposits at sediment-covered ridges, 2) the tectonics of sedimented rifts and controls on fluid flow, 3) the sedimentation history and diagenesis at sedimented rifts, and 4) the extent and importance of microbial activity in these environments. A series of holes was to be drilled across deposits at each of these sites to determine the sedimentary record of hydrothermal products adjacent to the deposits and to constrain the timing and duration of hydrothermal activity. Alteration and stockwork zones beneath the deposits were to be sampled to constrain the sources of metals and geochemical reactions that control mineralization and the parameters that controlled the fluid flow.

Middle Valley: Geology of the hydrothermal field

Middle Valley, a medium-rate spreading center (58 mm/yr), forms one leg of a Ridge-Transform-Transform unstable triple junction with the Sovanco Fracture Zone and the Nootka fault (Davis and Villinger, 1992). The proximity of Middle Valley to the cold Explorer Plate results in a reduced magma supply and a slow-spreading ridge morphology with a deep and wide axial trough. Current magmatic activity is mostly confined to the adjacent West Valley spreading center indicative of a recent jump in the location of the plate boundary. Proximity of the Middle Valley spreading center to an abundant supply of terrigenous sediment during the Pleistocene sea level lowstand has resulted in burial of the spreading center by 200 to >1000 m of turbiditic and hemipelagic sediment, with sediment thickness increasing to the north. Two areas separated by about 4 km were drilled during Leg 169, the Dead Dog vent field in the area of active venting (Site 858) and the Bent Hill area (Site 856) (Fig. 2).

Bent Hill

Bent Hill is one of a string of small mounds that runs parallel to the eastern rift bounding normal fault scarp. These features lie close to an inferred normal fault that appears to offset basement reflectors, but near-surface sediment layering imaged in seismic reflection profiles appears to be continuous across this fault. Bent Hill is a roughly circular feature 400 m in diameter that has been recently uplifted approximately 50 m (Fig. 3). It is bounded on the west by a steep scarp that parallels the rift-bounding faults and exposes semiconsolidated turbiditic sediment. Bright, reverse polarity seismic reflections that are limited in extent to the area under Bent Hill are interpreted to be generated at the interface between the base of basaltic sills and the underlying sediments (Rohr and Schmidt, 1994). The 35-m high Bent Hill massive sulfide (BHMS) mound is located 100 m south of Bent Hill. A twin peaked massive sulfide mound with a single active vent at its north end is located approximately 330 m farther south. These mounds are aligned parallel to the N-S scarp that constitutes the western side of Bent Hill. The BHMS mound is extensively weathered to iron oxyhydroxides and partially buried by sediment. During Leg 139, Hole 856H penetrated 94 m of massive sulfide before the hole had to be abandoned due to inflow of heavy sulfide sand from the upper weathered section of the borehole wall. A strong magnetic anomaly across this mound is related to the occurrence of magnetite and has been modeled to suggest that mineralization continues at least another 30 m below the level drilled and possibly much deeper (Tivey, 1994).

The morphology, degree of oxidation, and the lack of sediment cover on the mounds south of the BHMS deposit indicate that these deposits are younger than the Bent Hill deposit. A single 264˚C hydrothermal vent is present on the northern mound. Contoured heat flow values for the Bent Hill area show high values centered around this active vent (Davis and Villinger, 1992). The composition of the vent fluid is similar to those from the Dead Dog vent field, but this vent has lower salinity and only half as much dissolved Ca (Butterfield et al., 1994).

Dead Dog Vent Field

The principal center of hydrothermal activity in Middle Valley is the Dead Dog vent field. Contoured heat flow values show a concentric high which is coincident with a side scan acoustic anomaly (Fig. 4) that outlines the 800-m-long and 400-m-wide vent field. Sediment thickness over the fault block in the area surrounding the vent field is approximately 450 m and overlies a sill-sediment complex that forms the transition to oceanic crust (Davis, Mottl, Fisher, et al., 1992). However, hard acoustic reflectors that occur only immediately beneath the vent field were confirmed by drilling on Leg 139 to be the top of a volcanic edifice at only 250 m depth. The presence of more permeable volcanic basement penetrating up into the sediment cover acts as a conduit that focuses flow of hydrothermal fluid to the seafloor (Davis and Fisher, 1994). The vent field contains at least 20 active vents with exhalative fluid temperatures ranging up to 276˚C (Ames et al., 1993). Active vents occur predominantly on top of 5 to 15-m-high sediment-covered mounds a few tens of meters in diameter. Available data from piston cores and ODP Hole 858B suggested that subsurface deposition of anhydrite, Mg-rich smectite, and sulfide minerals contribute to the growth of the mounds. Because the high temperature hydrothermal fluid is strongly depleted in both Mg and SO_4, the abundance of these minerals in the subsurface requires that cold seawater (with abundant Mg and SO_4) is drawn into the subsurface by the vigorous upflow at the active vent sites.

A major step towards the establishment of seafloor observatories was taken on Leg 139 by instrumentation of two sealed boreholes in the Middle Valley hydrothermal field using the CORK system. One of the objectives of Leg 169 was opening these instrumented boreholes in order to allow sampling of hydrothermal fluids. Reinstrumentation of these holes was planned to allow active experimentation on induced seismicity in a seafloor hydrothermal system and hole-to-hole hydrologic experimentation designed to constrain the physical and hydrologic properties that control hydrothermal flow on the scale of an entire vent field.

Escanaba Trough: Geology of the hydrothermal field

The Gorda Ridge spreading center is located offshore of Oregon and northern California and is bounded by the Mendocino Fracture Zone on the south and the Blanco Fracture Zone on the north (Fig. 1). A small offset in the spreading axis at 41˚40’N latitude marks the northern boundary of Escanaba Trough, which forms the southernmost part of Gorda Ridge. Escanaba Trough is opening at a total rate of approximately 24 mm/yr and has a morphology consistent with its slow-spreading rate. The axial valley, which is at a depth of 3300 m, increases in width from about 5 km at the north end to more than 15 km near the intersection with the Mendocino Fracture Zone.

Escanaba Trough Reference Site

South of 41˚17’N latitude, the axial valley of Escanaba Trough is filled with several hundred meters (Fig. 5) of turbiditic sediment. The sedimentary cover thickens southward and is a kilometer or more in thickness near the Mendocino Fracture Zone. Turbiditic sediment enters the trough at the southern end and is channeled northward by the axial valley walls

(Vallier et al., 1973; Normark et al., 1994). Sedimentation was relatively rapid (up to 5 m/1000 yr) during sea level lowstands in the Pleistocene, and the entire sediment fill of the trough probably was deposited within the last 100,000 years (Normark et al., 1994; Davis and Becker, 1994). A reference hole through this sedimentary package and into basaltic basement was planned to provide background information to evaluate the sedimentary and thermal history in an area away from the hydrothermal upflow zone.

Central Hill Area

Seismic reflection surveys show that the floor of Escanaba Trough is generally a smooth, flat plain underlain by continuous and relatively undisturbed turbidites. However, local areas along the axis of spreading have irregular seafloor topography characterized by circular hills 0.5 to 1.2 km in diameter that are uplifted 50 to 120 m above the surrounding seafloor. The areas of sediment disruption are sites of recent axial rift igneous activity. The geologic and geophysical evidence suggests that axial rift igneous activity at these sites is manifested by the intrusion of dikes, sills, and laccoliths into the sediment with less abundant volcanic flows (Morton and Fox, 1994; Zierenberg et al., 1994, 1993). Sulfide mineralization has been sampled by dredging, sediment coring, or submersible at four igneous centers within the sediment-covered part of Escanaba Trough. The dominant morphologic feature in the area of operations for Leg 169 was Central Hill (Fig. 6).

The western, sediment-covered part of Central Hill contains the most extensive sulfide deposits observed in Escanaba Trough. The massive sulfide deposits on the west and southeast flanks of Central Hill are actively venting hydrothermal fluid, and the area on the northern flank shows indications of very recent hydrothermal activity, suggesting that these deposits are all part of the same hydrothermal system. The best explored and most hydrothermally active area of sulfide mineralization on Central Hill extends west and north from the northern end of the sediment-covered hill top. On the northern flank of the hill, massive sulfide extends more than 270 m from north to south and more than 100 m from east to west, but the western edge of the deposit has not been defined with certainty. Within this area there is nearly continuous outcrop of massive sulfide. All of the active hydrothermal vents occur in an area with abundant sulfide mounds along the northwestern flank of the hill. The major element composition of the end-member hydrothermal fluid of two actively discharging vents 275 m apart is identical (Campbell et al., 1994), a result that is consistent with the hypothesis that this large mineralized area is a single hydrothermal system hydrologically interconnected at depth.

Sulfide samples collected at the surface of the deposit are dominantly pyrrhotite with variable amounts of isocubanite and chalcopyrite and minor sphalerite, galena, lollingite, arsenopyrite, and boulangerite. Sulfate occurs as barite crusts and chimneys on massive sulfide and intergrown barite-anhydrite in active vents. When compared to Middle Valley, the abundance of barite and enrichment of metals such as lead, arsenic, antimony, and bismuth indicate extensive contribution from sediment source rocks (Koski et al., 1994). Precious metals are significantly enriched relative to Middle Valley massive sulfide. Sediment alteration associated with formation of massive sulfides is dominated by talc, Mg-rich chlorite, or Mg-rich smectite (Zierenberg et al. 1994).

RESULTS

Middle Valley

Bent Hill Area

Hole 856H had been drilled on Leg 139 to a depth of 93.8 m before abandonment due to unstable hole conditions. Our plan was to attempt to deepen this hole through the massive sulfide deposit sampled on Leg 139 and into the underlying alteration zone. We surmised that circulation of oxygenated seawater into the borehole during the last five years may have altered the pyrrhotite/pyrite massive sulfide assemblage to iron oxide/oxyhydroxide, effectively stabilizing the borehole wall. After reentry with a rotary coring bottom hole assembly (our only option as this hole was initiated with the same configuration) we successfully recovered 47 cores to a depth of 500 mbsf with recovery just over 12%. We note, however, that we experienced significantly higher recovery rates (34% in 9 cores) when the core barrel was retrieved prior to full penetration of a joint of drill pipe. Coring operations ended on August 28, when the scientific objectives had been achieved, and time allocated for this operation had expired.

Logging operations began with a temperature run to evaluate which tools would be operable in what was expected to be a particularly hostile (high temperature) environment. A ledge prevented the Bureau de Recherche Geologique et Miniere in Orleans (BRGM) temperature tool from logging to the bottom of the hole, so hole cleaning operations were initiated. Although we had dropped the first bit on the seafloor to allow future deepening of Hole 856H, the hole cleaning operation ended with dropping a bit in the bottom of the hole to avoid pulling the drill string out of an unstable hole. Two logging runs, first with the Triple Combo (natural gamma ray, sonic velocity, neutron porosity, resistivity), followed by the Formation Microscanner string were successfully completed. Internal temperature monitors on these tools, however, indicated it would be imprudent to continue logging operations with the more temperature sensitive geochemical tool, so logging operations were terminated. During one of the pipe trips made for cleaning Hole 856H, the ship was moved in DP mode to the Dead Dog hydrothermal mound to launch two Pop-Up Pore Pressure Instruments (PUPPIs). PUPPIs are pressure sensing probes, which were deployed by dropping them over the side of the *JOIDES Resolution*. The design of these instruments is such that they are programmable memory tools with a probe that penetrates 3 m into the seafloor sediment. The devices recorded differential pore pressure between two ports on the probes which were embedded in the seafloor. When time for operations at the Dead Dog area was complete, a coded acoustic signal severed the data loggers from the probes, and the data loggers floated to the sea surface for recovery. Installation and recovery of the PUPPIs was an operation similar to deployment and recovery of site transponder beacons, where after release on dGPS coordinates, the PUPPIs were tracked until emplaced, and recovered by hook from the *Resolution* prior to leaving the Dead Dog area. This release operation was undertaken during a pipe trip to maximize efficient use of ship time.

Lithostratigraphy

The lithostratigraphic characterization of the BHMS, initiated during Leg 139 and continued during Leg 169, is one of the most remarkable achievements of the Ocean Drilling Program. Eight holes were drilled in the vicinity of the BHMS to assess the thickness and lateral extent of the massive sulfide and to determine the nature of the hydrothermal feeder zone in the sediments and basalt underlying the deposit. BHMS is the result of a complex interaction between hemipelagic and turbiditic sedimentation, igneous activity, and hydrothermal circulation. The deposit includes iron- and zinc-rich massive and semi-massive sulfides, a well developed feeder zone characterized by crosscutting copper-rich veins and sulfide impregnation of sediment, and a deep stratiform zone of rich copper mineralization that may be developed into an important conduit for lateral fluid flow. Hydrothermal alteration provides a record of past and present fluid flow and is controlled by small variations in lithology and large-scale variations in sedimentary facies. A second massive sulfide mound was drilled 350 m south of the BHMS. The ODPMS mound is significantly enriched in Zn relative to the BHMS. It is not clear if it is correlative with BHMS or a product of a spatially and temporally separate hydrothermal system. However, it appears that both mounds are underlain at present by identical hydrothermal fluids.

The major lithologic units recognized in the Bent Hill area are summarized below and are shown on vertical sections constrained by the drilling. Eight lithostratigraphic units have been recognized as follows:

- Unit I: hemipelagic sediment (Holocene and upper Pleistocene)
- Unit II: Interbedded turbidites and hemipelagic sediments (Pleistocene)
- Unit III: Clastic sulfides
- Unit IV: Clastic sulfate-chimney debris
- Unit V: Massive and semi-massive sulfides

• Unit VI: Sulfide feeder zone and mineralized sediments

• Unit VII: Basaltic sills

• Unit VIII: Basaltic flows

Hole 856H

Hole 856H can be considered as a reference section where the major lithologies were drilled (Fig. 7). From top to bottom they include successively: massive sulfide (0-103.6 mbsf), a sulfide feeder zone (103.6-210.6 mbsf), interbedded turbidite and pelagic sediments (210.6-431.7 mbsf), a 39.4 m interval of basaltic sills and sediment, and 28.9 m of basaltic flows.

Most of the massive sulfides were drilled during Leg 139. During Leg 169, pyrrhotite- and pyrite-rich massive sulfides were drilled from the lower part of the mound between 98.8 and 103.6 mbsf (Unit V).

The underlying feeder zone is divided into three subunits. The uppermost unit is sulfide-veined siltstone and mudstone (Unit VIa, 103.6-152.9 mbsf) where the major sulfides are isocubanite, chalcopyrite, and pyrrhotite occurring in vertical veins. Below this interval (152.9 to 201 mbsf-Unit VIb), sediments have only minor disseminated and vein controlled sulfide. From 210.6 to 249.0 mbsf (Unit VIc) is a sulfide- banded sandstone, highly enriched in copper relative to the overlying mineralization, which was informally called the Deep Copper Zone (DCZ). The contact between the DCZ and the underlying sediment is extremely sharp. The next unit (Unit II, 210.6-431.7 mbsf) is non-mineralized to slightly mineralized turbidites. Based on hydrothermal alteration and color, three intervals have been defined. Subunit IIa is relatively unaltered sediment occurring in the upper (210.6-249.0 mbsf) and the lower part (3245.5-431.7 mbsf) of the unit and consists of gray fine sandstone. Between these two intervals is a greenish gray siltstone and mudstone (Unit IIb, 249.0-345.5 mbsf) with abundant chlorite. The next unit (Unit VII, 431.7-471.3 mbsf) is the basaltic sill complex where igneous rocks are variably altered and crosscut by veins containing quartz, chalcopyrite, pyrrhotite, sphalerite, calcite, and epidote. These sills are intercalated with indurated sediment. The underlying basaltic flows (Unit VIII, 471.1-500 mbsf) are similar in mineralogy and alteration to the sill unit.

Holes 1035A and 1035G

Holes 1035A and 1035G were drilled to 170.8 and 208.5 mbsf at 75 m and 65 m west of the top of the sulfide mound. Two types of mineralization were recovered. A sequence of surficial bedded clastic sulfide and sulfide sand interbedded with turbidites was intersected between 0 and 1.40 m. These sulfides consist of pyrrhotite, pyrite, sphalerite, and Cu-sulfides. A deeper massive sulfide zone was drilled between 55 and 61 mbsf in Hole 1035A and between 44.4 and 73.6 mbsf in Hole 1035G. In both holes the massive sulfide consists of recrystallized vuggy pyrite. Minor carbonates, anhydrite, and barite partially infill the vugs. Chalcopyrite and sphalerite are less than 5% by volume. The massive sulfides are underlain by hemipelagic silty claystone interbedded with fine sand turbidite and silty clay. Soft sediment deformation is pervasive in these sediments. Sulfides (<1%) consisting of sphalerite, pyrrhotite, and chalcopyrite occur as disseminated grains, pore filling, and rare subvertical veins. The alteration is moderate and authigenic anhydrite and pyrite are common as veins, nodules, and disseminated crystals. Compared to the central part of the mound this lateral extension is depleted in high temperature minerals such as chalcopyrite, isocubanite, pyrrhotite, and sphalerite. Highly silicified sediment that prevented penetration with the XCB was encountered at approximately 170 mbsf. Between 169.80 and 180 mbsf semi-massive pyrite and copper/iron sulfide with very minor pyrrhotite occur as impregnations in hydrothermally altered siltstone. Altered siltstone and sandstone with disseminated pyrite and pyrrhotite were recovered from the deepest part of the section (179.5-208.5 mbsf). These sediments are altered to clay, chlorite, epidote, and quartz, and sulfides (up to 5%) occur as subvertical veins and bedding parallel impregnation.

Hole 1035D

Hole 1035D was drilled to 173.9 mbsf at 75 m east of the mound. As for the western part of the mound, the surface mineralization consists of clastic sulfides occurring in several intervals between 0 and 12.3 mbsf. The entire 35.6 m of the turbidite sediment sequence is similar to that of Hole 1035A. Deeper in the hole, massive sulfide, sulfide-veined claystone, and semi-massive sulfide was sampled between 40.7 and 77.4 mbsf. Vuggy massive pyrite containing veins, patches, and disseminations of chalcopyrite, sphalerite, magnetite, and anhydrite, is the dominant sulfide type in the upper part of the core (40.6-67.8 mbsf). The lower part of the section consists of massive pyrrhotite intercalated with altered mudstone, cut and impregnated by pyrrhotite and pyrite. The massive sulfides from this hole are enriched in sphalerite relative to most of the sulfide recovered from Hole 856H. Under the massive sulfide is a feeder zone consisting of massive to semi-massive pyrrhotite-pyrite-magnetite with minor anhydrite and sulfide-impregnated mudstone (66.50 to 77.40 mbsf). Between 115.80 and 135 mbsf the sulfides are less abundant. Between 135.00 and 168.50 mbsf a section of siltstone with disseminated pyrite and pyrrhotite is pervasively altered to chlorite and clay. The lowermost core consists of highly fractured and intensely silicified silty claystone with disseminated sulfides that was too hard to penetrate with the XCB.

Holes 1035B and 1035C

Hole 1035B is located 51 m to the south of Hole 856H, just off the southern edge of the BHMS mound. The mud line piston core encountered a hard layer near the seafloor and was severely bent, requiring a pipe trip. Hole 1035C was started at the same site by using a camera survey to place the bit on seafloor where massive sulfide talus was separated by flat sedimented areas, and was cored with the XCB system. Coring between 0 and 44 mbsf recovered massive sulfide, but the hole was abandoned due to poor conditions, so the thickness of massive sulfide on the south flank of BHMS mound remains unconstrained.

Hole 1035F

This hole was drilled at the base of the BHMS mound 60 m south of Hole 856H. The surface of the sulfide deposit (0-14.5 mbsf) is characterized by clastic pyrrhotite and vuggy pyrite.

The clasts include gossanous iron-oxide fragments. In the subjacent cores, massive sulfide was recovered between 14.5 and 89.9 mbsf. This section includes massive to semi-massive pyrrhotite and pyrite with altered sediment (14.5-22.5 mbsf); vuggy massive pyrite with minor chalcopyrite, anhydrite, and sphalerite (22.5-77 mbsf), and massive to semi-massive, fine-grained pyrrhotite and pyrite with white clay-altered mudstone (77-89.9 mbsf). The pyrrhotitic sulfides are similar to massive sulfides from the upper and central part of Holes 856H and 856G, recovered on Leg 139. Between 89.9 and 99.7 mbsf, at the contact between sulfide and sediment, sulfide-banded siltstones and sandstones are present. They are mineralized with pyrite, pyrrhotite, and sphalerite which form irregular bedding-parallel bands and veins. Stringer zone sulfide mineralization was cored between 99.7 and 176.8 mbsf. Three zones are identified in the stringer mineralization. The upper zone (99.7-119 mbsf) comprises siltstone and sandstone in which pyrrhotite and chalcopyrite form an anastomosing network. In the next zone (119-157.5 mbsf) sulfide occurs both as veins and as disseminated minerals in sandstone and siltstones. The base of the stringer zone is sulfide-banded siltstone and sandstone (157.5-176.8 mbsf) where pyrite, pyrrhotite, and sphalerite form irregular bedding-parallel bands in altered sediments that are silicified and chloritized. The lowermost unit is altered sandstone and claystone (176.8-224.8 mbsf). Hydrothermally altered, interbedded greenish gray sandstone and medium gray silty claystone are pervasively silicified. Disseminated epidote, chlorite, and minor pyrite are observed.

Hole 1035E

Hole 1035E was located 100 m south of Hole 856H to test the southern extent of clastic sulfide shed from the BHMS mound, and to examine the possible continuity of the BHMS mound with the morphologically younger and hydrothermally active ODPMS mound that occurs further south. The sediments recovered (0.0-46.19 mbsf) are interbedded turbidites and hemipelagic mud with silty clay interbedded with clastic sulfide sand near the surface (4.10 to 9.58 mbsf). Coring problems prevented testing the possible subsurface connection between the two sulfide mounds.

Hole 1035H

Hole 1035 H was drilled on a relatively flat bench near the southern peak of the ODPMS mound, which is located about 350 m south of the BHMS mound. The only known active venting in the Bent Hill area prior to Leg 169 is located 50 m away at the north end of this mound and consists of a single anhydrite chimney issuing fluid at 265˚C. Hole 1035H recovered 238 m of a relatively complex and extremely interesting sequence with three massive sulfide zones interbedded with feeder zones and weakly mineralized sediments (Fig. 8). Sulfide-veined and impregnated sediment generally stratigraphically underlies the massive to semi-massive sulfide zones. These zones generally grade into nonmineralized sediment. The massive sulfide consists of coarse-grained pyrite variably infilled and replaced by sphalerite (5%-40%), magnetite (up to 30%), clay minerals, minor chalcopyrite, and traces of galena. Massive sulfide from this mound contains significantly more sphalerite than material recovered from the BHMS deposit.

The uppermost core (0-8.8 mbsf) recovered clastic vuggy pyrite and sphalerite and hydrothermally altered claystone. Between 8.8 and 30 mbsf is a unit of massive sulfide consisting of angular, variably sized clasts composed of pyrite, marcasite, and sphalerite with minor chalcopyrite and isocubanite in a matrix of finer grained clastic sulfides. Magnetite and hematite are present in variable amounts. The major non-sulfide phases are dolomite and ankerite. Underlying this massive sulfide is a sulfide feeder zone where fine sandstone, siltstone, and silty claystone are impregnated and cut by thin veins of pyrrhotite, pyrite, sphalerite, chalcopyrite, and anhydrite (30-55.2 mbsf). The feeder zone grades into weakly mineralized fine sandstone and claystone (55.2-74.6 mbsf). The next unit in the section is massive sulfide composed of pyrite, pyrrhotite, and sphalerite (74.6-84.2 mbsf) followed by a second feeder zone where siltstone and fine sandstone are veined and impregnated with pyrrhotite and chalcopyrite (80-123 mbsf). Pyrrhotite is the dominant sulfide mineral at the base of this unit. Sedimentary rocks are locally brecciated and hydrothermally altered to chlorite. Between 103.7 and 113.4 mbsf within this unit is a chloritized fine sandstone with minor chalcopyrite and pyrrhotite. Starting in the underlying section, an interval of base-metal-rich massive sulfide was intersected (123-142.3 mbsf) consisting of compact to vuggy black sphalerite (40% to 70% of the sulfides) with pyrite, magnetite, and talc or clay infilling voids. Copper sulfides are a minor component in this interval. This sulfide type has not been recognized in the BHMS. At the base of this massive sulfide zone, a short interval of highly altered and mineralized rocks rich in amphibole and epidote was recovered. Deeper in the section is a relatively complex feeder zone (142.3-190.3 mbsf) where three zones of massive to semi-massive sulfide (between 150 and 154 mbsf, 162 and 163 mbsf, and 180.7 and 182.3 mbsf) occur within sulfide-veined sediment. Silty claystone, siltstone, and sandstone are impregnated with Cu-sulfides and hydrothermally altered to chlorite. The semi-massive to massive sulfide with altered sediment contains up to 80% Cu-sulfide and has partly replaced and silicified both planar laminae and cross-bedding in the original sediment. This assemblage looks very similar to the banded Cu-Fe sulfide found in Hole 856H. Between 190.3 and 219.1 mbsf the sediments are less intensely mineralized. Interbedded claystone, siltstone, and sandstone are partly silicified and altered to chlorite and contain veinlets and impregnation of Cu-Fe sulfides. The last section was cored in hemipelagic and turbiditic sediment (219.1-247.9 mbsf). Interbedded claystone, siltstone, and sandstone are partly silicified, weakly chloritized, and contain anhydrite molds. Minor disseminated pyrite occurs locally in this interval.

Sedimentology

The sediments recovered in the Bent Hill area are characterized by Holocene and Pleistocene hemipelagic turbiditic deposits. The sedimentary column is predominantly composed of hemipelagic and terrigenous turbiditic beds but it also contains intrabasinal autochthonous and locally resedimented sulfide sands and breccias. Two major units are identified. Unit I consists of fine-grained hemipelagic sediment of Holocene and late Pleistocene age. Unit II is characterized by interbedded hemipelagic sediment of Pleistocene age. As these sediments are hosts for the various types of sulfide mineralization and hydrothermal alteration, several subunits are distinguished based on the dominant alteration mineral: Subunit IIa (unaltered), Subunit IIb (carbonate), Subunit IIc (anhydrite), and Subunit IId (silicates). Unit I is about 25 m thick; the occurrence of clastic sulfide and locally derived sands makes it difficult to identify this unit at Site 1035. Any sediment that overlies the shallow clastic sulfide was assigned to Unit I. In Subunit IIa the uppermost 7 to 17 m is interbedded by a 3- to 4-m-thick slump and mud-clast breccia, and turbidites beds are less than 1 decimeter thick. Subunit IIb is characterized by calcite and dolomite occurring as concretions, disseminated crystals, and thin layers. Subunit IIc is characterized by moderately altered clay to silty clay that contains authigenic anhydrite occurring as nodules, irregular veins, coarse crystalline concretions, and disseminated fine crystals. Local dissolution of anhydrite is correlated with high sulfate content of pore water from the same interval.

Organic geochemistry

Water collected at 73 mbsf from Hole 856H prior to drilling has 511 ppm methane indicating that methane is moving advectively through the sulfide deposit. Gas removed from lithified sediments (191 mbsf) consisted of equal amount of methane (18,000 ppm) and CO_2 with traces of propane and ethane. The occurrence of soot carbon in the same interval indicates that the gas may be adsorbed onto the carbon. Organic and carbonate carbon contents are low. Significant CH_4 and CO_2 concentrations were only encountered at depth in Holes 1035A and 1035G. Methane concentration increases dramatically at the bottom of Hole 1035A. Extractable bitumen shows accelerated maturation with depth for Holes 1035A, 1035D, and 1035E, but the low concentration indicates in situ alteration without migration. In the shallow sections of all holes a terrigenous source was identified as the dominant form of organic carbon.

Inorganic geochemistry

Pore fluid chemistry was investigated in the sediment cover of the sulfide mound in Holes 1035A, 1035D, 1035E, and 1035G. In Holes 1035D and 1035E, most constituents of the pore fluids display only minor changes with depth. Increase of Ca, Sr, and SO_4 above seawater values can be explained by the retrograde dissolution of anhydrite due to decreasing temperature. Conductive heating of pore water cannot produce the observed amount of anhydrite, but substantial downward circulation of seawater through the upper sediment is a likely cause. A small chloride maximum at about 25 mbsf is interpreted as a remnant of higher chloride content of seawater during the last glaciation. In Hole 1035A, Cl concentration shows a gradual increase with depth and a steep decrease below 150 mbsf. This decrease can be explained by an increasing contribution of the BHMS endmember hydrothermal fluid due to lateral advection. It is likely that at this depth an impermeable barrier prevents the influence of hydrothermal water in the upper sediments. Similar sharp enrichment is also seen for lithium and boron. The upper sediments are not significantly affected by hydrothermal water. One pore fluid sample collected in the feeder zone just under the sulfide mound shows strong similarities with the hydrothermal fluid previously sampled with *Alvin* from the active vent on the ODPMS mound. This hydrothermal fluid is easily distinguishable by its low chloride content from the fluid venting in the Dead Dog hydrothermal field 4 km to the northwest.

Paleomagnetism

Rock magnetic parameters reflect the varying lithologic units in Hole 856H by abrupt changes in the magnetomineralogy and the respective concentration of magnetic minerals. A transitional shift of magnetic signal indicates a downhole change from relatively high concentration of hematite to low concentration of magnetite, associated with an increase of paramagnetic minerals such as pyrite or hexagonal pyrrhotite. Thus, in general the magnetic signal seems to reflect a strong overprint caused by the hydrothermal alteration of the sediment.

Downhole measurements

The Triple Combo tool, composed of natural gamma ray (HNGS), resistivity (DIT), porosity (APS), sonic velocity (SDT), and density (HLDS) probes, was run in Hole 858H from 495 mbsf to the seafloor. The caliper confirmed that the hole was in a very good condition and the Formation Microscanner (FMS) was run to 491 mbsf. Good hole conditions and significant variability in the composition and physical properties of the different types of formations allowed the clearly identification of very distinct logging units and subunits.

Logging unit 1 (84.5-100 mbsf)

Massive sulfide is characterized by the highest densities (> 4 g/cm^3) and the lowest resistivity recorded in Hole 856H and corresponds to the massive pyrrhotite sampled at the base of the massive sulfide mound.

Logging unit 2 (100-210 mbsf)

This unit corresponds to the sulfide stringer zone. All the logs display very strong fluctuation related to variations in the intensity of the hydrothermal alteration and sulfide veining. From 100 to 145 mbsf, the resistivity reaches extremely high values but tends to decrease with depth, as do the density and the velocity, whereas the porosity reaches minimum values. This subunit corresponds to the most intensely sulfide-veined sediment identified in core samples between 105 and 155 mbsf. Between 145 and 187 mbsf, the resistivity and density curves remain relatively low and the porosity fluctuates considerably. This interval corresponds to sediment with some veins and sulfide impregnation. Between 187 and 210 mbsf, resistivity, density and sonic velocity are similar to that of the upper part of the stockwork. Low gamma-ray counts reflect the partly turbiditic nature of the sediment. This interval corresponds to the sulfide-banded sediments observed in the core samples. Over the entire unit FMS images give a very good picture of the veins network and of its change in density with depth.

Logging unit 3 (210-292 mbsf)

Below 210 mbsf the sediments are only slightly altered, and the logs become more stable and more representative of changes in structure and lithology through the succession of interbedded mudstones, siltstones, and sandstones. Logging Unit 3 is characterized in the

FMS images by a high level of fracturing, potentially related to faulting. Two intervals (221-239 and 250-270 mbsf) have low resistivity and high porosity. The high gamma-ray counts and low density indicate dominant clayey sediments in this interval. The tops of these two intervals are marked by a contact surface dipping 50 degrees to the west. Between these two intervals the FMS maps a succession of fractures dipping the same direction at about 50-70 degrees. The sharp decrease in potassium above 292 mbsf can be interpreted as the result of fault controlled hydrothermal circulation and alteration.

Logging Unit 4 (292-432 mbsf)

This unit is characterized by a progressive reduction in gamma-ray counts and an increase in resistivity, density, and sonic velocity. From 292 to 323 mbsf, resistivity is constant and FMS images show a succession of very fine beds dipping gently to the south (2°-10°). Some fractures dipping east are possibly conjugate to the main fault. At 323 mbsf, an increase in density, resistivity, and velocity, and a decrease in gamma-ray counts are interpreted to indicate a higher proportion of sand. The beds are thicker but display similar dips and azimuths.

Logging unit 5 (432 mbsf to bottom)

The occurrence of sills correlates with a strong increase in density, sonic velocity, and resistivity, and a drop in porosity and gamma-ray counts. Four sills are identified in the logs, their thicknesses varying between 2 and 6 m. FMS images suggest that some of these units may be pillow lava flows. The deepest part of the FMS record images pillow basalt between 471 mbsf and the bottom of the hole.

Temperature measurements indicate that the heat transfer is predominantly conductive at Site 1035, however, slight non-linearity of the curves for Holes 1035A and 1035E suggests that the regime is not purely conductive.

Structural Geology

Extensive stockwork mineralization was documented in Holes 856H, 1035F, and 1035H. Away from this stringer zone the vein density is typically very low. The transition between BHMS and the stringer zone is very sharp, except in Hole 1035F. We nave not documented a direct connection between igneous basement and the stockwork zone. With a few minor exceptions, all hydrothermal veins are millimeter-sized extension veins. Crosscutting veins and crack seal veins indicate multiple increments of cracking and mineral infilling. The veins have a strong tendency to be vertical although subhorizontal cracks are common. The intensity of veining implies a significant volume increase in the deeper part of the stringer zone, which could be induced by hydraulic fracturing. The quasi-absence of shear structures suggests that faults are absent in the BHMS deposit and that fluid flow is controlled by preexisting high permeability in sediments and by fluid-assisted extension veining. Coarse-grained sandstones act as major porous-flow conduits and also as major hydrothermal fluid collectors. This accounts for the lower density of veining in the coarse layers, characterized by mainly horizontal porous flow, and for the high subvertical vein density in the mudstone layers. Its also accounts for a greater sulfide enrichment in coarse layers both in lithified and non-lithified sediments. Basaltic sills are highly fractured and have induced fracturing in the surrounding sediments, thus they cannot be considered as a barrier for fluid flow.

Physical properties and the Deep Copper Zone

Magnetic susceptibility is consistently low between 40 and 120 mbsf in Hole 1035H. The deepest zone of high magnetic susceptibility occurs within the sulfide-impregnated sediments recovered from the bottoms of Holes 1035A and D at approximately 170 mbsf. The sediments are part of the laterally continuous Deep Copper Zone (DCZ), however no corresponding high magnetic susceptibility was found in the DCZ in Holes 856H, 1035G, 1035F, and 1035H. Another important feature is the subtle but significant low porosities (9% and 14%) and slightly higher bulk densities of two sandstone samples immediately below the DCZ (Hole 856H). There are also two samples from just above the DCZ which show low porosity, but these appear to be much more intensely mineralized than the sediments below the DCZ. Deeper in the section, the porosity increases gradually with depth. A similar pattern of increasing sediment porosity with depth immediately beneath the DCZ is also seen in Hole 1035G and possibly Holes 1035F and 1035H. The lower porosity beneath the DCZ may result from original sedimentation textures, early diagenesis, or alteration associated with sulfide mineralization.

Dead Dog Area

The major scientific objective for Site 858 (Hole 858G) (Fig. 4) was to replace the existing CORK and thermistor string as part of an active hydrologic flow experiment designed to enable temporal monitoring of changes in subseafloor temperature and pore pressure. Observations by the Alvin submersible in 1993 established that the pore pressure in the drill hole had returned to seafloor hydrostatic conditions, indicating a failure of the borehole seal, and that the datalogger had eventually failed due to flow of hydrothermal fluid through the base of the reentry cone. Because the hole was observed to be flowing in 1993 and because it was cased to basaltic basement, it represented a unique opportunity to sample formation fluids from the basalt that could be compared to fluids venting through the overlying sediment cover only a few tens of meters away from the hole. Therefore, measuring the temperature profile and obtaining high temperature borehole fluids were important ancillary objectives for this site. A planned hole-to-hole hydrologic experiment involving monitoring the pressure in Hole 858G in response to a transient pressure pulse to be induced by drilling in Hole 857D, which is located 1.6 km to the south, dictated that the temperature structure in Hole 858G should be disturbed as little as possible during operations.

<u>CORK activities at Hole 858G</u>

Initial observation of the CORK in Hole 858G from the VIT-TV revealed no evidence that the fluid flow observed earlier, was continuing. Upon recovery of the lower half of the

CORK housing, we discovered that the inside housing of the CORK body was coated with hydrothermal precipitates, predominantly anhydrite, but with abundant pyrrhotite and pyrite. Naturally occurring hydrothermal chimneys from the Dead Dog vent field are predominantly composed of anhydrite, with only minor amounts of pyrite and trace amounts of pyrrhotite. Although the seals in the CORK had clearly failed due to the high temperature, examination of the location of the precipitates and the still open flow channels showed that the fluid flow may have originated in the sediment underlying the reentry funnel and that flow out of the cased hole may not have been contributing to the precipitation of hydrothermal minerals in the CORK.

The VIT was run to near the top of the reentry cone following removal of the CORK, but again, no evidence for flow of hydrothermal fluids could be observed from the open borehole. However, a Water Sampling Temperature Probe (WSTP) run 20 m into the casing indicated fluid temperatures in excess of 220˚C prior to failure of an O-ring in the tool. The fluid sample collected contained a mixture of seawater and hydrothermal fluid that extrapolates to a hydrothermal end member similar to fluids sampled by Alvin in the vent field. A temperature run with the UHTMSM dewared tool (see “Operations” section for tool description) confirmed the high temperatures at the top of the open borehole and indicated that the borehole was essentially isothermal at 272˚C (near the maximum measured in the vent field) at depths below 85 mbsf. The temperature tool could only be run to 205 mbsf due to an obstruction in the cased portion of the drill hole. This obstruction probably sealed the casing thereby preventing rapid flow of hydrothermal fluid from the open borehole. A water sample was taken from the borehole at 100 mbsf within the isothermal section with the Los Alamos water sampler. Failure of the seals in this tool led to both inflow of seawater and extensive boiling of the fluid sample upon retrieval through the water column.

We were forced to circulate drilling fluid (seawater) in the borehole while cleaning out the obstruction in the casing. The drillstring was advanced to 387 mbsf, near the level where the pipe last tagged bottom on Leg 139. A wash core was recovered from an unlined core barrel and is believed to be representative of the material drilled from inside the casing at depths below 205 mbsf. The wash core was predominantly loosely aggregated, fine-grained pyrrhotite and pyrite with minor amounts of anhydrite. Fluid sampled from the wash core had a very low magnesium content consistent with a high temperature origin and minimal dilution with seawater. The presence of an extensive interval of precipitated sulfide from within the casing may be an indication that the casing is no longer hydrologically isolated from the sedimentary formation.

Although we were forced to disturb the thermal structure of Hole 858G, we were successful in reinstrumenting the hole with a 370-m-long thermistor string and pressure transducer and in setting a new CORK in the reentry funnel (Fig. 9).

CORK activities at Hole 857D

The operation plan at Hole 857D was to remove the CORK and 300-m-long thermistor string set on Leg 139, to deepen the hole for 12 to 24 hr in order to circulate fluid and cool the hole, and to reCORK with an 898-m-long thermistor string (Fig. 7). This hole was drilled to 936 m on Leg 139 and has a reentry cone with 11-3/4" casing set at 573.8 mbsf. The CORK was damaged on Leg 146 by a collision with the running tool in high heave conditions. The data logger and the upper part of the CORK were successfully recovered, but the thermistor string and sinker bar were lost in the hole. The lower part of the CORK body remained in the hole, so our operations team devised a method to extract it using fishing tools available on the *JOIDES Resolution*. On the second attempt (after a pipe trip to modify the fishing tool), the remainder of the CORK was successfully removed.

In preparation for a temperature log and water sampling program prior to deepening Hole 857D, we ran into the hole with a grappling tool and recovered approximately 250 m of the 300-m-long thermistor string. Our intention was to begin temperature and water sample runs, but neither the UHTMSM nor the BRGM temperature tools were completely functional during bench tests. Since we could not collect a water sample with the WSTP without knowing the borehole temperature, and since our intent was to initiate downhole flow, we decided to postpone temperature logging and move to Site 1035 to begin a 2-3 day coring operation, before returning to Hole 857D to complete the CORK operation.

We returned to Hole 857D after terminating operations at Hole 1035A. As we reentered the hole, it appeared that mud stirred up in the reentry funnel was being drawn down the borehole. In order to determine the depth of the clear hole and maximum temperature before attempting to collect a water sample, we opted to run a sinker bar equipped with temperature tabs on the coring wireline until it met an obstruction. The sinker bar grounded at 642 mbsf and when we pulled it back to the rig floor we noted that the temperature tabs indicated borehole temperatures were less than 108˚C. The drill pipe was lowered to attempt a WSTP sample, but at 377 mbsf met an obstruction within the cased section of the hole that required reaming. After clearing this obstruction the pipe was lowered to 621 mbsf and we used the WSTP to collect a borehole temperature and water sample. The temperature was approximately 2˚C, and the water sample was seawater, indicating a strong downhole flow to this depth. The hole was washed and reamed against light resistance to 929 mbsf (8 m above TD). As far as we know, the sinker bar from the original thermistor string as well as some prongs from the thermistor retrieval tool are still in the bottom of the hole.

Considering our questionable long term weather forecast, the high priority of reinstrumenting the hole, and the knowledge that the hole was clear and cool to a depth sufficient for deployment of our 898-m-long thermistor string (Fig. 169-PR-9), we decided to forego an attempt to deepen Hole 857D and proceed with CORKing operations. The CORK, thermistor string, and datalogger were installed without incident. As with Holes 856H and 858G, we were able to achieve our high priority objectives in a technologically challenging working environment. Much credit goes to the engineers and drillers who planned and executed this difficult operation.

Site 1036

Site 1036 was located at the active Dead Dog vent field (Fig. 4) to (1) constrain the fluid flow rates and pathways for hydrothermal fluid and seawater entrained into the hydrothermal upflow zone, (2) study the mode of formation of the hydrothermal mounds and test a model that predicted the mounds' growth by subseafloor mineral precipitation and inflationary growth, (3) determine the effects of hydrothermal activity on sediment diagenesis and alteration, and (4) determine the presence, continuity, and nature of a suspected cap-rock horizon at 30 mbsf. In order to meet these objectives we drilled Holes 1035A, 1035B, and 1035C along a NW-SE transect from the top to the margin of the 7-m-high Dead Dog active hydrothermal mound. Hole 1036A was located about 9 m west of a 268˚C active vent and was cored to 38.5 mbsf. Hole 1036B was offset about 37 m to the NW and cored to a depth of 52.3 mbsf. Hole 1036C was offset another 34 m to the NW and cored to a depth of 54.2 mbsf.

<u>Sedimentology</u>

Three major lithologic units identified in the Middle Valley were identified (I, II, and IV), and five subunits defined by alteration were recognized.

Lithologic Unit I is silty clay and has a relatively consistent thickness between holes (25.09 m at Hole 1036A, 25.60 m at Hole 1036B, and 26.70 m at Hole 1036C). The age of this unit is Holocene to late Pleistocene and it is interpreted to be largely a hemipelagic sequence. On the basis of hydrothermal/diagenetic alteration, lithologic Unit I has been subdivided into three subunits.

Subunit IA lacks distinctive hydrothermal or diagenetic products, and consists of slightly altered hemipelagic silty clay with several thin (0.1- to 10-cm-thick) laminae and beds of silt. These silty units are composed of quartz, feldspar, mica, clay, and chlorite with trace amounts of calcite, hornblende, pyroxene, epidote, and pyrite.

Subunit IB is distinguished from *Subunit IA* by the presence of authigenic carbonate. The core from Hole 1036A contains just a few dolomite nodules. In the core from Hole 1036B, numerous dolomite and calcite nodules are found in the interval from 10.20 to 32.20 mbsf. Hydrothermal alteration also affected the preservation of microfossils in the cores. Core-catcher samples prepared for paleontological analysis were devoid of foraminifers below 9.5 mbsf in Hole 1036A, below 18.6 mbsf in Hole 1036B, and below 35.0 mbsf in Hole 1036C. Siliceous microfossils disappear at even shallower burial depths in all holes.

Subunit IC contains authigenic anhydrite as disseminated crystals, nodules, and cement, and is a distinctive alteration facies of the hydrothermal system. The depth of first appearance of anhydrite was 9.5 mbsf in Hole 1036A and 18.55 mbsf in Hole 1036B. The first appearance of anhydrite in Hole 1036C (*Subunit IIB*) is at 42.20 mbsf. This depth may indicate the approximate position of the 160˚C isotherm.

Lithologic Unit II is characterized by hemipelagic silty clays interbedded with silt to fine sand turbidites. It is subdivided into *Subunit IIB*, characterized by the occurrence of diagenetic carbonates, and *Subunit IIC* distinguished by the presence of anhydrite nodules and cement. The boundary between *Subunit IIB* and *IIC* is defined as the first down-core appearance of non-vein anhydrite. For example, Hole 1036C contains abundant calcite cement above 40.9 mbsf and contains anhydrite, but no calcite, below 42.0 mbsf.

Lithologic Unit IV. Hole 1036A was drilled less than 10 m from an active hydrothermal vent surrounded by an anhydrite apron formed by collapse of an anhydrite chimney. The first 6.10 m section in Hole 1036A is assigned to *Unit IV* and accounts for most of the 7-m bathymetric relief of the Dead Dog Mound. *Unit IV* is a heterogeneous mixture of clasts derived from collapse of anhydrite chimneys, now partly altered to gypsum, very fine-grained pyrrhotite with subordinate pyrite and sphalerite, and greenish gray clay, probably a Mg-bearing smectite. The lowermost 1.6 m of the sequence has a dark color, probably a result of the slow, ongoing process of gypsum dissolution, leaving behind a residue of clay and sulfide. *Unit IV* is underlain by an unaltered, homogeneous, silty clay that appears to be of hemipelagic origin (*Subunit IA*).

Drilling at Site 1036 showed that flat lying *Subunits IA* and *IIA* have not been significantly displaced since deposition. The relief of the Dead Dog mound is close to the stratigraphic thickness of chimney-derived rubble, hence the mound is nearly entirely a build-up of rubble and is not caused by authigenic hydrothermal mineral precipitation in the subsurface or tectonic uplift. The Dead Dog mound is presumably a recently formed feature. The upper boundaries of the carbonate and anhydrite alteration subunits deepen away from the mound, reflecting the decreasing geothermal gradients.

Structural Geology

Although Hole 1036A is only 9 m away from an active vent, no major hydrothermal vein network was intercepted at depth and most sediments are not highly lithified by hydrothermal alteration. Only a few hydraulic breccias and some anhydrite veins are observed. The absence of a stockwork zone underlying the mound and the lack of extensive induration suggest that the Dead Dog hydrothermal mound is an immature feature, consistent with the occurrence of collapsed chimney material overlying very young sediments.

Biostratigraphy

Biostratigraphic zonation of the quaternary sequence at Middle Valley is limited to planktonic foraminifers, because other fossils such as diatoms, radiolarians, and calcareous nannofossils are poorly preserved in hydrothermal settings. Planktonic foraminifers are abundant to common to 9.94, 18.61, and about 26 mbsf in the core from Holes 1036A, B, and C, respectively. The depth where foraminifers disappear coincides roughly with the shallowest occurrence of weakly indurated sediments. Regional sedimentation rates constrained by the depth to the 125 ka horizon identified by foram assemblages range from 17 to 33 cm/1000 yr, which is surprisingly slow considering the young age of the basement and the total thickness of the sediment filling Middle Valley.

Organic Geochemistry

Interstitial water collected from Hole 1036C cores contains methane and hydrocarbon derived from high temperature alteration of organic matter. Hydrothermal petroleum is found in discrete horizons in sediments from Hole 1036A (12 -17 mbsf), Hole 1036B (24-35 mbsf), and Hole 1036C (32-35 mbsf). This petroleum has migrated only a short distance ahead of the heat front and resides at an in situ temperature of 100°-150˚C. CO_2 increases near the oil horizon, but there is no correlation between methane and the oil horizon. Total organic carbon decreases with increasing depth in Hole 1036A, close to the vent, and increases with depth in Hole 1036C, at the base of the mound.

Inorganic Geochemistry

Normal seawater concentrations are present in pore fluids sampled from shallow depths, but below 20 mbsf there is 10-m-thick layer that shows high magnesium (twice the seawater value), low calcium, and low sodium concentrations. This implies high-temperature (> 200˚ C) alteration in the vicinity of the vent fluid conduit, probably involving downwelling seawater that has undergone reaction and is subsequently transported laterally through this section. Fluids with compositions similar to those sampled at Dead Dog vent are present below 40 mbsf in cores from Hole 1035B, whereas end member hydrothermal fluids were not detected in samples from Hole 1035C, probably because the depth of influence of the hydrothermal fluids rapidly deepens away from the vent. The evidence does not support the presence of a cap rock controlling hydrothermal fluid flow below Holes 1036A and 1036B.

Physical Properties

High gamma-ray and wet bulk densities correspond to the occurrence of nodules in cores from Holes 1036A, B and C. Both measures of bulk density indicate a general increase down section. This is correlated to a decrease in porosity from 70%, at the surface, to 50% or less, at 40 mbsf. Near the vent, porosity in cores from Hole 1036A drops abruptly to less than 30% at about 30 mbsf near the contact between lithologic Units I and II. The depth at which the magnetic susceptibility of sediments decreases to near zero (magnetic wipe out zone) increases with distance from the vent and may be related to hydrothermal alteration and shallowing of isotherms near the vent. Magnetic peaks in the deeper cores from Holes 1036A and B in the magnetic wipe out zone are due to local pyrrhotite precipitation. The natural remanent magnetization of cores from Site 1036 was measured for quasi-continuous sections. Hydrothermal activity significantly affects the paleomagnetic signal and overprints the record of the Brunhes Chron, with the level of affected sediment decreasing with proximity to the hydrothermal vent.

Esacanaba Trough

Central Hill Area

A transect of holes (Holes 1038A to 1038I) was made in the vicinity of Central Hill in Escanaba Trough with the highest priority to drill through the massive sulfide deposits and into the alteration zone near the center of the hydrothermal upflow zone. A primary objective was to establish the causes of the major compositional differences between the deposits at Middle Valley and Escanaba Trough. A series of shallow RCB exploratory holes was targeted primarily at the exposed mounds of massive sulfide in order to establish the extent, composition, and drillability of the massive sulfide in this area prior to starting a deeper drill hole.

Massive sulfide recovered from Central Hill suggests that the mineralization forms only a thin (5-15 m) veneer over the sediment. No major intersection of massive sulfides was recovered.The absence of a well-developed vein-dominated feeder zone in the sediment under the sulfide mounds indicates that hydrothermal venting was probably diffuse and short lived. This is consistent with the lack of chimneys and the general occurrence of high temperature pyrrhotite crusts on the sediment observed during submersible dives. Massive sulfides consist predominantly of massive pyrrhotite and vuggy pyrite. Sphalerite is locally abundant and is associated with pyrrhotite.

Sedimentology

Of the eight lithologic units identified in the reference hole (see Site 1037B below), only Units 2, 3, and 8 can be identified with any degree of certainty at Site 1038. Using grain size and magnetic susceptibility data, a correlation can be made between the upper 100 m of cores in Holes 1038A, 1038B, 1038G, 1038I, and the reference hole (Hole 1037B); below 100 mbsf stratigraphic correlation become more tenuous. In Hole 1038I, there is a strong correlation between MST signature and other physical property measurements in the upper 80 m of the hole. MST data proved to be a valuable tool in establishing correlations between cores recovered from Site 1038 and the reference hole at Site 1037, but some correlations are tenuous and require confirmation from shorebased analyses.

Near surface sands lack lateral continuity, suggesting that they may have been locally derived, perhaps by slumping off the steep fault scarps that surround the basin. Unit 3, defined in the reference hole, is characterized by thicker, more sand-rich turbidites separated by relatively thinner mudstone intervals, and can be correlated with sands recovered at Site 1038. The top of this interval is identified in all holes that penetrated to a depth in excess of 80 mbsf. This unit is interpreted to be correlative to the top of the regionally developed transparent seismic layer. Despite the fact that there is 40 m of relief between Holes 1038B and 1038I, the top of Unit 3 occurs within 6.1 m in all the holes, which implies that the topographic expression of Central Hill is very young.

Due to poor recovery Units 4, 5, and 6 are not easily identified at Site 1038. Correlation of the lower section of sediment drilled at Hole 1038I with Unit 6 in the reference hole based on similarities in the physical properties requires rapid thickening of strata above Unit 6 to account for changes in sediment thickness between these two sites, which are separated by about 5 km. If the top of Unit 8 in Hole 1038I is instead accepted as the first occurrence of stacked siltstone turbidites with no obvious hemipelagic intervals, then the sediment thicknesses are more readily correlated, but the sandy intervals derived from the Klamath Mountains, initially identified in DSDP Hole 35 and assigned to Unit 8 at Site 1038, appear to have not been recovered.

Biostratigraphy

Most samples examined from Site 1038 contain very few foraminifers or are barren. Their alteration is clearly associated with thermal and hydrothermal effects. Hole 1038F provides confirmation that Holocene sedimentation is exceptionally fast, probably in excess of 290 cm/1000 yr.

Igneous Petrology

A basaltic layer from 1 to at least 5-m thick was intersected in three holes (Holes 1038G, 1038H, and 1038I) at depths between 142 and 162 mbsf. This unit could have been either a thin flow erupted on sediment or a thin sill. The basalt intersected at the base of Hole 1038I (403 mbsf) is thought to be a flow, based on the presence of fresh glass and a very narrow (2 mm) baked upper contact. There is, however, insufficient core penetration in this interval to ascertain if this is indeed a flow, in which case it most likely was erupted over sediment, or is a sill.

Inorganic Geochemistry

Pore fluids collected from Site 1038 show a wide range in chemical compositions. A hydrothermal component is obvious in all the holes and dominates pore fluid chemistry at shallow depths below hydrothermally active and inactive sulfide mounds. The Cl concentration ranges from 300 to 800 mM indicating the presence of hydrothermal fluid affected by phase separation. In most holes, the high salinity component dominates pore fluids. Low salinity pore fluid is particularly evident in sand-rich layers in Holes 1038A, H, and I. This suggests a preferential vapor loss and migration through sand layers after boiling. Pore fluid compositions also appear to be modified by anhydrite dissolution, Mg-metasomatism, and chlorite formation.

Hole 1038I allowed recovery of pore fluid from deeper in the section. The thermal gradient in the upper part of Hole 1038I is approximately 2˚C/m. High temperature results in concentrations of Li and B below 300 mbsf that are far higher than those recorded in the reference hole. Furthermore, the concentration of Mg declines far more rapidly with depth than in the reference hole. There is a marked change in the composition of pore fluid in the sand layer of lithologic Unit 3. Ca, Cl, Mg, Sr, and Na/Cl ratio decrease while Li, B, K, and NH_4 concentrations increase. This is consistent with lateral flow of a hydrothermal component with low Cl through the sand layer. This fluid acquired high concentrations of Li, B, K, and NH_4 by reaction with sediment. Fluid with similar composition was sampled at Holes 1038A and 1038H, where the low Cl concentration is related to phase segregation following boiling. High salinity fluids were recovered from sediment beneath a thin basalt layer penetrated at 161 mbsf in Hole 1038I. These fluids could be conjugate brines to the low salinity fluids sampled in the overlying sediment intervals. Concentration of Cl, Ca, K, Na, Mg, and NH_4 increase while H_4SiO_4, Li, and B show a small reduction. The relationship between the Na and Ca content with Cl fits on the mixing line, indicating a single source for the high and low-Cl fluids.

Organic Geochemistry

High methane concentration in gas was found in Holes 1038E, 1038H, 1038F, 1038G, and 1038I. Except for Hole 1038I, which was drilled away from the hydrothermal field, methane in the recovered cores has a thermogenic origin. The presence of benzene and toluene confirm high temperature cracking of organic matter. Bitumen fluorescence also indicates a high maturation temperature of 150˚C to 250˚C. The estimated temperature of organic maturation is higher than in Middle Valley. The full range of maturity is observed. Hydrothermal petroleum occurs in the shallow section of several holes. The regional maturation of organic matter has been rapid for all holes. In Hole 1038I, methane has a biogenic origin at shallow levels and a thermogenic origin deeper in the section. Hydrocarbon compositions reflect the terrigenous source of organic matter in the sediments deposited in Escanaba Trough.

Escanaba Trough Reference Site

At Site 1037B a complete sedimentary sequence of the Escanaba Trough fill sediment was cored between 0 and 495.60 mbsf (Table 169-RS-PR-1). Beneath this sequence, between 495.60 and 507.8 mbsf, metamorphosed claystone and siltstone was recovered. Basalt was recovered from 507.8 to 546 mbsf. The sedimentary succession is divided into 8 lithostratigraphic units defined on the basis of sand/silt-dominant versus mud-dominant turbidites and changes in composition and sedimentary structure.

Sedimentology

Unit 1 is 3 cm of oxidized mud from the surface, underlain by hemipelagic sediment. Unit 2 consists of 10 turbidite beds up to 12.5 m thick, some of them containing wood fragments. Some microcrystalline sulfide is associated with the organic matter. Unit 3 comprises a 50.5 m package of massive sand where grain size variation is very subtle. Coring disturbance makes interpretation of the depositional environment uncertain, but it appears that instantaneous deposition due to deceleration of a density flow is necessary to account for the lack of grading and the very poor sorting. Unit 4 is composed of 6 mud turbidite beds up to 8 m thick. Unit 5 is similar to Unit 3 and comprises 37 m of poorly sorted sand where three fining-upward and some parallel laminated intervals have been recognized. Unit 6 is the first indurated muddy turbidite below the sand of Unit 5. The upper 60 m consists of thick very fine grained turbidites. Unit 7 is homogeneous calcareous silty claystone with rare graded beds. In the lower 60 m the same type of sediment shows an incipient calcite cementation. No obvious hemipelagic beds are recognized. The turbiditic or hemipelagic nature of this unit remains to be determined. The top of Unit 8 is a 13-m-thick graded turbidite of fine-grained sandstone to claystone that marks the transition to dominant siltstone and minor fine-grained sandstone turbidite beds of various thickness. Carbonate cementation is moderate. Cores recovered between 495.6 and 507.8 mbsf are silicified calcareous claystone rubble with less than 20% recovery. These rocks have been thermally altered and occur just above the transition from Escanaba Trough sediment fill to igneous basement. Some of the recovered basalt is quite fresh, and ranges from nearly aphyric chilled margins with minor hyaloclastite, to medium-grained, intersertal to subophitic, highly plagioclase- clinopyroxene-olivine phyric, diabasic textured basalt. Coarser grained basalts began to deteriorate on the description table, and pieces that had been oriented intervals of core up to several centimeters long disaggregated to rubble as the core dried.

Biostratigraphy

Based on foraminiferal assemblages, sedimentation rates at this site appear to be exceptionally rapid. The base of the Holocene sequence has tentatively been placed at the base of lithologic Unit 2 at 73.1 mbsf, suggesting a sedimentation rate of 731 cm/1000 yr. A tentative pick of the 125 K.y. horizon at 317 mbsf suggests a sedimentation rate of 212 cm/1000 yr for upper Pleistocene sediments in the Escanaba Trough.

Inorganic Geochemistry

The relatively rapid sedimentation rate in the Escanaba Trough helps to preserve the chemical signatures in pore waters, and diffusive processes are likely to influence signals only above about 35 m. This permits interpretation of the pore water concentration-depth profiles in terms of sedimentary provenance and diagenetic features. At 360 mbsf the concentration profile of several species (Na, K, Ca, Cl, B, H_4SiO_4, NH_4, and Na/Cl ratio) are interpreted as showing a sudden change in the principal source of sediment fill in the Escanaba Trough from the Columbia River above to the Klamath Mountains below. These two areas of sediment provenance have rather different mineral assemblages; sediments from the Columbia River are principally volcanic and pyroxene rich, while sediments from the Klamath Mountains are amphibole rich. Diagenetic reaction in these sediments provide a source of Na, Ca, Li, and B to pore waters and a sink for K, alkalinity, and ammonia. A decrease in Mg and K concentration with depth is interpreted as being due to clay mineral formation.

Organic Geochemistry

The organic matter in the sediments of this reference site is generally immature from the top to approximately 450 mbsf. There are a few horizons with more mature bitumen which is interpreted to be derived from recycled older sedimentary detritus carried in by turbidites, however, the low extract yields throughout the hole indicate that there are no petroleum zones. Below 450 mbsf the organic matter is thermally altered, but low concentrations of bitumens reflect in situ maturation without migration/expulsion.

Physical Properties

Porosity decreases from 70% near the seafloor to 40% at the base of the sedimentary section and 10% in the basalt and associated altered sediments below 500 mbsf. The MST logs proved particularly useful in easing identification and classification of sedimentary units. Fluctuations in magnetic susceptibility correspond to boundaries of turbidites or hemipelagic units identified based on grain size distributions.

Downhole Measurements

Hole 1037B was logged from 100 to 535 mbsf using the Triple Combo tool, composed of temperature (TLT), resistivity (DIT), density-caliper (HLDS), porosity (APS), and natural gamma ray (HNGS) probes. A second run was composed of acceleration (HRA), sonic (SDT), and resistivity (DIT) probes. The gamma-ray and resistivity logs correlate well with Pleistocene lithostratigraphic sequences identified from core recovery and also show distinctive fining upward sequences within turbiditic sections. The density, velocity, and porosity logs were affected by irregular borehole conditions as the caliper from the HLDS showed that, for the most part, the hole diameter is over 16 inches. Adara temperatures recorded maximum formation temperatures of 15˚C at 85 mbsf which extrapolate to 84˚C at 500 mbsf.

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FIGURE CAPTIONS

Figure 1. Location map showing tectonic setting of the sediment-covered spreading centers at Middle Valley and Escanaba Trough on the Juan de Fuca-Gorda Ridge spreading system.

Figure 2. Bathymetry of Middle Valley (Davis and Villinger, 1992) shown as contours drawn at 10-m intervals. Dead Dog vent field in the area of active venting (Sites 856 and 1035) and Bent Hill (Sites 858 and 1036) are outlined.

Figure 3. Map of Bent Hill (Middle Valley area) showing the location of Bent Hill and the two mounds (Bent Hill and Ore Drilling Program massive sulfide) to the south. The positions of holes drilled during Leg 139 (black circles) and Leg 169 (white circles) are shown. Modified from Goodfellow and Peter (1994).

Figure 4. Map of Dead Dog vent field (Middle Valley area) showing location of the major hydrothermal mounds, active vents, and the holes drilled on Leg 169 (Holes 1036A, B, and C). The limit of the vent field was determined as the contour of the acoustic side scan sonar reflector. Modified from Butterfield et al. (1994).

Figure 5. Map of Escanaba Trough in the southern portion of the Gorda Ridge spreading center showing the sediment-filled portion of the trough (light shading), intra-trough terraces (intermediate shading), and the volcanic centers (dark shading) that rise through and locally pierce the sediment cover. The location of Sites 1037 (reference hole) and 1038 drilled during Leg 169 are shown. The white box shows the position of Fig. 9.

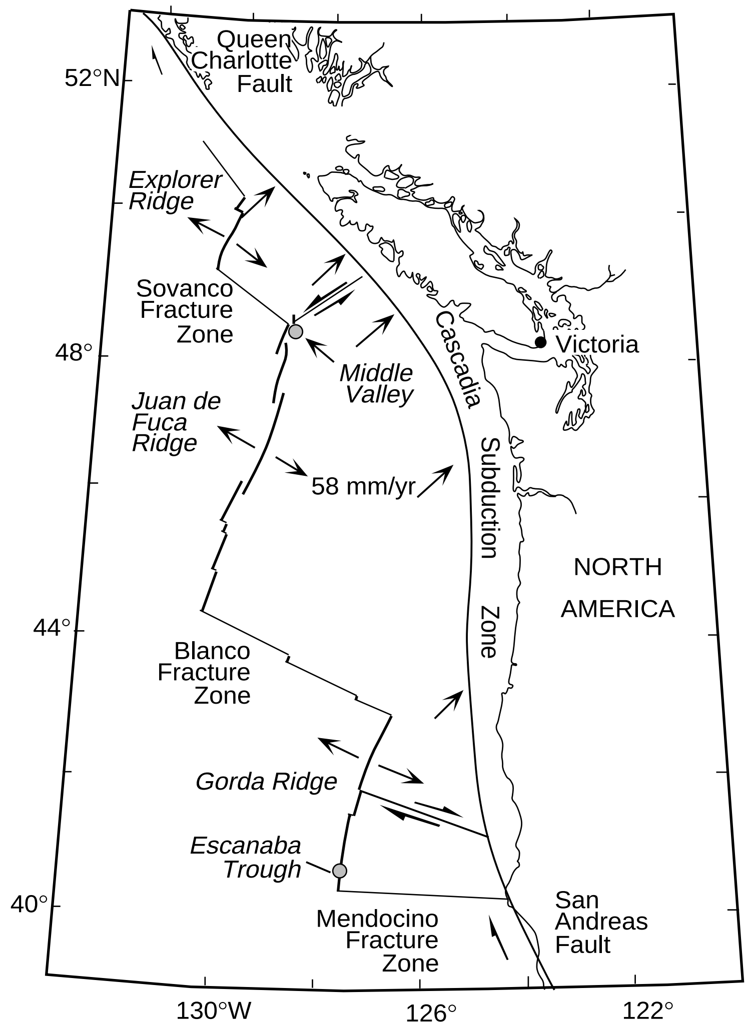
Figure 6. Detailed map of Central Hill (Escanaba Trough area) and the Northern Escanaba Trough study area (NESCA) showing the position of holes drilled at Site 1038 during Leg 169. Location of active vents, fault scarps, and exposed volcanic rock are based on camera tows and submersible tracks shown as thin lines.

Figure 7. Bent Hill Massive Sulfide in Middle Valley. Schematic graphic Log of Hole 856H showing, from the seafloor down, the massive sulfide mound, the underlying feeder zone,

and the sulfide-rich banded sandstone at its base, the turbidite hemipelagic sediment, the basaltic sill complex, and the lower basaltic flows.

Figure 8. Ore Drilling Program Massive Sulfide in Middle Valley. Schematic graphic Log of Hole 1035H showing the complex succession of three massive sulfide zones each of which is underlined by a feeder zone.

Figure 9. Diagram showing the depth to basement in the two Middle Valley holes which were reinstrumented with CORKs. Basement (shaded) at Site 857 is defined as the top of a sill-sediment complex at 470 mbsf. Basement rises to 250 mbsf under Site 858 and is extrusive basalt (from Davis and Becker, 1994b). Lines and circles at the center of the hole represent the temperature string and the position of the thermistors (black circles).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Charlotte
Fault
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Ridge
Sovanco
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Zone
48°
Middle
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Cascadia
Subduction
Zone
Victoria
NORTH
AMERICA
44°
Blanco
Fracture
Zone
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Escanaba
Trough
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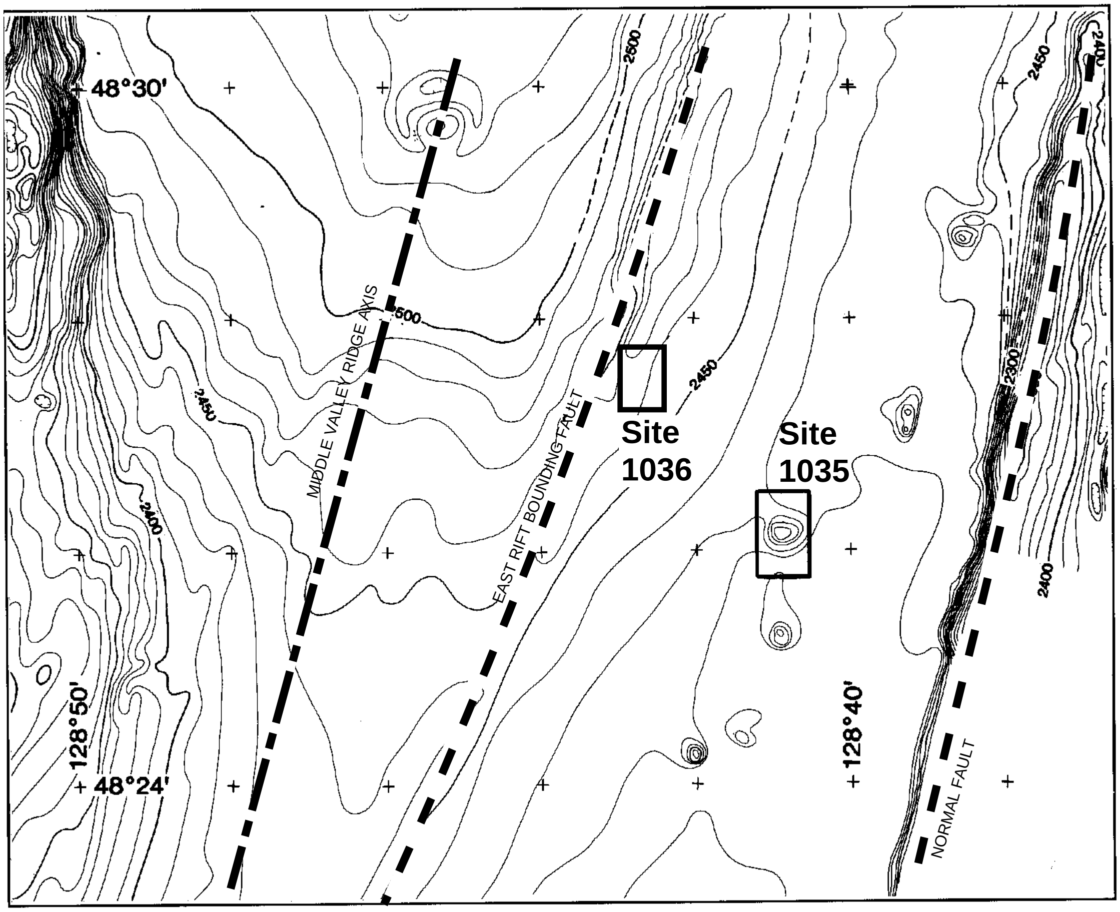
Fault
130°W
126°
122°



48°30'
48°24'
128°50'
128°40'
MIDDLE VALLEY RIDGE AXIS
EAST RIFT BOUNDING FAULT
NORMAL FAULT
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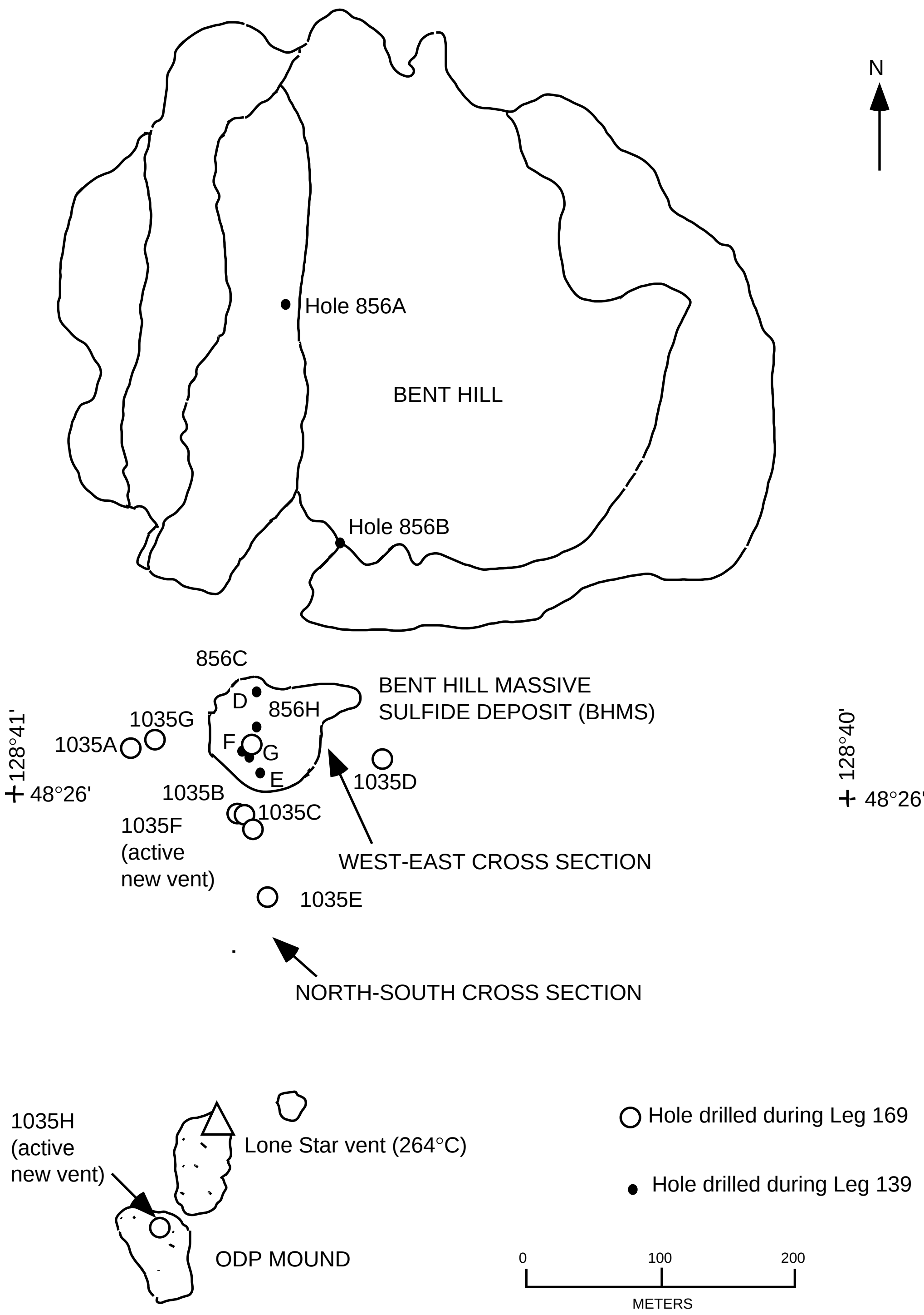
Site
1035
2500
2450
2400
2300


N
Hole 856A
BENT HILL
Hole 856B
856C
BENT HILL MASSIVE
SULFIDE DEPOSIT (BHMS)
D
856H
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1035A
F
G
E
128°41'
48°26'
1035B
1035D
128°40'
48°26'
1035F
(active
new vent)
1035C
WEST-EAST CROSS SECTION
1035E
NORTH-SOUTH CROSS SECTION
1035H
(active
new vent)
Lone Star vent (264°C)
ODP MOUND
Hole drilled during Leg 169
Hole drilled during Leg 139
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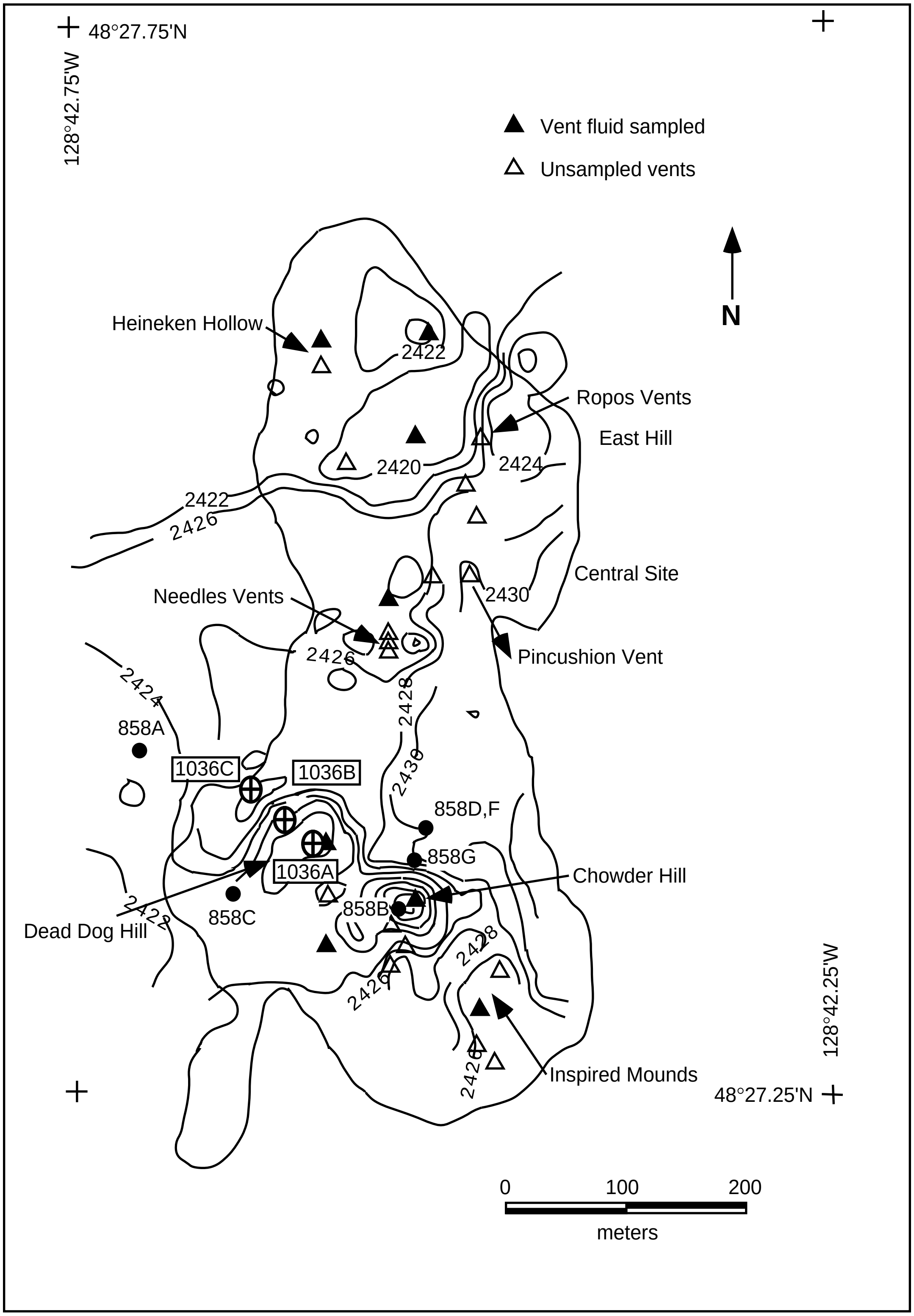
100
200
METERS


48°27.75'N
128°42.75'W
Vent fluid sampled
Unsampled vents
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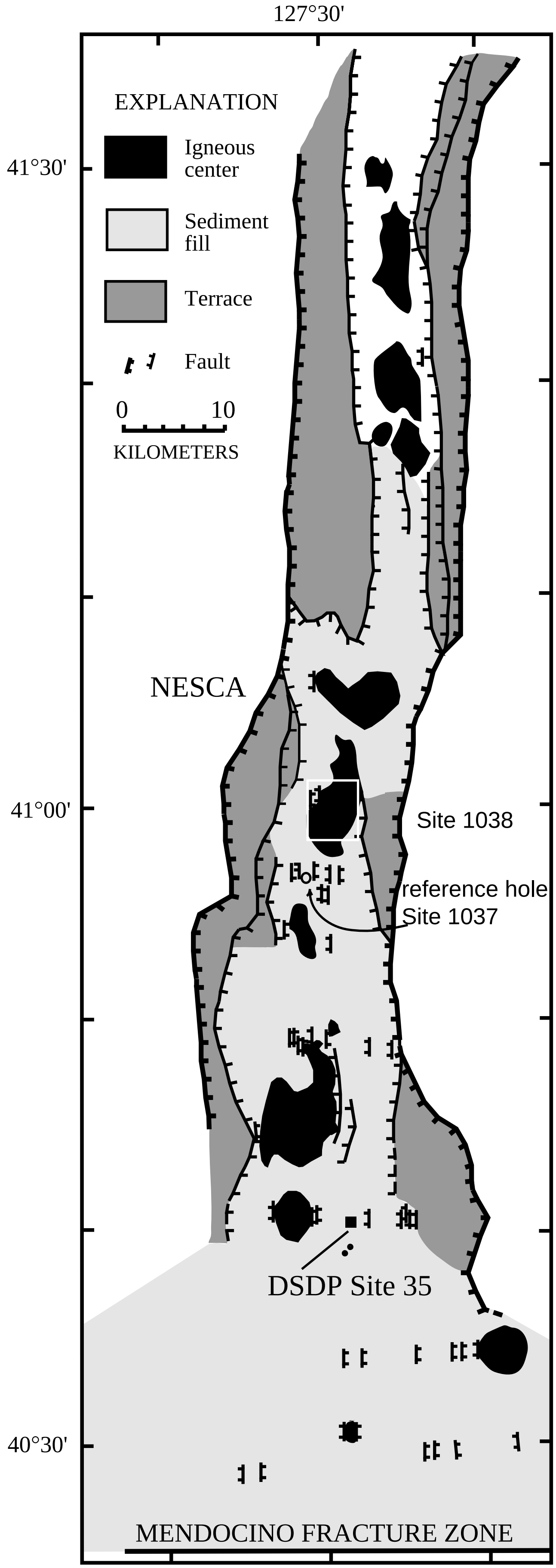
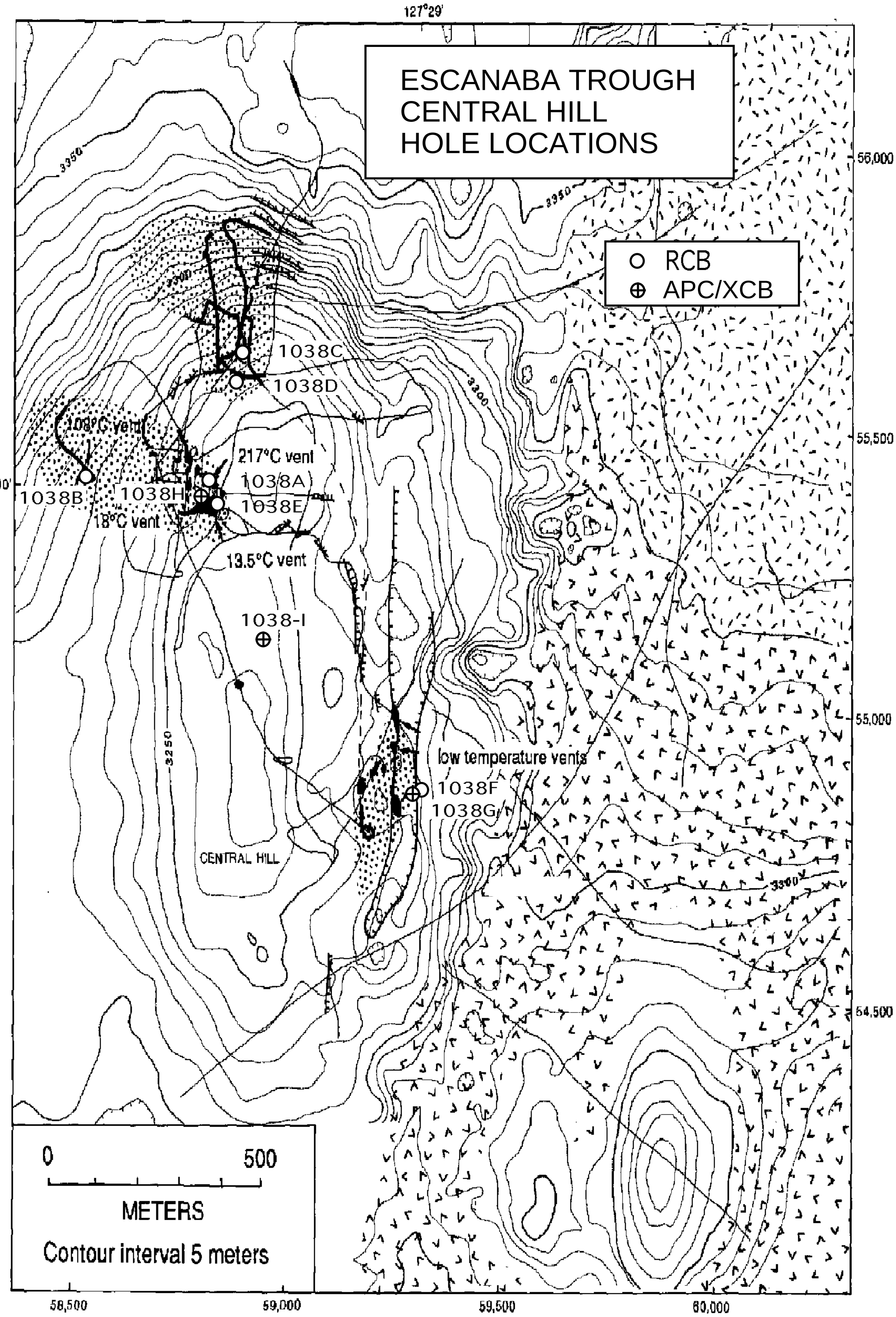
Heineken Hollow
2422
Ropos Vents
East Hill
2420
2424
2422
2426
Central Site
Needles Vents
2430
2426
Pincushion Vent
2424
2428
858A
1036C
1036B
2430
858D,F
858G
1036A
Chowder Hill
Dead Dog Hill
2422
858C
858B
2428
2426
2426
Inspired Mounds
128°42.25'W
48°27.25'N
0
100
200
meters


127°30'
EXPLANATION
Igneous center
Sediment fill
Terrace
Fault
0
10
KILOMETERS
41°30'
41°00'
40°30'
NESCA
Site 1038
reference hole
Site 1037
DSDP Site 35
MENDOCINO FRACTURE ZONE

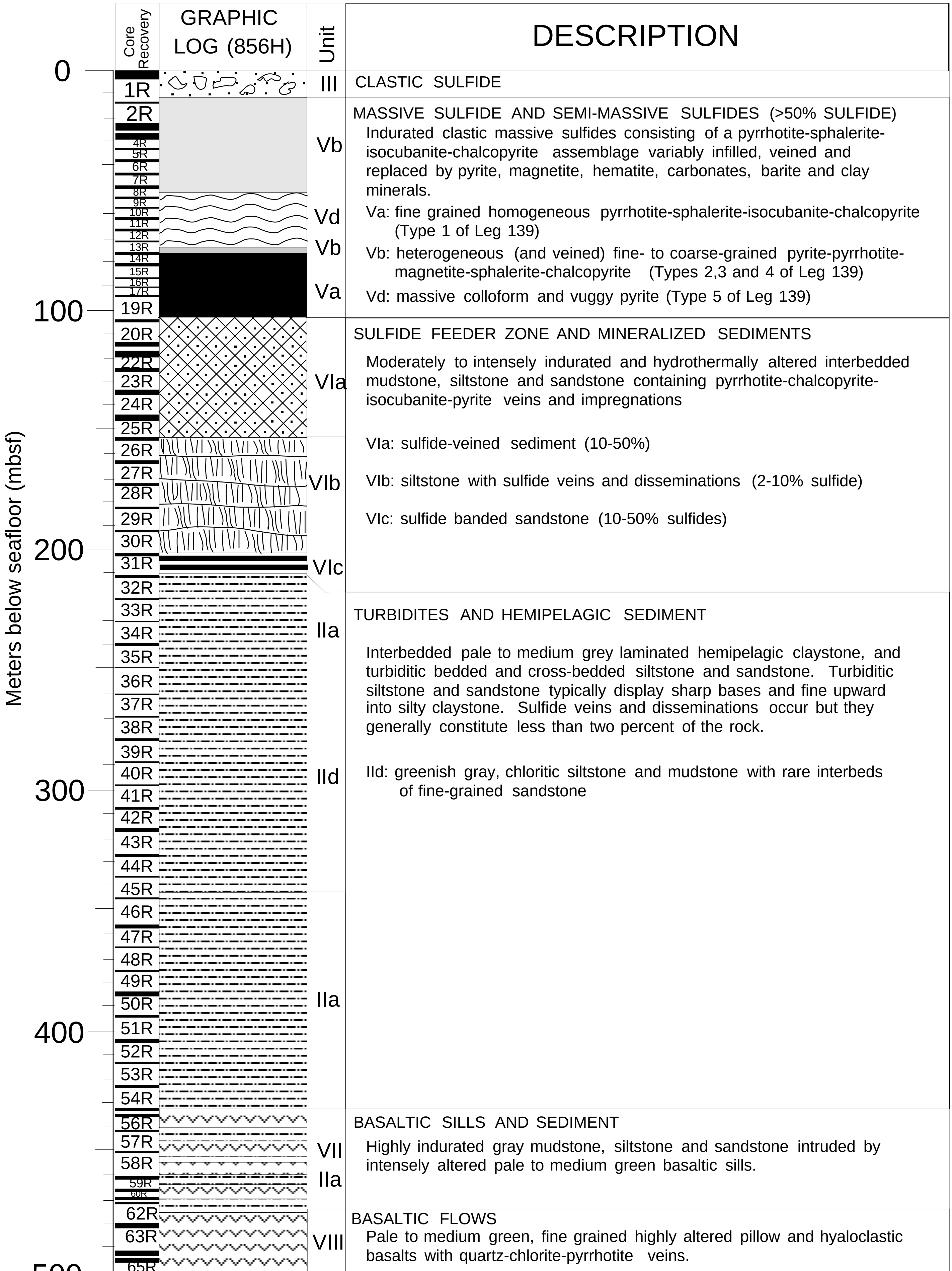


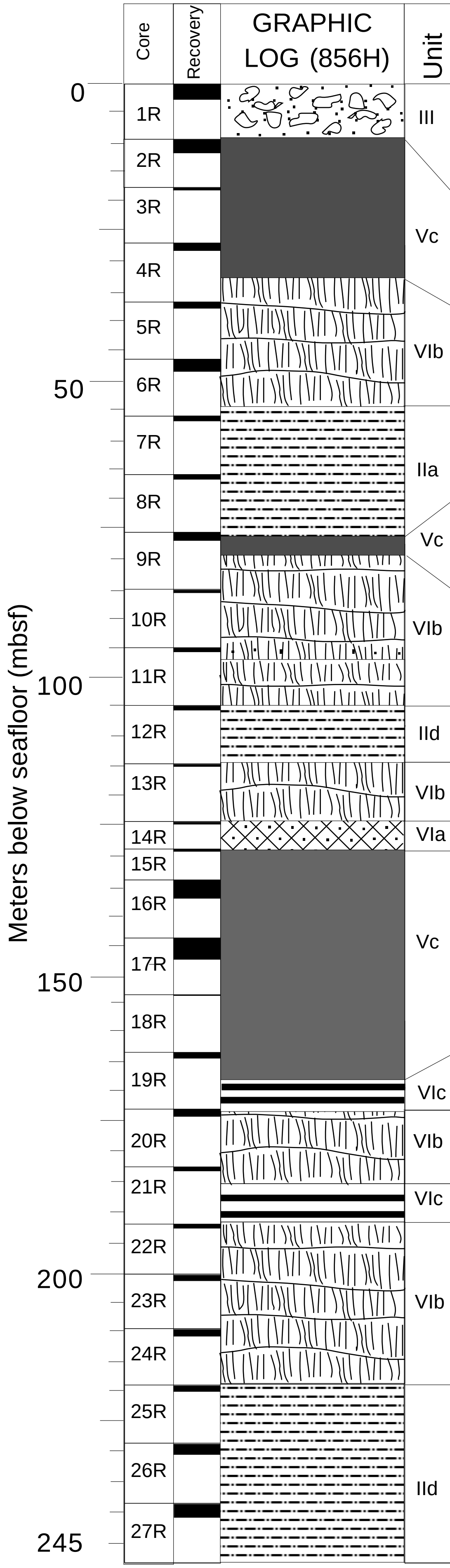
Sulfide

Lobate flows

Pillow basalt

Sediment


Meters below seafloor (mbsf)
0
100
200
300
400
500
Core Recovery
GRAPHIC LOG (856H)
Unit
DESCRIPTION
1R
2R
4R
5R
6R
7R
8R
9R
10R
11R
12R
13R
14R
15R
16R
17R
19R
20R
22R
23R
24R
25R
26R
27R
28R
29R
30R
31R
32R
33R
34R
35R
36R
37R
38R
39R
40R
41R
42R
43R
44R
45R
46R
47R
48R
49R
50R
51R
52R
53R
54R
56R
57R
58R
59R
60R
62R
63R
65R
III
Vb
Vd
Vb
Va
VIa
VIb
VIc
IIa
IId
IIa
VII
IIa
VIII
CLASTIC SULFIDE
MASSIVE SULFIDE AND SEMI-MASSIVE SULFIDES (>50% SULFIDE)
Indurated clastic massive sulfides consisting of a pyrrhotite-sphalerite-isocubanite-chalcopyrite assemblage variably infilled, veined and replaced by pyrite, magnetite, hematite, carbonates, barite and clay minerals.
Va: fine grained homogeneous pyrrhotite-sphalerite-isocubanite-chalcopyrite (Type 1 of Leg 139)
Vb: heterogeneous (and veined) fine- to coarse-grained pyrite-pyrrhotite-magnetite-sphalerite-chalcopyrite (Types 2,3 and 4 of Leg 139)
Vd: massive colloform and vuggy pyrite (Type 5 of Leg 139)
SULFIDE FEEDER ZONE AND MINERALIZED SEDIMENTS
Moderately to intensely indurated and hydrothermally altered interbedded mudstone, siltstone and sandstone containing pyrrhotite-chalcopyrite-isocubanite-pyrite veins and impregnations
VIa: sulfide-veined sediment (10-50%)
VIb: siltstone with sulfide veins and disseminations (2-10% sulfide)
VIc: sulfide banded sandstone (10-50% sulfides)
TURBIDITES AND HEMIPELAGIC SEDIMENT
Interbedded pale to medium grey laminated hemipelagic claystone, and turbiditic bedded and cross-bedded siltstone and sandstone. Turbiditic siltstone and sandstone typically display sharp bases and fine upward into silty claystone. Sulfide veins and disseminations occur but they generally constitute less than two percent of the rock.
IId: greenish gray, chloritic siltstone and mudstone with rare interbeds of fine-grained sandstone
BASALTIC SILLS AND SEDIMENT
Highly indurated gray mudstone, siltstone and sandstone intruded by intensely altered pale to medium green basaltic sills.
BASALTIC FLOWS
Pale to medium green, fine grained highly altered pillow and hyaloclastic basalts with quartz-chlorite-pyrrhotite veins.



DESCRIPTION

CLASTIC SULFIDES
Sulfide breccia consisting of irregular and angular sulfide clasts of vuggy pyrite and hydrothermally altered claystone.

MASSIVE AND SEMI-MASSIVE SULFIDES (>50% SULFIDE)
Sulfide breccia consisting of angular and variably sized clasts composed of pyrite, sphalerite, chalcopyrite, isocubanite, hematite and dolomite set in a matrix of finer grained clastic sulfides.

SULFIDE FEEDER ZONE AND MINERALIZED SEDIMENTS
Fine sandstone, siltstone and silty claystone with impregnations and minor veins of pyrrhotite, pyrite, sphalerite, chalcopyrite and anhydrite.

TURBIDITES AND HEMIPELAGIC SEDIMENTS
Interbedded indurated fine sandstone and claystone weakly mineralized with pyrrhotite veinlets and impregnations.

MASSIVE SULFIDES
Fine- to medium-grained massive sulfide composed of sphalerite, isocubanite, pyrite and pyrrhotite.

SULFIDE FEEDER ZONE AND MINERALIZED SEDIMENTS
Siltstone and fine sandstone with veins and impregnations of pyrrhotite and chalcopyrite. Sedimentary rocks are locally brecciated and hydrothermally altered to chlorite.

TURBIDITES AND HEMIPELAGIC SEDIMENTS
Sandstone altered to chlorite and with minor pyrrhotite and chalcopyrite.

SULFIDE FEEDER ZONE AND MINERALIZED SEDIMENTS
Fine sandstone and siltstone banded, veined and impregnated with dominantly pyrrhotite.

MASSIVE AND SEMI-MASSIVE SULFIDE WITH SEDIMENT
Compact to vuggy massive sulfide composed of black sphalerite (10-70%), pyrite (5- 60%), pyrrhotite (10-40%) and magnetite with a soft silicate mineral (talc or clay) filling voids.
Neoblastic pyrite variably infilled and replaced by black sphalerite (5-40%), magnetite, clay minerals (up to 60%), minor chalcopyrite and trace galena. Sediment has been hydrothermally altered to chlorite and minor epidote.

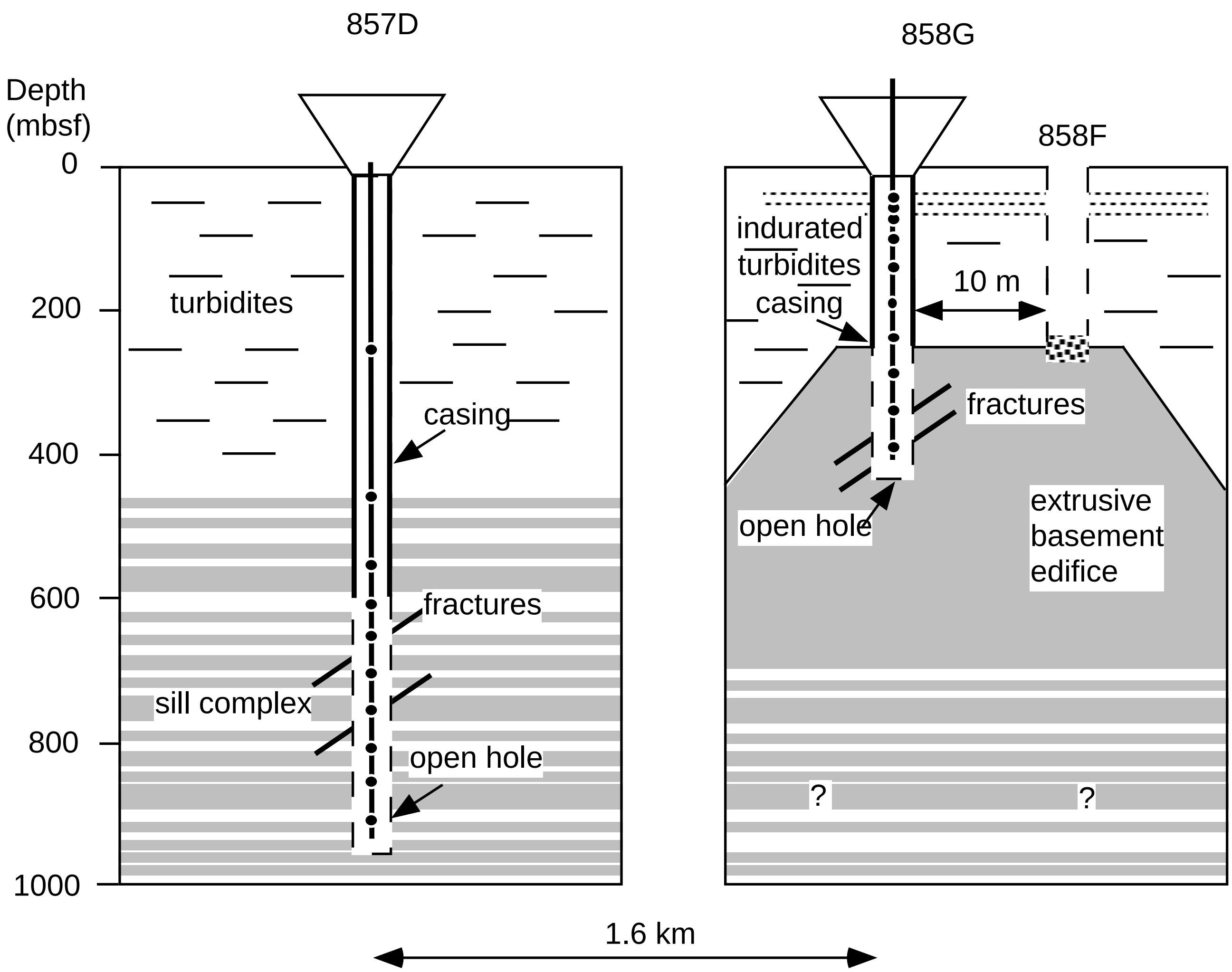
SULFIDE FEEDER ZONE AND MINERALIZED SEDIMENTS
VIc: Sulfide banded and impregnated sediment containing up to 80% Cu-Fe-sulfide and pyrrhotite within a matrix of hydrothermally altered mudstone.

VIc: Hydrothermally chloritized and silicified silty claystone, siltstone and sandstone with bands and impregnations of Cu-Fe-sulfides.

VIb: Interbedded claystone, siltstone and sandstone, partly silicified and containing impregnations of Cu-Fe-sulfides.

TURBIDITES AND HEMIPELAGIC SEDIMENTS

Interbedded claystone, siltstone and sandstone, partly silicified and and weakly chloritized, containing anhydrite molds. Minor disseminated pyrite occurs locally.


857D
858G
858F
Depth
(mbsf)
0
200
400
600
800
1000
turbidites
casing
fractures
sill complex
open hole
indurated
turbidites
casing
10 m
fractures
open hole
extrusive
basement
edifice
?
?
1.6 km

OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 169 were:

Operations Manager: Gene Pollard

Schlumberger Engineer: Jonathan Kreb

ODP Development Engineer: Leon Holloway

Engineering Technician: Jim Briggs

OVERVIEW

Objectives

Middle Valley had three holes planned at the Dead Dog active hydrothermal field, and several more planned at the Bent Hill inactive sulfide mound. An attempt was planned to deepen Hole 856H on Bent Hill, where a Drill-In-Casing had been set and the hole cored to 93.8 m during Leg 139. Holes 858G and 857D in the Middle Valley hydrothermal field were cased, and CORKs and instrumented strings were installed on Leg 139. Operations to remove and replace the instrument strings and CORKs in those boreholes were planned to allow subsurface sampling of hydrothermal fluids, allow sampling of hyper-thermophylic bacteria that may have colonized the thermistor strings, and permit determination of in situ temperature and pore pressure. Hole 857D was to be deepened as part of a hole-to-hole CORK experiment where the effects of circulating fluid in one hole might be monitored in another.

Leg 169 Technical Accomplishments

- Hole 856H (500.0 m total depth) was the first penetration of an oceanic sulfide mound through the massive sulfides, stockwork mineralization zone, underlying sediment, basalt sills, and upper pillow basalt section.
- The first logs were obtained through an oceanic sulfide mound at Hole 856H.
- Pop Up Pore Pressure Instruments (PUPPIs) were deployed and recovered at Holes 1036B and 1036C.

Report Depths and Times

Depth measurements are in meters. Unless otherwise noted, depths in this report refer to “meters below rig floor” (mbrf), in which drill pipe measurements (DPM) are referenced to the top of the “dual elevator stool” (DES) on the rig floor. The “DPM” depths on Leg 169 were 11.1-11.8 m above sea level (depending on the ship's draft). “Meters below sea floor” (mbsf) refers to the indicated depth below the seafloor, which is based on recovery or apparent seafloor contact for each hole. Unless otherwise noted, all times in this report refer to ship time. The shipboard clocks were maintained on US Western Time Zone = GMT -7 hr and College Station CST =GMT -5 hr. Shipboard times remained the same for the remainder of the leg. Sites were positioned during the leg by using the shipboard differential Global Positioning System (dGPS) to position on GPS coordinates from prior site surveys.

PORT CALL IN VICTORIA, B. C.

Leg 169 began with the first line ashore in Victoria, B. C. at the Ogden Point, WestCan Terminal, Pier A at 1515 hr on 21 August. Normal port call activities and unloading and loading had been completed on 16 and 17 August during the Leg 169S port call so the Leg 169 port call was primarily for the purpose of changing scientific parties. The cores from Saanich Inlet Holes 1033B and 1034B were off-loaded. The ship's departure was delayed for a few hours while a replacement flew in to replace the ODP curator, who had a medical problem. The last line ashore was at 0045 hr on 22 August, and the ship departed for Hole 858G.

TRANSIT FROM VICTORIA TO SITE 858

The 218 nmi transit from Victoria to Hole 858G required 20 hr and 25 min. at an average speed of 10.76 kts. The coarse was changed to clear a large fleet of fishing vessels.

SITE 858

Hole 858G

A Datasonics 354M retrievable commandable beacon (208 dB) was dropped at 2115 hr on 22 August on the dGPS coordinates for Hole 858G: Latitude 48˚27.360'N, Longitude 128˚42.531'W. A data logger retrieval BHA was run as follows: modified CORK running tool, pony drill collar, 2 X 8-1/4" drill collars (DC), tapered drill collar (TDC), 2 stands of 5-1/2" transition drill pipe, crossover (XO), and 5" drill pipe (DP). The BHA was positioned over Hole 858G at the given dGPS coordinates when the VIT-TV was run. The modified CORK running tool was jayed-in after numerous attempts by setting down a 15K lb weight and applying left hand torque. A 10K lb test-pull confirmed latch-in. The wireline fishing tool was run to retrieve the data logger. A 400 lb overpull was noted and it was assumed that the data logger released and was being retrieved at 2 m/min on the wireline. When the 400-m-long thermistor string would have been clear of the CORK, numerous unsuccessful attempts were made to unjay from the CORK. Something appeared to be preventing movement of the running tool. The ship was offset about 5 m in a circle around the site, and about 15K lb of weight were set down with right-hand torque to release the running tool. After unjaying, the ship was moved 20 m off the hole to retrieve the data logger overshot; however, it was empty and did not appear to have engaged the data logger. The running tool was pulled for inspection to determine why engagement and release were so difficult. The bottom end of the funnel was bent in two places (from setting down on ROV platform ribs?) and some brinelling was noted in the jay-slots, indicating that the running tool may have been tilted slightly relative to the CORK. The funnel was shortened by three inches, the jay slots were dressed, the skirt lip was beveled in the jay slot, the running tool was painted black to reduce glare from the TV lights, and the 75 W TV light was replaced with a 50 W bulb. The modified CORK running tool was run again; however, the seas had increased to 6-7 ft, heave was 1-2 m, the roll was erratic, and the weight indicator was varying by 20-30K lb. Although winds were only up to 17 kts on location, locally seas were in a confused state. The attempt to stab over the CORK was aborted and the tools were pulled out. The beacon was turned off and left in place for the return as soon as weather permitted.

SITE 856

Hole 856H

The ship was moved in DP mode to Hole 856H, where a Drill-in-Casing (DIC) had been set with 12 m of 11-3/4" casing during Leg 139. The hole had been cored to 93.8 mbsf, making it the deepest oceanic hole in sediment-covered massive sulfides. Operations were terminated on Leg 139 due to unstable hole problems; however, there was a possibility that several years of water flow in the open hole had cemented or stabilized some of the upper hole section. The plan was to obtain a temperature profile and fluid sample and attempt to deepen the hole. The water depth was 2434.5 mbrf. The RCBBHA was run as follows: 9-7/8" RBI CC-7 bit, MBR, HS, OCB, TS, HS, 7 X 8-1/4" DC,TDC, 2 stands of 5-1/2" transition DP, XO. The hole was relocated and reentered in 45 min. The bit encountered fill at 73.8 m, and the hole was washed 20 m in soft fill to TD at 93.8 m with moderate torque and packing-off on the last connection. RCB wash barrel Core 169-856H-18W was pulled with 3 pieces of massive sulfide recovered. RCB Cores 169-856H-19R to 65R were taken from 93.8 to500.0 m with 12.1% recovery. Coring 406.2 m required 88.5 operating hours including two precautionary short trips. The rate of penetration averaged 5.0 m/hr in massive sulfides and 38.4 m/hr in thermally altered mudstones. Recovery was reduced by brittle mudstone fracturing and jamming in the 8 finger and 8 finger combination core catchers and core liner. The massive sulfide zone extended to 110 m, with a sulfide stringer zone of hydrothermally altered mudstone with sulfide veins and pyrite banding to 202 m. Below the sulfides were brittle mudstones to 432 m, basalt sills and sediment to 472 m, and pillow basalts and flows to 500 m. Hole conditions while coring on Leg 169 were good with only occasional erratic torque and fill on connections. Sepiolite mud sweeps were circulated near the end of each core. Coring parameters were 10-25 Kips WOB and 50 rpm at 100-200 amps torque, circulating 250 gpm at 350 psi.

After conditioning the hole for logs, the core bit was dropped on the seafloor to leave the hole clean for future drilling. The hole was reentered with the open end drill string, which was parked at 22.5 m for logging. The main logging tools had relatively low temperature ratings (Triple Combo and Sonic/FMS to 175˚C and Geochem to 130˚C); therefore, a temperature run was planned first to check bottom hole temperatures and thermal rebound rates. The temperature tool from the Bureau de Recherche Geologique et Miniere in Orleans (BRGM)was chosen for the first run because it was rated to 250°C. The 2.5-m-long BRGM temperature tool weighed only about 50 kg; therefore, the loggers were advised that it was not heavy enough to meet ODP third party tool guidelines (227 kg minimum). A 1-1/2" slotted sinker bar (30 kg) was added to the line but the tool weight was still not adequate to permit the winch operator to “see” the tool. The logging line was run to an apparent depth of 471 m but the BRGM tool was pulled because of erratic readings. The logging tool had evidently stopped on a shallow ledge or bridge at about 61 m (without the winch operator's knowledge) while the logging line continued to be run into the hole. The new Schlumberger high-temperature logging line was twisted, kinked, and knotted and 300 m were cut off. An attempt was made to clean out the ledges with the open end pipe. It was worked past ledges from 50 to 63 m, but could not be worked deeper and was pulled. The bit was not dropped in the hole because the intention was to leave the hole clear for future deepening.

DEPLOYING PUPPI's

On 29 August, the ship was moved in DP mode to Site 1036 and while tripping pipe a PUPPI was dropped on the locations of planned Holes 1036B and 1036C. The ship then returned to Hole 856H.

RETURN TO HOLE 856H

A reentry/logging bit was run because the problem was assumed to be ledges based on Leg 139 logs and open end pipe behavior. The hole was reentered in 45 min. The reentry/cleanout bit could not be worked past an obstruction at 61 m, where a ledge was evident on Leg 139 logs. The logging bit was pulled and severe wear was noted on the throat and outside of the bit face, indicating a hard material had blocked the hole. The hole was unstable and bridging over so a 9-7/8" Smith three-cone drill bit was run to clean out the hole. The hole was reamed as required from 36.5 to 93.5, 126.5 to 209.5, 375.5 to 395.5, and 487.5 to 500.0 mbsf. A conditioning trip was made back to 85 m, and 11 m of fill was cleaned out on bottom. Sepiolite mud (115 bbl) was spotted in the hole in an effort to stabilize it and reduce the inflow of hot water and the bit was dropped in the bottom of the hole. The open end pipe was pulled to 85 m for logging. The Triple Combo log was run to 495 m. The GR/Sonic/FMS log was run to 491 m; however, the FMS data was erratic (the internal tool temperature read 86˚C). The tool appeared to be slipping with and without the wireline heave compensator. The tool was pulled, and an external temperature tab read

182˚C (the FMS temperature limit is 175˚C). The Schlumberger FMS logging tool has an internal temperature sensor that was reading 90˚C. The FMS sonde was damaged by heat and the transmitter was damaged, which left only one operational FMS tool. The open end drill string was run to 500 m, and the hole was circulated 1 hour (2 hole volumes) to cool the hole. The pipe was pulled back to 85 m, and the second run was made with the GR/FMS (no Sonic) to 385 m. The second FMS run was successful, but the external temperature tab read 176˚ C when the tool was retrieved, so the geochemical log was canceled because its temperature limit is 130˚C. The pipe was pulled, clearing the rotary table at 1330 hr on 1 September. The primary beacon was generating erratic signals, so it was recovered. The backup beacon was turned off for the return to Site 1035. The pipe cleared the rotary at 1330 hr on 1 September.

RETURN TO HOLE 858G

The ship returned to Hole 858G in DP mode during the trip to pickup the modified CORK running tool. The environmental conditions were good (seas 2 ft, swells 5 ft, heave 0.6 m). The hole was reentered in 15 min; however, the running tool rotated freely indicating that it had not jayed-in. After putting 15 K lb on the running tool, an overpull to 10 K lb indicated successful jay-in. The data logger overshot was run on wireline, and an unsuccessful attempt was made to retrieve the data logger by jarring and pumping with 15 K lb weight down to 10 K lb tension on the running tool. The running tool appeared to release easily, and the TV showed the upper portion of the CORK and possibly the upper mandrel and data logger (without instrument cable) engaged in the running tool body. The overshot was retrieved, and the running tool was retrieved; however, the fish was lost. The jay-slots in the running tool had engaged the CORK; therefore, they must have un-jayed and dropped the fish while pulling back to the ship.

The CORK pulling tool was run in an attempt to retrieve the bottom latch and seal portion of the CORK. The reentry required 2.25 hr and was more difficult because the flat skirt on the tool was difficult to position in the small throat on the flat ROV platform. A tapered throat on the ROV platform would aid in reentry. The CORK pulling tool was spudded and circulated down several meters into the throat with 15 Kips and 250 gpm at 150 psi; however, the tool would not jay into the lower CORK body. The evidence indicated that the running tool might be hanging up on the ROV platform. The ROV platform pulling tool was modified to change it from wireline to free fall deployment. It was dropped and engaged the ROV platform grating with both arms.

A considerable quantity of material was circulated out of the reentry cone throat. The pipe had been worked up and down and circulated while installing the platform tool, and the pipe had gone down another 1.5 m over the CORK. When an attempt was made to pull the platform pulling tool, the CORK tool was found to have been jayed-in while washing and working the tool. The CORK was pulled with increasing tension and circulated for 45 min., finally coming free with 100,000 lb overpull.

The lower CORK body and ROV platform were pulled to the ship in 4.25 hr, and the tools were laid down in 5 hr, including sampling for biological samples and minerals. The ROV platform was only held by one blade on the platform pulling tool, and both blades on the other arm had been overloaded and bent down. The inside of the lower CORK body was full of 3" thick mineralized deposits. The viton seals were brittle and had failed, allowing hydrothermal fluids to circulated past the seals and through the upper CORK body until the mineral deposits choked off flow. The nuts were gone (by cathodic corrosion?) from 4 of 8 release rods. All surfaces were coated with fine black film about 1 mm thick. The 400-m-long kevlar thermistor string and 2-m-long stainless steel weight bar remained in the hole. No trace of the kevlar was found.

A 9-7/8" RBI C-7 RCB bit was run to clean out the hole if required, and the bit was set at 2446 mbrf (20 mbsf) for fluid sampling. The WSTP tool was run to 2443 m, and a good hydrothermal fluid sample was obtained. However, the 150 C limit of the temperature tool was approached, the gradient record was lost, and an O-ring leak shorted out the electronics. The “Ultra High Temperature-Multi Sensor Memory-Geophysical Research

Corporation” (UHT-MSM-GRC or Becker) temperature tool was run for the first time ever. The tool is 8.5 ft long x 2-1/8 in. OD, has a temperature rating of 350˚C, and is run on the coring wireline. The Becker tool set down on an obstruction at 2631 mbrf (205 mbsf = 64.7 m above the 11-3/4" casing shoe) and read a constant 273˚C from 205 to20 m, which indicates flow up the hole. The lithium batteries were 90˚C when the tool was retrieved; therefore, the batteries were allowed to cool before extracting the samples. The lithium batteries have a temperature rating of 150˚C and could explode at 180˚C. A safety procedure was adopted to cool the batteries on future runs.

The Los Alamos fluid sampler tool was run in to 200 m (2526 mbrf); however, the viton valve seats melted and the hydrothermal fluid sample had mixed with seawater on the wireline trip out. The bit tagged fill at 205 m (same as the Becker tool). To avoid circulating cold seawater into the hole, an unsuccessful attempt was made to rotate down without circulation. The hole was cleaned out to 387 m in soft material, but the pipe stuck at 326 mbsf when pulling out of the hole. The pipe was worked for 4 hr at up to 200 K lb overpull, the rotary was stalled at 800 amps, and the hole was packing off (500 psi at 50 gpm). To avoid contaminating the hole for water samples, no mud had been pumped while cleaning out the hole as requested. The kevlar thermistor string was initially suspected as causing the stuck pipe incident by wadding up around the BHA; however, an inspection with the bit in the reentry cone showed the BHA was clean. A 20 and 30 bbl tandem sepiolite mud sweep was circulated and immediately freed the pipe.

Wash barrel 169-858G-18W was retrieved with loose sulfides, anhydrites, and plastic electrical wrap and insulation from the thermistor string. No kevlar was ever recovered, leading to speculation that it had fallen apart. The problem was evidently a combination of a boulder or ledge sticking at the shoe and inadequate hole cleaning with seawater. The pipe actually stuck a second time at 278 mbsf because circulation stopped before the mud cleared the seafloor. The reentry cone throat in the CORK setting and seal area was washed and rotated in with the bit, and a short trip was made to 385 mbsf without tagging fill. The 9-7/8" RBI CC-7 bit was pulled after 31 hr in 273˚C hydrothermal fluid. The body was blackened, the cones rotated easily, and a few teeth were chipped; however, the bit still appeared usable.

The CORK BHA was run as follows: stinger of 2 joints of 7-1/4" DC, crossover, CORK assembly (11-3/4" stretch version), CORK setting tool, seal bore pony DC, 5 joints 8-1/4" DC, tapered DC, 6 joints of 5-1/2" DP, crossover. The hole was reentered at 2130 hr on 4 September. A 400-m-long kevlar-encased thermistor string (8 sensors) was run with a 2-m stainless steel sinker bar on bottom. The data logger was latched in and had to be jarred off. The CORK was landed and latched in at 1000 psi. A 10K lb pull verified latch in. The CORK was released at 0745 hr on 5 September. A new solid deck ROV platform was dropped, and a TV inspection showed the platform and CORK were in good shape. The beacon was turned off for a later return to the Dead Dog sites. The weather forecast was good for the next few days so a decision was made to go to Hole 857D for another CORK replacement job.

HOLE 857D

The 0.6 nmi transit was made in 1 hr in DP mode while running pipe. A Datasonics 354M beacon was deployed twice and released for unknown reasons; therefore, another beacon was dropped. Hole 857D had been drilled to 936 m on Leg 139 and has a reentry cone with 11-3/4" casing set at 573.8 m (3005.0 mbrf). The water depth is 2431.5 mbrf. A CORK was set with a 300-m-long thermistor and fluid sampler string. The CORK was knocked over on Leg 146 by a collision with the running tool in high heave conditions. The *Alvin* submersible installed an overshot on the data logger in a subsequent unsuccessful fishing attempt, but the rope broke. The object was to retrieve the damaged CORK and 300-m thermistor string, deepen the hole, and reCORK the hole.

A CORK pulling BHA was run consisting of: CORK running tool, seal bore pony DC, 5 joints 8-1/4" DC, tapered DC, 6 joints of 5-1/2" DP, crossover. The running tool was stabbed over the damaged CORK data logger at 1945 hr on 5 September. An unsuccessful attempt was made to wash down over the CORK. Interference with the ROV platform was suspected (the platform was damaged from a heavy blow on Leg 146); therefore, the platform pulling tool was dropped. The platform pulling tool engaged both arms, and the platform came free with 40 Kips pull. No other fish could be seen and the platform was dropped on the seafloor 70 m southwest of Hole 857D to save time.

On returning to the platform, it was noted that the data logger was missing and a fish was in the CORK pulling tool. The data logger was recovered with the upper CORK body (above the sealing bulkhead and six release rods). The 300-m thermistor string and sinker bar was lost in the hole. The CORK body had few deposits and appeared to have been an effective seal. A long length of rope dumped by the *Alvin* was wrapped around the CORK body while dropping the platform. The remaining CORK fish was a 5-1/4 in. diameter data logger seal sleeve and mandrel extending 26 in. above a sealing bulkhead, with a latch ring, seal, and lower CORK body below. The seal sleeve was 10 in. below the throat (if all of the fish was recovered after rotating in the sea floor to dump the platform). An 8-7/8 in. overshot with a 5-3/8 in. basket grapple was slightly larger than desirable; however, it was the closest catch size available for an outside catch of the fish. The cut lip guide was shortened, and a 22 in. funnel was welded above the overshot to act as a centering guide in the 24 in. wide reentry cone throat. A bumper sub was run because the weather was deteriorating rapidly with 18-27 kt winds and rain.

The overshot could not be stabbed over the fish, and marks on the overshot indicated that the centering guide was ineffective because it was too far above the cut lip guide. The centering guide could not be welded to the overshot body; therefore, it was welded on a short 9-5/8 in. stem so the funnel could be positioned just above the cut lip guide. The overshot assembly was run again without the bumper sub. The overshot was engaged and the fish pulled free with 30K lb. The ship was offset 70 m southwest, and the overshot was pulled. No fish was recovered; however, the grapple indicated it had been over a fish; therefore, it was assumed that the fish was dropped on the seafloor to the southwest.

A wireline spear was selected to fish the thermistor string, sinker bar, and the bottom of the data logger (if they remained in the hole). The spear had a hole in the nose so the temperature and fluid samplers were checked to ensure adequate internal clearance and the top plate and nose holes were beveled. The wireline spear was run in to the seafloor, and the seafloor was searched for the dropped fish without success. The spear reentered Hole 857D, and tagged an obstruction at 20.8 mbsf. The spear was rotated to secure the cable fish, and pulled to the ship with cable trailing from the cone throat. The ship was turned broadside to the current, the center thrusters were shut down, and observers were posted to look for floating cable as a precaution. A significant portion of the thermistor string was recovered (but not the sinker bar), consisting of >200 m of braided kevlar cable and tygon water sample tube. The water sample tube was clamped off in sections to preserve fluid samples. The braided kevlar jacket had deteriorated progressively with depth below 200 m. The bottom of the sample tube was colored and plugged with clay, indicating possible contact with sediments. Four 1/2 by 3 in. long spear prongs were left in the hole in addition to the 270-lb thermistor sinker bar. The temperature and fluid sampler tools were being serviced and repaired; therefore, a decision was made to go to Site 1035, and the beacon (S/N 1253) was turned off. The bit cleared the rotary table at 2100 hr on 7 September.

SITE 1035

Hole 1035A (Proposed Site BH-3)

The ship was moved in DP mode to Hole 1035A at 48 26.020'N, 128 40.920'W about 73 m west of Hole 856H. The beacon (S/N 1256) from Hole 856H could not be turned back on and a new beacon (S/N 614) was dropped. An APC/XCB/MDCB BHA was run as follows: 11-7/16" Security S86F 4-cone core bit (S/N 478459), LBS w/ LFV, SBDC,LSS, LTS, MHS, 10' DCS, MDCB latch sub, 5 X 8-1/4" DC, tapered DC, 6 jts 5-1/2"transition DP, crossover, and 5" DP. Hole 1035A was spudded at 0600 hr on 8 September. The seafloor was at 2456.4 mbrf. APC Cores 1035A-1H to 6H were taken from 0 to 55.0 m with 100%

recovery in clays and sulfide sands and breccias. The last two cores were partial strokes with 20-40K lb overpull, and the liner was shattered on the last core, prompting a change to the XCB system. XCB Cores 169-1035A-7X to 19X were taken from 55.0 to 170.8 m with 55.6% recovery in clays and sulfides. Five of 13 cores jammed in the core catcher, and the XCB hard formation shoe was destroyed on the last core. A decision was made to return to Hole 857D to finish the cleanout and CORK installation. The bit cleared the rotary table at 2100 hr on 9 September. Beacon S/N 1256 was recovered and beacon S/N614 was turned off.

Return to Hole 857D

The ship was moved in DP mode back to Hole 857D while tripping pipe. The beacon (S/N 1253) was turned back on. A 9-7/8" RBI CC-7 core bit (S/N BK317) was run with a FV, BS, OCB, TS, HS, 4 DC, TDC, 2 stands 5-1/2" DP, XO. Hole 857D was reentered at 2200 hr on 9 September, and the bit was run in to 22 m. Silt stirred up in the water was being sucked down the hole, confirming that the hole was still taking water. A sinker bar was run in to 642 m, and an external temperature tab indicated the maximum temperature was less than 108˚C. Drill pipe was run in to 377 m, where an obstruction was noted. The hole was washed and reamed from 359 to 446 m against generally light resistance using 5K lb wob. The pipe was run in to 621 m, and a WSTP water sample was taken. The temperature was 2˚C, and the sample proved to be seawater, which confirmed a strong down flow to that depth. The hole was washed and reamed against light resistance from 611 to 929 m (3360 mbrf or 8 m above TD).

Left in Hole 857D are one 2-1/2" by 2-m-long 270-lb thermistor sinker bar and 4 each 1/2" X 3" long wireline spear prongs. A decision was made not to deepen the hole due to time constraints and a questionable long term weather forecast. Hole conditions appeared to be stable with occasional light resistance and minor ledges noted. The bit cleared the rotary at 2000 hr on 10 September and had anhydrite on the teeth and spiral stabilizer blades. The CORK assembly consisted of: stinger of 3 junk knobby joints, XO, CORK assembly (11-

3/4" stretch version), CORK running tool, S. Sub, 5 DC, TDC, 2 std 5-1/2"DP, XO. Hole 857D was reentered at 0200 hr on 11 September. A 2-1/2" by 2-m-long 270-lb sinker bar, 898 m of 5/8" braided kevlar thermistor string with 9 thermistors, and a data logger were run on CWL, latched into the CORK, and test pulled to 15K lb. The ROV platform was dropped at 0845 hr. The installation was checked with the TV, and the CORK was released at 1000 hr. The running tool cleared the rotary at 1445 hr on 11 September.

Hole 1035B (Proposed Site BH-7)

The ship was moved in DP mode to Hole 1035B about 51 m south of the Bent Hill massive sulfide deposit. The same APC/XCB/MDCB BHA was run without a monel DC. Hole 1035B was spudded at 2130 hr on 11 September. Core 169-1035B-1H was a partial stroke in a hard layer near the seafloor, and the core barrel could not be pulled. The TV revealed that the core barrel was bent at ~90˚. The pipe was pulled, and a small sample of mud was taken for paleontological reference from the bent core barrel and archived as Core 169-1035B-1H. The bit cleared the rotary at 0530 hr on 12 September.

Hole 1035C (Proposed Site BH-7)

The ship was not moved because hard massive sulfides at the seafloor were assumed to be the cause of the APC refusal on Hole 1035B. The VIT-TV was run because of the bent core barrel and an unclear seafloor indication on the PDR (2465.4-2469.4 mbrf), and the seafloor was found at 2459.0 mbrf. Hole 1035C was spudded at 1215 hr on 12 September. The XCB coring system was used for spudding because of the hard surface. XCB Cores 169-1035C-1X to 5X were taken from 0 to 44.0 m (2503.0 mbrf) with 4.8% recovery. Core 169-1035C-4X had some torque and a mud sweep was circulated. On Core 169-1035C-5X, there was 7 m of fill on the connection and the torque increased despite circulating another mud sweep. The pipe was pulled because the hole was unstable and caving in. The bit cleared the seafloor at 2050 hr on 12 September. A strobe light was noted on the surface about 1 nmi northwest of the ship. As soon as the bit cleared the seafloor, the ship gave chase on the assumption that one or both of the PUPPIs had released prematurely. Beacon

774 was recovered and had released for unknown reasons from near Hole 858G on Dead Dog mound.

Hole 1035D (Proposed Site BH-2)

The ship was moved in DP mode to Hole 1035D on the east side of the Bent Hill massive sulfide deposit about 73 m east of Hole 856H. The water depth was 2459.8 mbrf. Hole 1035D was spudded at 0100 hr on 13 September. APC Cores 169-1035D-1H to 5H were taken from 0 to 40.6 m (2500.4 mbrf) with 110.5% recovery. Core 169-1035D-5H was a partial stroke that penetrated no more than 7.0 m (the bit hit a hard layer) and had at least 2 m of suck-in for a 9.91-m apparent recovery. XCB Cores 169-1035D-6X to 7X were taken from 40.6 to 57.7 m with 2.9% recovery. Recovery was very poor in the black sulfide powder matrix with massive pyrite nodules. Broken sulfides, anhydrite, and pyrite nodules jammed in the core catchers. Massive sulfides with anhydrite cementation were cored successfully at TAG using the MDCB system, and anhydrite cementation was increasing; therefore, the MDCB system was run in an attempt to improve recovery. The hole was drilled with an XCB shoe and center bit from 57.7 to 59.3 m, and a mud sweep was circulated to clean the hole. The MDCB was run with standard thruster and bit nozzles, 5K lb wob, and no DP rotation, circulating 38 spm (190 gpm) at 1225-1200 psi. Core 169-1035D-8N was taken from 59.3 to 60.8 m (1.5 m stroke per paint marks on the core barrel) in 15 min. with 0.09 m (6.0%) recovery. The piece of massive sulfide and pyrite indicated rotation in the core catcher. XCB coring was resumed with Cores 169-1035D-9X to 24X from 60.8 to 178.5 m (2638.3 mbrf) with 5.0% recovery. Recovery was poor because 13 of 18 XCB cores jammed in the XCB shoe throat and core catcher. Operations were terminated when the objective of the hard layer at about 170 mbsf was reached.

Hole 1035E (Prospectus Site BH7)

The ship was moved in DP mode to the next location at Hole 1035E (site BH) about 100 m south of Hole 856H. The water depth was 2465.0 mbrf. APC Cores 169-1035E-1H to 5H were taken from 0 to 45.5 m (2510.5 mbrf) with 104.8% recovery. Core 169-1035E-5H was a partial stroke that bounced back and wrapped the coring wireline (CWL) around the sinker bars. The CWL then parted at 12K lb overpull when attempting to pull it, and the BHA was pulled.

SITE 1036

Hole 1036A (Prospectus Site DD-1)

The ship was moved in DP mode to Site 1036. A TV survey was run for 2.25 hr to locate the top of the Dead Dog mound and confirm that the site was free of clams. The water depth was 2419.0 mbrf. Hole 1036A was spudded at 2115 hr on 15 September. APC Cores 169-1036A-1H to 4H were taken from 0 to 33.0 m (2452.0 mbrf) with 103.8% recovery. Core 169-1036A-4H was a partial stroke and the core liner had to be pumped out of the core barrel in pieces. XCB Cores 169-1036A-5X to 6X were taken from 33.0 to 38.5 m (2457.5 mbrf) with 10.0% recovery. The XCB shoe was destroyed in 45 min. on Core 169-1036A-6X; therefore, XCB coring was terminated. The bit cleared the seafloor at 0730 hr on 16 September.

Hole 1036B (Prospectus Site DD-2)

The ship was moved in DP mode to Hole 1036B. A TV survey was run for 1.75 hr to locate the edge of the Dead Dog mound and confirm that the site was free of clams. The seafloor was tagged at 2426.0 mbrf. Hole 1036B was spudded at 0945 hr. APC Cores 169-1036B-1H to 3H were taken from 0 to 27.7 m with 102.1% recovery. XCB Cores 169-1036B-4X to 6X were taken from 27.7 to 52.3 m (2479.1 mbrf) with 75.0% recovery. The hole was terminated at the target depth. The bit cleared the seafloor at 1830 hr on 16 September.

Hole 1036C (Prospectus Site DD-3)

The ship was moved in DP mode to Hole 1036C off the edge of Dead Dog mound. Hole1036C was spudded at 2045 hr on 16 September. The seafloor was estimated at 2425.1 mbrf. APC Cores 169-1036C-1H to 4H were taken from 0 to 34.9 m with 101.2% recovery. XCB Cores 169-1036C-5X to 6X were taken from 34.9 to 54.2 m (2479.3 mbrf) with

60.0% recovery. The XCB shoe was destroyed, and the hole was terminated at the target depth. The bit cleared the rotary table at 1000 hr on 17 September.

RECOVERING PUPPI's

The two PUPPIs that were deployed at Dead Dog mound on 29 August were recalled and recovered. Initial analysis of the pressures recorded by the PUPPIs indicates that the shallow sediment is underpressured relative to the seafloor (i.e., the area is an inflow zone).

Hole 1035F (Prospectus Site BH-7)

The ship was moved in DP mode back to Hole 1035B and offset 10 m south to improve the 3-dimensional image of the Bent Hill massive sulfide deposit by using rotary coring to recover the deeper sections. The hole was at the base of the Bent Hill massive sulfide mound and 40 m south of Hole 856H. The same RCB BHA was run with an MBR to release the bit in case the pipe became stuck at the bit. The seafloor was assumed to be at 2459.0 mbrf. Hole 1035F was spudded at 1500 hr on 17 September. RCB Cores 169-1035F-1R to 23R were taken from 0 to 224.8 m (2683.8 mbrf) with 10.0% recovery. The upper hole was unstable, and two sepiolite mud sweeps were required to stabilize the hole. Torque and hole fill were controlled with sepiolite mud sweeps every other core. Five of 23 cores were jammed in the bit throat or core catcher. The plan was to return to Hole 1035F for logs after completing other work; therefore, a Free Fall Funnel (FFF) was deployed. The FFF position was concealed by heavy flow coming out of the hole; however, the FFF appeared to be in position based on sonar returns. The bit cleared the seafloor at 1000 hr.

Hole 1035G (Prospectus Site BH-3)

The ship was moved in DP mode back to Hole 1035A and offset 10 m east (near the base of the mound) to recover the deeper sections. The hole was 65 m west of Hole 856H. The seafloor was tagged at 2456.0 mbrf while the TV was down. Hole 1035G was spudded at 1245 hr on 19 September. The hole was washed from 0 to 44.4 m with a center bit through the silty clay interval, and wash barrel Core 169-1035G-1W had no recovery. RCB Cores

169-1035G-2R to 5R were taken from 44.4 to 83.3 m in the massive sulfide and stringer zone. The hole was washed from 83.3-140.9 m in silty claystone, and wash barrel Core 169-1035G-6W had 4.5 m recovery. RCB Cores 169-1035G-7R to 13R were taken from 140.9 to 208.5 m (2664.5 mbrf). Coring was terminated at the target depth. The VIT-TV was run to the seafloor, and a ±15 in. hole was observed with a small cuttings mound, no crater, and no visible flow in or out.

Return to Hole 1035F

The ship was moved in DP mode back to Hole 1035F with the VIT-TV down. A strong flow was observed coming out of the FFF throat and billowing upward to more than 40 m above seafloor with abundant suspended debris.

Hole 1035H (Proposed Site BH-8)

The ship was moved in DP mode to the mound 200 m south of the BHMS deposit (now called ODPMS mound). The mound was surveyed for a good core site on the upper plateau. Hole 1035H was spudded at 2030 hr on 20 September on a reasonably flat bench, adjacent to an inactive toppled chimney and 8 m from the top of the mound. The seafloor was tagged at 2455 mbrf. RCB Cores 169-1035H-1R to 16R were taken from 0 to 142.3 m (2597.3 mbrf) with 12.5% recovery. The standard butyrate (tenite) core liners are rated to 150°C service. On Core 169-1035H-11R, the butyrate liner melted completely (into a white lump around the core) during a 20-minute shutdown when the overshot sheared. The butyrate core liners on Cores 169-1035H-12R to 14R were partially melted.The quick-release polypak seal at the top of the RCB inner barrel (OD3203) was melted on some runs.

After Core 169-1035H-16R at 142.3 m, the pipe was pulled up to 74.3 m, and the Los Alamos water sampler was run. The sampler timer slid back in the case and failed to go off. A temperature tab on the sampler turned black out to 399°C. The VIT-TV was run to the seafloor, and a strong flow was observed coming from the hole. RCB Cores 169-1035H-17R to 27R were taken from 142.3 to 247.9 m with 11.1% recovery. Coring was terminated due to time constraints. The Ultem core liners were used well above the design temperature of 200 C on Cores 169-1035H-15R to 27R by maintaining circulation at 175 gpm. The liners are extrusion fabricated at 330°-357°C. On Core 169-1035H-26R, an Ultem liner melted (like shrink wrap) around the core and sucked into a V shape above the core. The core was cold when recovered.

On Core 169-1035H-26R, the torque increased from 150 to 200 amps and pressure increased from 400 to 550 psi. The pipe was pulled to 74.5 m, and a perforated and blanked off core catcher sub was run with various temperature sensitive tabs and materials (lead, tin, and engineering materials such as O-rings and seals). The temperature tabs indicated a 316°C flowing temperature; however, water may have invaded the tab. The butyrate core liner samples were melted and black, the 200°C Ultem liner sample was melted, the APC seal ring was dissolved, but the viton and 70 and 90 durometer O-rings were not affected. The Los Alamos water sampler was run to 74.5 m but failed to get a sample when the O-rings and valve seat failed. The VIT-TV was run to check the wellbore, and sample nets were attached to the VIT frame to trap material being expelled from the hole. There was a heavy and relatively-clear flow out of the hole with small flakes being blown up to 22 m above the hole. The VIT sample net was run to 6 m above the seafloor and recovered anhydrite flakes, sediment pebbles, and massive sulfide flakes to 2-cm diameter. Some sea surface shrimp and crustaceans were also recovered. The bit cleared the rotary at 0530 hr on 23 September.

The drill pipe that had been below the seafloor and the BHA were coated with 1/16 in. of anhydrite and clay. All the connections were broken, checked, and redoped as a precaution. The dope had been dried out, and the threads were dry. The bottom two drill collars had to be broken out with rig tongs; however, there was no obvious thread damage. The MBR was cemented up with anhydrite and had to be junked. The 9-7/8" RBI CC-7 bit was graded T7B7, SF, BT, CT, LT, I, TD, NR, and had extensive tooth loss in the heel rows, some broken and chipped teeth in the intermediate rows, four loose cones with failed seals, and minor stabilizer gage wear. The bit cored 681.2 m in massive sulfides in 38.4 rotating hours, and logged at least 116 hr in hot holes. The beacon was recovered.

Medivac

Vancouver Island Helicopters chopper arrived at 1130 hr on 22 September to medivac an ODL employee suffering from internal bleeding. The chopper took 75 gal of helifuel and departed at 1200 hr for Victoria General Hospital.

TRANSIT TO ESCANABA TROUGH

The 447 nmi transit to Escanaba Trough required 40.75 hr at an average speed of 10.6kt. The ship was slowed to 6 kt, the new 6-channel seismic streamer was deployed to check the signal, and a 6-nmi survey was completed in 1.75 hr. A Datasonics 354M 211dB beacon was dropped at 2300 hr on 24 September on Prospectus Site ET-7 at 40 57.30'N, 127 30.90'W. The standard APC/XCB BHA was run.

SITE 1037 (PROPOSED SITE ET-7)

Hole 1037A

Hole 1037A was spudded at 0800 hr on 25 September. The seafloor was estimated at 3314.0 mbrf based on recovery. APC Core 169-1037A-1H was taken from 0 to 9.5 m (3323.5 mbrf). The recovery was a full core liner (9.79 m) for 103.1% recovery; therefore, the seafloor core and measurement were questionable and the hole was spudded again.

Hole 1037B

Hole 1037B was spudded at 0840 hr on 25 September. The seafloor was estimated at 3311.9 mbrf based on recovery. APC Cores 169-1037B-1H to 19H were taken from 0 to 177.6 mbsf (3489.5 mbrf) with 99.4% recovery. No orientation was done, but Adara temperature measurements were taken on Cores 169-1037B-3H, 5H, 7H, and 9H. A WSTP temperature run was cancelled because the formation became too hard. Twelve of the last 13 cores were partial strokes. XCB Cores 169-1037B-20X to 55X were taken from 177.6-501.2 mbsf (to 3813.1 mbrf) with 73.1% recovery. Core 169-1037B-53X was pulled after coring 5.5 m in 75 min. and wearing out a soft formation XCB shoe. Core 169-1037B-54X cored 4.1 m in 105 min. and the shoe was jammed. Core 169-1037B-55X was pulled after coring 1.5 m in 50 min. and the hard formation shoe was completely destroyed and grooved in a manner that could indicate a loose bit cone. In addition, the torque was erratic and recovery dropped from near 100% to 22.5% in the last three cores; therefore, the bit was pulled because the rock was too hard for the XCB shoes and there was a reasonable chance that a cone was loose and could be lost in the hole.

A FFF was dropped and checked with the VIT-TV, showing the FFF top at the seafloor. The APC/XCB bit was worn but in good shape. An RCB BHA with an RBI CC-4 bit (for drilling the sediment section) and an MBR was run. The hole was reentered at 0545 hr on 30 September, and the bit was washed to bottom with 7 m of soft fill. RCB Cores 169-1037B-56R to 62R were taken from 501.2 to 546.0 mbsf (3857.9 mbrf) with 27.2% recovery. Basalt was encountered in Core 169-1037B-57R (top at 507.8 m), and the overall rate of penetration on the last 4 cores in solid basalt was 1.5 m/hr. The last 4 cores were partial cores that jammed in the liner support sleeve or liner with 43% recovery. Overall recovery for Hole 1037B was 77.9%. The hole was conditioned for logging with a short trip. The bit was pulled to 247 m when heavy flow back and an apparent loss of 20K lb string weight was noted.

Suspecting a BHA loss, a core barrel was run, but the bit was tagged twice at the correct depth. The circulating pressure indicated the core barrel was not seating, but the string weight with the top drive looked correct; therefore, it is assumed that a piece of core had fallen out of the core barrel and opened the float valve. The apparent loss of weight may have been a reduction in drag in the enlarged hole and 10 stands of drillpipe that had been pulled. The bit was run back to bottom, 30 m of fill was washed and reamed out to bottom, and the bit was dropped. The pump pressure indicated the hole was packing off, so the bit was pulled up 1 stand to close the sleeve and circulate sepiolite mud.

SITE 1038 (PROPOSED SITE ET1-4)

Hole 1038A

The ship was moved in DP mode 3.1 nmi in 4.5 hr at 0.7 kt to Site 1038 at dGPS coordinates 41°00.012'N, 127°29.633'W. Datasonics beacon S/N 1247 was dropped at 1556 hr on 2 October. Operations were shut down for 1 hr to reinstall and test the DCS sensor electronic equipment. The VIT-TV was run, and a TV survey was conducted over Site 1038 for 0.75 hr. Marker 6X (deployed by submersible) was located, and Hole 1038A (41°00.0163'N, 127 °29.6851'W) was spudded at 0130 hr on 3 October in sulfides. The seafloor was tagged at 3348.0 mbrf. The TV was pulled, and RCB Cores 169-1038A-1R to 12R were taken from 0 to 114.5 mbsf (3348.0 mbrf) with 2.3% recovery. Core 169-1038A-1R encountered massive sulfides, but recovery was very poor in the remaining cores. The TV was run to check the hole and confirmed that there was no flow from Hole 1038A. The hole at the seafloor was ruggose and about 18 in. wide. The bit cleared the seafloor at 2030 hr on 3 October.

Hole 1038B

The ship was moved in DP mode 300 m west of Hole 1038A, and the bottom was checked with the TV. Hole 1038B (41°00.0247'N, 127°29.8707'W) was spudded at 2240 hr on 3 October. The seafloor was tagged at 3266.0 mbrf. RCB Cores 169-1038B-1R to 13R were taken from 0 to 120.5 mbsf (3386.5 mbrf) with 11.5% recovery. The bit cleared the seafloor at 1700 hr on 4 October. The TV was not run until after pulling out of the hole because there were three crossing swells from remote storms, which caused rolls to 4 and heave to 2.75 m, and the ship could not be rotated because the current was shifting from 0 to 4 kt and abruptly changing direction by more than 90°.

Hole 1038C

The ship was moved in DP mode 76 m east and 259 m north of Hole 1038A. A site was selected on top of the mound on the north edge with the TV survey. Hole 1038C

(41°00.1816'N, 127°29.6037'W) was spudded at 2200 hr on 4 October. The seafloor was tagged at 3239.0 mbrf. RCB Cores 169-1038C-1R to 4R were taken from 0 to 41.8 mbsf (3280.8 mbrf) with7.6% recovery. The bit cleared the seafloor at 0515 hr on 5 October.

Hole 1038D

The ship was moved in DP mode 12 m west and 64 m south of Hole 1038A. A site was selected with the TV beside a pile of what appeared to be sulfide chimney fragments and boulders. The seafloor was tagged at 3237.0 mbrf, and Hole 1038D (41°00.1441'N, 127°29.6146'W) was spudded at 0745 hr on 5 October. RCB Cores 169-1038D-1R to 4R were taken from 0 to 43.8 mbsf (3280.8 mbrf) with 7.4% recovery. The bit cleared the seafloor at 1540 hr on 5 October.

Hole 1038E

The ship was moved 300 m south to Hole 1035A, which still had no flow coming from it. The ship was moved about 35 m east and 31 m north of Hole 1038A. The seafloor was tagged at 3221.0 mbrf, and Hole 1038E (41°00.0012'N, 127°29.6463'W) was spudded at 1845 hr on 5 October. RCB Cores 169-1038E-1R to 4R were taken from 0 to 40.6 mbsf (3261.6 mbrf) with 5.9% recovery. The bit cleared the seafloor at 0015 hr on 6 October.

Hole 1038F

The ship was moved 435 m south and 525 m east of Hole 1035A to the edge of a sulfide mound. The seafloor was tagged at 3252.0 mbrf, and Hole 1038F (40°59.7304'N, 127°29.2877'W) was spudded at 0615 hr on 6 October. RCB Cores 169-1038F-1R to 4R were taken from 0 to 38.4 mbsf (3290.4 mbrf) with 17.2% recovery. The RCB BHA was pulled, and the bit cleared the rotary at 1745 hr on 6 October.

Hole 1038G

We made a pipe trip and the standard APC/XCB BHA was run to obtain sediment cores near the sulfide mound outcrops on the east side of Bent Hill. The plan was to move the ship 5 m west of Hole 1038F to a 3- to 4-m-deep and 20-m-wide depression in the sulfide deposit. Clams in the depression indicated diffuse flow and the seafloor was tagged at 3251.0 mbrf, and Hole 1038G (40°59.7255'N, 127°29.2865'W) was spudded at 0245 hr on 6 October. XCB Cores 169-1038G-1X to 2X were taken from 0 to 22.0 mbsf with no recovery to penetrate through potentially hard sulfides just below the seafloor. The bit penetrated through a firm upper surface on Core 1X into soft sediments; therefore, APC coring was initiated. APC Cores 169-1038G-3H to 5H were taken from 22.0 to 50.5 mbsf. Cores 169-1038G-3H and 4H were noticeably warmer and very gassy, and the core liners were blackened by heat. On Core 169-1038G-5H the liner was softened and pushed back up into the liner by the core, which jammed the liner and doubled the thickness of the liner tube (like a tubing upset). XCB Cores 169-1038G-6X to 16X were taken from 50.5 to 147.0 mbsf (3398.0 mbrf). Basalt was encountered on Cores 169-1038G-15X and 16X. Coring was terminated when the XCB shoe was destroyed on Core 169-1038G-16X.

Hole 1038H

The ship was moved in DP mode back to Hole 1038A at 41°00.016'N, 127°29.685'W. A TV survey was conducted. The seafloor was tagged at 3234.0 mbrf, and Hole 1038H was spudded at 1030 hr on 8 October. XCB Cores 169-1038H-1X to 20X were taken from 0 to 192.8 mbsf with 16% recovery. The bit cleared the sea floor at 1400 hr on 9 October.

Hole 1038I

The ship was moved 250 m south and 130 m east from Hole 1038A onto Central Hill. An XCB core barrel was run. The seafloor was tagged with the bit at 3227.0 mbrf. Hole 1038I was spudded at 1600 hr on 9 October. XCB Cores 169-1038I-1X to 2X were taken from 0 to 17.3 mbsf with 55.7% recovery. APC Cores 169-1038I-3H to 7H were taken from 17.3 to 64.8 mbsf with 102.0% recovery. An Adara temperature measurement was taken on Core 169-1038I-3H and the Davis-Villinger temperature probe (DVTP) was run after Core 169-1038I-6H at 55.3 mbsf. The last three APC cores were partial strokes with 50-60K lb overpull so APC coring was terminated. XCB Cores 169-1038I-8X to 43X were taken from 64.8 to 404.0 mbsf (3631.0 mbrf) with 40.0% recovery. Coring was terminated when time for operations on Leg 169 expired.

Drill Pipe Loss

Coring was finished at Hole 1038I, and about 123 stands (1200 m) of 5" drill pipe had been pulled to prepare for the transit to Los Angeles. The seafloor had been cleared, and the ship had been moved slowly in DP mode about 0.4 nmi southeast of Central Hill (in preparation for changing out the coring wire line) to 40°59.60'N, 127°28.98'W. While pulling pipe at about 1700 hr, the roughnecks attempted to put both bails under the pickup elevator ears, but only one bail engaged. When the elevators were picked up, the engaged bail tilted the elevator, slipped off the ear, and broke off the end of the elevator-ear latch. The elevators flipped up on one side, and the 5" drill pipe bent and broke 0.7 m below the top of the tool joint box. No one was injured. The incident can be attributed to combined operator and crew error, with end of leg fatigue as an extenuating factor. Lost on the seafloor were: 81 stands (2298 m) of 5" drill pipe, and 127 m of BHA (crossover, 2 stands of 5-1/2" drill pipe, tapered drill collar, 5 X 8-1/4" drill collars, HS, TS, LS, SBDC, bit sub, 11-7/16" Sec S86F bit).

OPERATIONS SUMMARY

OCEAN DRILLING PROGRAM

SITE SUMMARY

LEG 169

HOLE	LATITUDE	LONGITUDE	WATER DEPTH (mbrf)	NO. OF CORES	INTER-VAL CORED (meters)	CORE RECOV-ERED (meters)	PERCENT RECOV-ERED (percent)	DRILLED (meters)	TOTAL PENE-TRATION (meters)	TIME ON HOLE (hours)	TIME ON SITE (days)
856H	48 26.020’	128 40.859’	2434.5	47	406.2	49.11	12.1%	0.0	406.2	204.50	8.5
			-	-	-	-	-	-	-	-	-
HOLE 856H TOTALS:				47	406.2	49.11	12.1%	0.0	406.2	204.50	8.5
858G	“48 27,360’”	128 42.531’	2426.2	0	0.0	0.00	0.0%	0.0	0.0	124.25	5.2
HOLE 858G TOTALS:				0	0.0	0.00	0.0%	0.0	0.0	124.25	5.2
857D	48 26.517’	128 42.651’	2431.5	0	0.0	0.00	0.0%	0.0	0.0	103.50	4.3
HOLE 857D TOTALS:				0	0.0	0.00	0.0%	0.0	0.0	103.50	4.3
1035A	48 26.0204’	128 40.9219’	2456.4	19	170.8	119.46	69.9%	0.0	170.8	42.75	1.8
1035B	48 25.9923’	128 40.8553’	2459.0	1	0.1	0.10	100.0%	0.0	0.1	8.00	0.3
1035C	48 25.9917’	128 40.8615’	2459.0	5	44.0	2.09	4.8%	0.0	44.0	22.00	0.9
1035D	48 26.0208’	128 40.7985’	2459.8	24	176.9	51.37	29.0%	1.6	178.5	53.00	2.2
1035E	48 25.9657’	128 40.8555’	2465.0	5	45.5	47.72	104.9%	0.0	45.5	12.00	0.5
1035F	48 25.9873’	128 40.8607’	2459.0	23	224.8	22.55	10.0%	0.0	224.8	48.00	2.0
1035G	48 26.0242’	128 40.9140’	2456.0	11	106.5	16.63	15.6%	102.0	208.5	26.25	1.1
1035H	48 25.8321’	128 40.9108’	2455.0	27	247.9	33.25	13.4%	0.0	247.9	65.25	2.7
Site BH TOTALS:				115	1016.5	293.17	28.8%	103.6	1120.1	277.25	11.6
1036A	48 27.3703’	128 42.5849’	2419.0	6	38.5	34.79	90.4%	0.0	38.5	7.50	0.3
1036B	48 27.3840’	128 42.6069’	2426.8	6	52.3	46.72	89.3%	0.0	52.3	11.00	0.5
1036C	48 27.3982’	128 42.6309’	2425.1	6	54.2	46.87	86.5%	0.0	54.2	15.50	0.6
Site DD TOTALS:				18	145.0	128.38	88.5%	0.0	145.0	34.00	1.4
1037A	40 57.2967’	127 30.9093’	3314.0	1	9.5	9.79	103.1%	0.0	9.5	9.50	0.4
1037B	40 57.2992’	127 30.9004’	3311.9	62	546.0	425.26	77.9%	0.0	546.0	176.75	7.4
Site ET-7 TOTALS:				63	555.5	435.05	78.3%	0.0	555.5	186.25	7.8
1038A	41 00.0163’	127 29.6851’	3233.5	12	114.5	2.65	2.3%	0.0	114.5	27.25	1.1
1038B	41 00.0247’	127 29.8707’	3266.0	13	120.5	13.80	11.5%	0.0	120.5	20.50	0.9
1038C	41 00.1816’	127 29.6037’	3239.0	4	41.8	3.16	7.6%	0.0	41.8	12.25	0.5
1038D	41 00.1441’	127 29.6146’	3237.0	4	43.8	3.23	7.4%	0.0	43.8	10.50	0.4
1038E	41 00.0012’	127 29.6463’	3221.0	4	40.6	2.41	5.9%	0.0	40.6	8.50	0.4

HOLE	LATITUDE	LONGITUDE	WATER DEPTH (mbrf)	NO. OF CORES	INTER-VAL CORED (meters)	CORE RECOV-ERED (meters)	PERCENT RECOV-ERED (percent)	DRILLED (meters)	TOTAL PENE-TRATION (meters)	TIME ON HOLE (hours)	TIME ON SITE (days)
1038F	40 59.7304’	127 29.2877’	3252.0	4	38.4	6.62	17.2%	0.0	38.4	17.50	0.7
1038G	40 59.7255’	127 29.2865’	3251.0	16	147.0	44.88	30.5%	0.0	147.0	37.50	1.6
1038H	41 00.0054’	127 29.6533’	3234.0	20	192.8	29.99	15.6%	0.0	192.8	30.75	1.3
1038I	40 59.8831’	127 29.5639’	3227.0	43	404.0	191.13	47.3%	0.0	404.0	75.25	3.1
Site ET-1-10 TOTALS:				120	1143.4	297.87	26.1%	0.0	1143.4	240.00	10.0
LEG 169 TOTALS:				363	3266.6	1203.58	36.8%	103.6	3370.2	1169.8	48.7

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard *JOIDES Resolution* for Leg 169 were:

Cesar Flores	Marine Computer Specialist
Tim Fulton	Marine Lab Specialist (Photographer)
Edwin Garrett	Marine Lab Specialist (Paleomagnetics)
Dennis Graham	Marine Lab Specialist (Underway Geophysics)
Gus Gustafson	Marine Lab Specialist (Downhole Tools)
Michiko Hitchcox	Marine Lab Specialist (Yeoperson)
John Lee	Marine Lab Specialist (Chemistry)
Kevin MacKillop	Marine Lab Specialist (Physical Properties)
Chris Mato	Marine Lab Specialist (Curator)
Eric Meissner	Marine Electronics Specialist
Bill Mills	Laboratory Officer
Mike Moore	Marine Lab Specialist (Storekeeper)
Dwight Mossman	Marine Electronics Specialist
Heidi Pass	Marine Lab Specialist (Core Lab)
Chieh Peng	Marine Lab Specialist (Chemistry)
Don Sims	Marine Lab Specialist (Assistant LO, Thin Section)
Joel Sparks	Marine Lab Specialist (X-ray)
Barry Weber	Marine Computer Specialist

GENERAL LEG INFORMATION

Port Call (Victoria)

The *JOIDES Resolution* docked in Victoria, Canada on the 15th of August, ending Leg 168. The following morning the Leg 169 crew arrived and began crossovers and other logistic activities. In addition to our normal logistic activities, daily public relation tours were conducted for Canadian VIP’s and the general public. Other port call activities included:

- Fison XRF service call
- Completion of DCS phase III
- Ceremonial blessing by two Saanich native american chiefs.

Upon completion of the Saanich coring, the ship returned to Victoria to discharge the Leg 169S scientists, cores, and samples. That afternoon the Leg 169 science party joined the ship and the following morning we departed to start Leg 169 science operations.

Laboratory Activities

Except for the rare unaltered sediment sections, core recovery was generally low. The recovered massive sulfides were curated under the hard rock guidelines and sealed in foil bags that were first purged with nitrogen then evacuated to prevent the sulfides from oxidizing. These special handling requirements kept the staff busy in spite of the low recovery.

Technical support in the XRF, Thin Section, Downhole Measurement, and Chemistry labs played key roles in supporting the leg’s scientific objectives. Work in the Downhole laboratory was especially challenging this trip because of the variety of tools deployed and the extremely hot hole conditions. Also, the technical staff assisted with the recovery and deployment of data loggers with thermistor strings in two of the CORKed holes.

Transit Activities

Technicians routinely collected navigational data on all transits. Bathymetric, and magnetic data was only collected on the Victoria-Middle Valley and Middle Valley-Escanaba Trough transits. The were no seismic surveys conducted in support of Leg 169. All sites were located by GPS coordinates and camera surveys. During the transit from Middle Valley to the

Escanaba Trough, the new streamer was successfully tested. Also, a second successful test was conducted on the transit to Los Angeles.

LABORATORY SUMMARIES

Downhole Measurements Laboratory

The Adara, Water Sampler and Temperature Probe (WSTP), and Los Alamos water sampler were operated by ODP personnel. Extreme hot water (>200˚C) conditions constrained deployment of the WSTP and Adara. Confirmation that downhole conditions did not exceed 150˚C and 100˚C, for the WSTP and Adara respectively, was required before deployment in hydrothermally active holes. In holes with water temperatures exceeding these limitations the Los Alamos high temperature water sampler was used, but met with only minor success because of its aged O-rings and poor design. Technicians assisted the shipboard loggers with thermistor string deployments at the two CORK sites.

Core Laboratory

Activities in the core laboratory were normal for a hard rock leg except for the special handling of the sulfide cores. H_2S monitors where installed on the catwalk, core locker, and air intake for the ship’s house and hand held monitors were used as necessary. Although, this leg was identified a potential “H_2S leg”, no other H_2S safety precautions (rig floor monitors, wind socks, classes, or drills) were taken by the ODP Drilling Operations Manager. The ship’s crew completed a few maintenance projects on the core stack, nevertheless, the whole lab stack is rapidly deteriorating because of neglect at the last dry dock and the lack of a serious maintenance effort since.

Curation

Massive sulfides, borehole water samples and mineralized CORKs provided many curatorial challenges.

Paleomagnetics Laboratory

The new 2G magnetometer hardware functioned very well but the lack of adequate software was a problem. However, the newly written ODP labview software, CRYO, rectified this deficiency making the system adequate for shipboard needs.

Physical Properties Laboratory

In addition to the normal science support activities, a number of special projects were completed during the leg. These projects included 1) software upgrades for MST, VS, and MAD, 2) completion and verification of the JANUS upload software for the MST, VS, and MAD data, 3) evaluation of the GEOTEK Multi-Sensor Split Core Logger, and 4) installation of the new MST track.

Chemistry Laboratory

Along with high resolution in situ water samples, open borehole samples of hydrothermal fluids were analyzed. Geochemists handled most of the wet chemistry analyses such as calcium, magnesium, and chloride titrations, spectrophotometer tests for boron, silicate, and NH_4. They also handled the AAS analysis for Li, Sr, Zn, Pb, and Mn. The Dionex was utilized to run for anions and cations.

At the hydrothermal sites, heavy hydrocarbons were commonly encountered. Aromatic (benzene - toluene) and some other carcinogenic compounds were found in the samples. The cores containing potential health hazards were identified and marked. However the levels of these compounds were found to be very low, unless they were concentrated in tar balls.

Thin Section Laboratory

The thin section laboratory received only moderate use with the lithology types evenly distributed between basalts, sediments, and sulfides. The table top under the Logitech and Petrothin equipment was replaced.

X-ray Laboratory

Over 130 samples were analyzed by X-ray diffraction (XRD) on Leg 169. After a brief teaching session, scientist Damon Teagle prepared and ran virtually all of these samples throughout the leg. Approximately 40 samples were glycolated (designated with a ‘G’ suffix) to help identify various sheet silicates and the rest were prepared as simple bulk mineral smear-slides. The results were used only for mineral identification and a wide variety of silicate and sulfide minerals were determined using the ODP-1 XRD pattern database.

The X-ray fluorescence spectrometer (XRF) was completely recalibrated for major and trace elements following a service call during the Victoria, BC portcall. The calibration took much longer than usual (3-4 weeks!) because of the need to sort-out the ARL software, and several elements required more than one calibration. Once running, the XRF worked very well analyzing 31+ samples for major and trace elements.

Computer Service

During this leg the preproduction testing of the JANUS system continued, with the goals of identifying problems and allowing the marine technicians to gain experience using the system. We entered all corelog data and the necessary operations data needed to support corelog. We also tested the sample application, although not all sample data for this leg were entered into JANUS. At the start of Leg 169S we rebuilt the Oracle database used with JANUS and at that time it was configured for the production environment. We used this leg to complete the transition of the shipboard Unix environment to follow closely the shore environment. This included completing the upgrade of the general purpose SUN work stations to Solaris 2.5. Splicer was upgraded to a Solaris version with minimum testing.

Electronic Services

The laboratory equipment operated satisfactorily during the leg. No major problems occurred with the majority of the equipment that were out of the ordinary, compared to past leg experiences. As always the first two weeks were spent addressing minor problems that were discovered during start-up operations and setting up equipment to fit the personal needs and preferences of the laboratory scientists and technicians.

Photography Laboratory

This was a low core recovery leg. There were, however, a large amount of close-up requests at Site 1035. Also, there were requests for photos of CORK operations and special events.

Underway Geophysics Laboratory

Navigation, bathymetry, magnetics, and seismic data were collected during Leg 169. The site locations were well surveyed from previous expeditions. All beacons were dropped on predetermined coordinates. A short seismic survey was done during the approach to Site 1037 and again on the transit to Los Angeles to test a new multichannel streamer. Both tests were successful. Hole positions were determined by averaging differential GPS fixes taken at a one minute interval over a period of several hours for each hole.

Fantail

The 80” water gun was deployed to test the 6 channel seismic system. Otherwise, fantail maintenance projects were minimal.

GONE BUT NOT FORGOTTEN

On September 11th at 1030, Captain Ed Oonk led the ship’s crew in a memorial service to the memory of Lou Garrison. Lou’s ashes were scattered over the sea while coring in Middle Valley. A memorial inscribed “In Memory of Lou Garrison” was attached to the ROV platform at Hole 875D at Middle Valley.

We’ll all miss his leadership and friendship.

LEG 169 LABORATORY STATISTICS

GENERAL

Sites:....................................7

Holes: 25

Meters Drilled: ....103.6 m

Meters Cored:........................3266.6m

Meters Recovered: ....1203.58 m

Number of Samples

General Samples: 5,806

Chemistry Samples: 2,344

LABORATORY ANALYSIS

Magnetics Laboratory

Cryomagnetometer:...............1476 sections

Discrete Measurements:........30

Oriented cores: 0

Physical Properties

MST: ....881 sections

Discrete Velocity: 0

Strength: 0

Thermal Conductivity: 190

Moisture / Density: 398

Chemistry

Rock Eval:.............................0

Water Chemistry: 203

Head Space/Vacutainer: 193

Inorganic Carbonate:.............193

Carbon Nitrogen Sulfur: 193

X-ray

XRF:.....................................32

XRD:....................................130

Downhole

Adara:....................................10

WSTP:...................................7

Davis-Villenger Temp. Tool:1

Los Alamos Water Sampler:.4

Thin Sections: 81

Underway Geophysics:

Total Transit..........................3473 nmi

Bathymetry:...........................499 nmi

Magnetics:.............................442 nmi

Seismic..................................18 nmi