OCEAN DRILLING PROGRAM

LEG 169 SCIENTIFIC PROSPECTUS

SEDIMENTARY RIDGES II

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This Scientific Prospectus is based on pre-cruise JOIDES panel discussions. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists and the Operations Superintendent that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Planning Committee and the Pollution Prevention and Safety Panel.

ABSTRACT

As the second leg of a planned two leg program, Leg 169 will address a broad range of scientific problems, but the major emphasis of the leg is to investigate the genesis of massive sulfide deposits. This project in the northeast Pacific ocean basin will be focused in two ideal laboratories for investigating sediment-hosted massive sulfide deposits, 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 that encompass the drilling strategy of this leg are 1) mechanism of formation of massive sulfide deposits at sediment-covered ridges, 2) tectonics of sedimented rifts and controls on fluid flow, 3) sedimentation history and diagenesis at sedimented rifts, and 4) extent and importance of bacterial activity in these environments. We will address these problems by drilling deposits of differing maturity, and by drilling a series of holes across deposits at each of these sites. By examining the sedimentary record of hydrothermal products adjacent to the deposits, we will attempt to constrain the timing and duration of hydrothermal activity. Sampling of the alteration zones beneath the deposits will constrain the sources of metals in the deposits and geochemical reactions that control mineralization. Opening sealed, instrumented boreholes in the Middle Valley hydrothermal field will allow the first subsurface sampling of hydrothermal fluids from an ODP borehole. Additionally, we intend to perform the first active hole-to-hole hydrologic experiment designed to constrain the physical and hydrologic properties that control hydrothermal flow on the scale of an entire vent field.

We plan to unseal, log, sample borehole fluid, and reseal with an instrumented CORK two holes originally sealed and instrumented on the first of this two leg program (Leg 139). One of these holes (Hole 857D) will be deepened prior to sealing and instrumentation. This prospectus details two primary sites (one each in Middle Valley and Escanaba Trough) for deep penetration through sediment-hosted massive sulfide deposits and eventually through the underlying alteration zone. We propose one primary and multiple alternate sites for sampling the principal center of hydrothermal activity in Middle Valley, the Dead Dog vent field. A primary sedimentary reference site in Escanaba Trough is targeted, and several alternate sites that will be drilled as time and recovery dictate are presented. Drilling at Middle Valley and Escanaba Trough will enhance the broad scale constraints on hydrothermal circulation through the upper oceanic crust at a sediment-covered spreading centers developed subsequent to Leg 139. The presence of instrumented boreholes

allows active experimentation as well as continued monitoring and sampling of hydrothermal fluids at ridge crests. Our multidisciplinary approach, encompassing integrated geological, geophysical, geochemical, hydrological, and biological investigations ensures the most productive yet economical exploration and utilization of these exceptional natural laboratories.

INTRODUCTION

Leg 169 is the second leg of a planned two leg program to investigate the geological, geophysical, geochemical, and biological processes at sediment-covered spreading centers. The leg will address a broad range of scientific problems, but the major emphasis of the leg is to investigate the genesis of massive sulfide deposits. The highly successful Leg 139 drilling also addressed a wide range of problems, but was primarily focused on establishing the broad scale constraints on hydrothermal circulation of seawater through the upper oceanic crust at a sediment covered spreading center. Among the many accomplishments of Leg 139, a few highlights are listed below. Leg 139 represented the first significant penetration and recovery of zero age oceanic crust and established that the uppermost part of the oceanic crust formed at sediment-covered spreading centers is composed not of extrusive basalts, but of interlayered basaltic sills and metasediments. This leg safely drilled into an active hydrothermal upflow zone, within 10´s of meters of hydrothermal vents, and successfully recovered core and geophysical logs from rock at temperatures near 300°C. We established that the composition of the venting fluids was consistent with hydrothermal mineral assemblages in metasediments and metabasaltic rocks recovered from a hydrothermal reservoir zone in the upper oceanic crust. Drilling on the flanks of the ridge established that relatively unaltered seawater is recharging into oceanic basement in the area near one of the rift-bounding normal faults. The leg established the presence of an extensive seafloor ore deposit by penetrating 94 meters of massive sulfide. A major step towards the establishment of seafloor observatories was taken by instrumentation of sealed borehole using the CORK system. Geophysical logging, downhole experimentation, and borehole instrumentation provided the first direct constraints on the physical properties of an active submarine hydrothermal system (Davis, Mottl, Fisher, et al., 1992). We look forward with great excitement to the opportunity to extend and refine the scientific insight gained on Leg 139 during the second leg of sedimented ridges drilling on Leg 169.

SCIENTIFIC OBJECTIVES

The primary focus of the second leg of drilling is investigation of the mechanisms of formation of massive sulfide deposits at sedimented ridges. Middle Valley and Escanaba Trough (Fig. 1) are ideal laboratories for systematically establishing the origin of these deposits. The individual deposits in these two areas are considerably larger than most deposits discovered thus far on bare-rock ridges and are large enough to be easily targeted and drilled by the JOIDES *Resolution*. Differences in both the maturity and composition of the massive sulfide deposits at the two ridge segments indicate that comparison of the different deposits should provide more information on the processes controlling massive sulfide generation than could be obtained by more extensive drilling of only one of the deposits. The composition of deposits in Escanaba Trough indicates a dominantly sedimentary source for the metals, whereas those in Middle Valley appear to be intermediate between basaltic and sedimentary sources (Figs. 2, 3). The primary objectives of this leg are to investigate the following areas:

I. Mechanism of formation of massive sulfide deposits at sediment covered ridges

Size and geometry of sulfide deposits and hydrothermal alteration zones

Compositional variations within and between deposits

Source of metals in massive sulfides

Constraints on fluid temperatures and compositions that deposited massive sulfide

Composition of fluids in producing boreholes

Timing and duration of hydrothermal activity

Formation of hydrothermal mounds in active vent fields

II. Tectonics of sedimented rifts and controls on fluid flow

Controls on igneous activity at sedimented rifts and the importance of sill emplacement

Permeability and structural controls on hydrothermal circulation

Interrelationship of faulting and fluid flow

Constraints for hydrologic modeling

Factors controlling fluid flow on the scale of individual vent complexes and the importance of subseafloor fluid mixing

III. Sedimentation history and diagenesis at sedimented rifts

Source and deposition rate of sediments

Diagenetic reactions in high heat flow regime

Organic matter alteration and generation of hydrothermal petroleum

IV. Extent and importance of bacterial activity

Role of bacteria in oxidation of organic matter, reduction of sulfate, and precipitation of carbonate

Activity of thermophilic bacteria in sealed boreholes at known temperatures and fluid compositions

Extent of thermophilic and nonthermophilic bacteria in the subsurface and relationship to hydrothermal fluid compositions

Comparison of bacterial populations in active and inactive hydrothermal deposits

Our drilling strategy involves drilling deposits of differing maturity to investigate the evolution of hydrothermal deposits. Factors that control the location, size, and composition of massive sulfide deposits will be investigated by drilling a series of holes across deposits at each of the sites. Examination of the sedimentary record of hydrothermal products adjacent to the deposits will provide constraints on the timing and duration of hydrothermal activity. Drilling of the alteration zones beneath the deposits will constrain the sources of metals in the deposits and geochemical reactions that control mineralization. The existence of cased and sealed boreholes in the Middle Valley hydrothermal field will allow the first subsurface sampling of hydrothermal fluids from an ODP borehole, and potentially allow us to sample hyperthermophyllic chemolithoauthotrophic bacteria that may have colonized the thermistor strings in the sealed holes. Furthermore, reinstrumentation of these holes will allow active experimentation on induced seismicity in a seafloor hydrothermal system and hole-to-hole hydrologic experimentation designed to constrain for the first time the physical and hydrologic properties that control hydrothermal flow on the scale of an entire vent field. The scientific objectives for the three primary work areas are outlined below and are summarized on a hole-by-hole basis in Table 1. This table correlates the primary objectives with the major results from the sites drilled on Leg 139, and shows which scientific objectives will be addressed by the sites proposed for Leg 169.

I. MIDDLE VALLEY - Dead Dog active hydrothermal field and CORK operation

Priority Targets: Holes 858G, 857D, DD1-4

• Measure temperature gradient and sample hydrothermal fluids in sealed Holes 858G and 857D with minimum disturbance for Hole 858G.

• Deepen Hole 857D to recover deeper portions of the sill-sediment complex

• Log Hole 857D to determine changes in physical properties related to hydrothermal alteration, determine structural effects of sill emplacement, and tectonic controls on fluid flow

• Reinstrument and reseal Holes 858G and 857D to determine in situ temperature and pore pressure

• Conduct hole-to-hole experiment on hydraulic conductivity and induced seismicity

• Determine the mechanism of growth of hydrothermal mounds in the active vent fields

• Measure pore fluid composition and constrain the extent of lateral flow and fluid mixing in the shallow subsurface

• Establish the extent and importance of a potential hydrological seal (caprock) in focusing hydrothermal discharge

• Determine the extent of microbiological activity within the sealed boreholes and sediments in an active hydrothermal field

• Study organic matter maturation as a function of the present thermal regime and determine peak paleotemperatures recorded by organic matter

II. MIDDLE VALLEY: Bent Hill inactive sulfide mound

PRIORITY TARGETS: Holes BH1, BH2-6, BH8

• Investigate vertical extent of massive sulfide

• Determine mineralogical, textural, and compositional zonation of the hydrothermal precipitates

• Determine the relative importance of sedimentary and basaltic sources for the different hydrothermal assemblages

• Document the mechanism of mound growth and maturation and the relative importance of subsurface precipitation and recrystallization versus growth at the surface via chimney formation

• Study the mineralogical and chemical variation related to late stage alteration

• Determine type, zonation, and extent of hydrothermal alteration in the stockwork zone under the sulfide mound

• Determine the extent, composition, and zonation of alteration lateral to the deposit

• Identify mechanisms that focus hydrothermal flow including formation of caprocks, intrusion of sills, and faulting

• Compare the microbiological activity in an active hydrothermal field (Dead Dog) with microbiology in an inactive mound (Bent Hill)

• Establish the timing and duration of hydrothermal deposition, oxidation, and redeposition by mass wasting of the deposit as recorded in adjacent sediments

• Compare a deposit with a basalt-dominated geochemical signature (Bent Hill) with a deposit characterized by a sediment-dominated geochemical signature (Escanaba Trough)

III - ESCANABA TROUGH: active sulfide mound

PRIORITY TARGETS: ET7, ET1-4, ET5

- Drill a reference section in sediments away from any hydrothermal influence to determine stratigraphy, sediment sources, depositional history, organic geochemistry, and physical properties outside of the thermal effects of vents
- Determine pore water composition to study diagenetic reactions
- All the investigations listed above for the Bent Hill sites

REGIONAL GEOLOGY

Leg 169 will drill in two areas in the northeast Pacific; Middle Valley at the northern end of the Juan de Fuca Ridge and Escanaba Trough at the southern end of the Gorda Ridge (Fig. 1). Both sites are sediment-covered seafloor spreading centers that contain both active hydrothermal systems and massive sulfide deposits formed from recently active hydrothermal venting.

Middle Valley Geology

Middle Valley forms one leg of a Ridge-Transform-Transform unstable triple junction with the Sovanco fracture zone and the Nootka fault (Fig. 1A; Davis and Villinger, 1992). Middle Valley is a medium-rate spreading center (58 mm/yr), but the proximity to the cold Explorer plate results in a reduced magma supply and a slow-spreading ridge morphology with a deep and wide axial trough. A ridge jump is in progress and current magmatic activity is mostly confined to the West Valley spreading center. Proximity of the Middle Valley spreading center to an abundant supply of terrigenous sediment during the Pleistocene low stand of sea level 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 main areas are targeted for drilling (Fig. 1B), the Dead Dog vent field in the area of active venting (Site 858) and the Bent Hill area (Site 856).

Dead Dog Vent Field

The principle center of hydrothermal activity in Middle Valley is the Dead Dog vent field (Fig. 4). Contoured heat flow values show a concentric high which is coincident with a side scan acoustic anomaly that outlines the vent field. The vent field contains at least 20 active vents with temperatures ranging up to 276°C (Ames et al., 1993). Active vents occur predominantly on top of 5-15 m high sediment-covered mounds a few tens of meters in diameter. The vent fluid composition indicates significant interaction of hydrothermal fluid with sediment and the resultant chimneys are predominantly composed of anhydrite with only minor Mg-rich phyllosilicates and sulfide minerals. Available data from piston cores and ODP Hole 858B suggest that subsurface deposition of anhydrite, Mg-rich smectite, and sulfide minerals contribute to the growth of the mounds. Surface deposition of collapsed chimney debris may also contribute to the growth of the mounds, but appears to be of relatively minor importance. Following collapse of the unstable chimney structures, the anhydrite dissolves in the cold seawater. The uppermost sediment recovered from Hole 858B appears to have formed in this manner, however, this layer is only a few meters thick and does not account for the bulk of the anhydrite, Mg-smectite, and sulfide that occurs at greater depth within the mound. 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.

Seismic profiles across the vent field show it is located about 2 km east of prominent basement fault (Fig. 5; Rohr and Schmidt, 1994). 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 to be the top of a volcanic edifice at only 250 m depth (Fig. 6). The presence of more permeable volcanic basement penetrating up into the sediment cover acts as a conduit to focus flow of hydrothermal fluid to the seafloor (Davis and Fisher, 1994).

Bent Hill

Bent Hill is one of a string of small topographic highs that run parallel to the eastern rift bounding normal fault scarp (Fig. 1B). These bathymetric highs include volcanic cones to the south where sediment cover thins and uplifted sediment hills to the north. These features lie close to a normal fault that offsets basement reflectors (herein referred to as the Site 856 fault), but near surface sediment layering appears to be continuous across this fault. The transition from essentially nonmagnetic oceanic crust that typifies the center of Middle Valley to crust with normal levels of magnetization passes through this area and probably marks the boundary between normal extrusive basalt and the sill-sediment complex that forms the upper oceanic crust in center of Middle Valley (Currie and Davis, 1994). Bent Hill is a roughly circular feature 400 m in diameter that has been recently uplifted approximately 50 m (Fig. 7). It is bounded on the west by a steep scarp that parallels the rift bounding faults and exposes semiconsolidated turbiditic sediment. A very primitive olivine-rich sill, which is peterogenetically distinct from the diabases and basalts recovered by drilling elsewhere in Middle Valley, was recovered at the base of the two drill holes that penetrated Bent Hill (Fig. 8). 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 these sills and the underlying sediments (Rohr and Schmidt, 1994).

A ridge of massive sulfide that rises 35 m above the surrounding turbidite fill of the valley is located approximate 100 m south of the southern edge of Bent Hill and is referred to here as the Bent Hill deposit (Figs. 7, 8). The massive sulfide mound is extensively weathered to iron oxyhydroxides and partially buried by sediment. Massive sulfide extends a minimum distance of 60 m N-S and 90 m E-W. Hole 856H penetrated 94 m of massive sulfide (Fig. 8) 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 late stage hydrothermal alteration of pyrrhotite to pyrite and 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).

A second mound of massive sulfide occurs approximately 300 m further south and is referred to here as the Sunnyside Up deposit. The morphology, degree of oxidation, and sediment cover indicate that this deposit is younger than the Bent Hill deposit. A single 264°C hydrothermal vent is present on the north flank of this deposit. Contoured heat flow values for the Bent Hill area show high values centered around this active vent. 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.

Escanaba Trough Geology

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. 1C). 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 the 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.

South of 41°17´N latitude, the axial valley of Escanaba Trough is filled with several hundred meters of turbiditic sediment (Figs. 9, 10). 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 low stands of sea level in the Pleistocene, and the entire sediment fill of the trough was probably deposited within the last 100,000 years (Normark et al., 1994; Davis and Becker, 1994a).

Seismic reflection surveys show that the floor of Escanaba Trough is generally a smooth, flat plain underlain by continuous and relatively undisturbed turbidites (Fig. 11; Davis and Becker; 1994a; Morton and Fox, 1994). 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 sediment cover in these areas is described as moderately to highly disturbed based on the discontinuity or absence of seismic reflectors (Fig. 10; Morton and Fox, 1994). Morton et al. (1994) mapped the distribution of the topographically rough, seismically disturbed zones, which typically are 3 to 6 km wide oval-shaped areas aligned along the spreading axis. The strongly disturbed zones are also areas of high heat flow (Fig. 11; Davis and Becker, 1994a).

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). Sulfide mineralization has been sampled by dredging, sediment coring, or submersible at four igneous centers within the sediment-covered part of Escanaba Trough. The northern Escabana Trough study area (NESCA) (Figs. 10, 12) contains several large massive sulfide deposits including an area of active hydrothermal venting. The dominant morphologic features in the NESCA are the Southwest (SW) Hill and the Central Hill (Figs.

10, 12). The SW Hill is an elongated sediment hill that has been uplifted by 120 m above the surrounding turbidite plane. The steep sides of the hill expose semiconsolidated turbiditic sediment. Massive sulfide deposits occur at the base of the scarp that bounds the uplifted sediment hill. SW Hill is interpreted to have formed by uplift of sediment over a laccolithic sill; high permeability fault zones that accommodated the uplift provided pathways for flow of hydrothermal fluid to the seafloor (Denlinger and Holmes, 1994).

A large exposure of volcanic rock occurs east of the crest of the Central Hill (Fig. 12). The elevated area east of the Central Hill is covered by glassy basalt pillows 1 to 2 m in diameter. Lava tubes drape the north flank of the hill indicating flow to the north. These lava tubes fed sheet flow basalts that ponded within the central depression of the spreading center. The area of Central Hill west of the outcropping pillow basalt is interpreted to have been uplifted by intrusion of basalt into the sediment. The western, sediment-covered part of the Central Hill contains the most extensive sulfide deposits observed in Escanaba Trough. The massive sulfide deposits on the west and southeast flanks of the 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. An extensive area of massive sulfide is exposed on the north slope of the Central 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 with few sediment-covered areas. The best explored and most hydrothermally active area of sulfide mineralization on the Central Hill extends west from the northern end of the sediment covered hill top (Fig. 12). This is not an area of continuous sulfide outcrop, but rather a region of abundant, closely spaced sulfide mounds. The mounds are typically 20 to 60 m in diameter and 5 to 10 m high. Two mounds were observed actively discharging high-temperature hydrothermal fluid; one near the eastern margin of the sulfide area was venting 217°C fluid, and one on the western edge of the explored area was venting 108°C fluid (Fig. 12). Even though these mounds are 275 m apart, the major-element composition of the end-member fluid at each vent 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.

DRILLING PLAN/STRATEGY

The relative order of operations and the exact placement of some drill holes in the massive sulfide deposits will need to be determined at sea based on weather conditions and results of completed drill holes. Successful CORK emplacements and packer deployments require relatively quiet seas. The first operation site proposed for this leg is a return to Site 858 from ODP Leg 139. During that leg, Hole 858G (48°27.360´N, 128°42.531´W; Figs. 1, 5) was instrumented with a CORK and thermistor string. Submersible observations of Hole 858G show that the CORK has failed and this hole is now exuding hydrothermal fluid (Davis and Becker, 1994a). We plan to extract the thermistor and data logger from the CORK through the drill string before recovering the CORK. The Kevlar cable supporting the thermistor string will be sampled for thermophilic bacteria that may have colonized the string during the 5 yr it has been bathed in hydrothermal fluid. In order to ensure minimal disturbance of bore fluids, we intend to acquire a temperature log and a water sample prior to recovering the CORK. Minimizing the thermal disturbance of the fluid in the borehole is intended to limit the possibility of reestablishing the strong down-hole fluid flow initiated when the hole was first drilled. The slender diameter of the Becker temperature tool should allow a sandline deployment through the hole in the CORK head left by removal of the thermistor and data logger. Since water temperatures are expected to be in excess of 200°C, which is beyond the operational limits of the WSTP or Fisseler water sampler, we propose deployment of the Los Alamos water sampler. This tool also has a slimline configuration, and can be deployed by sandline prior to removal of the existing CORK. The water sample should be taken from the interval below the borehole casing string (260 mbsf). In the event that the thermistor and data logger cannot be removed without pulling the CORK, both will be recovered and the temperature log and water sample will be recovered on a second pipe trip. Once the CORK is recovered, the seals will be inspected to determine if seal failure is responsible for the fluid leakage recognized by submersible observations. If the seals are determined to have failed, a new CORK instrumented with a thermistor string and data logger will be installed. One ultimate benefit of successful deployment of an instrumented CORK will be the acquisition of temperature and pressure data that may detect the transient overpressure that will be induced when we unseal and deepen Hole 857D, which is located 1.6 km to the south. Alternatively, if seal failure cannot be demonstrated as the cause of fluid leakage from the CORK, an open-pipe artificial chimney will be installed in the borehole to allow future deployment of sandline/wireline tools. During the transit to the next site, we propose to offset to a position halfway between Sites 858 and 857 (~800 m SSW) and deploy the first of three Pop-Up Pore Pressure Instruments (PUPPI´s). The experiment designed to use these instruments will be described below.

In order to maximize the time available for thermal recovery of Hole 858G prior to deepening Hole 857D, our second operation will be at ODP Site 856 (48°26.020´N, 128°40.859´W, Figs. 1, 5), the Bent Hill massive sulfide deposit (Fig. 7, 8). The highest priority for drilling at the Bent Hill deposit will be to complete a hole through the massive sulfide deposit and into the underlying alteration zone. Hole 856H was drilled to a depth of 94 mbsf prior to abandonment on Leg 139 (Fig. 7, 8). This hole is equipped with a reentry funnel and 12 m of 11-3/4 in drill-in casing. The hole was left open and unobstructed. The introduction of oxygenated seawater into the massive sulfide deposit will likely have altered the pyrrhotite/pyrite massive sulfide deposit to iron oxide/ oxyhydroxide. Since degradation of the borehole walls during operations on Leg 139 was the cause for abandonment of this hole, we suspect that alteration may have cemented and stabilized the borehole. Taking advantage of the 94 m of penetration already achieved, we intend to reenter Hole 856H and drill through the massive sulfide deposit and into the alteration zone that is anticipated to underlie this deposit. Total depth of this hole will be dependent on drilling conditions and nature of the recovered core. If we are unable to successfully deepen this hole, we will offset a few meters and attempt to drill in a casing to isolate the upper part of the formation. We intend to deepen this hole (BH1) to at least 250 m, through the massive sulfide deposit and into the underlying alteration zone, possibly taking advantage of the MDCB to enhance recovery in the massive sulfide deposit. Drilling operations will be followed by a full logging suite.

Completion of this hole (BH1) through the massive sulfide deposit and alteration zone will accomplish one of the primary objectives of drilling in Middle Valley. However, we also wish to characterize the lateral variability and timing of hydrothermal activity recorded in sediments adjacent to the sulfide deposit. The exact placement of holes to accomplish this will be determined by the size of the massive sulfide deposit and underlying alteration zone as well as by the time available for drilling operations. Due to the large uncertainty in the amount of time necessary to deepen and CORK Hole 857D, we deem it necessary to proceed with this operation after completing our deep penetration hole. With this strategy we will maintain the flexibility to complete as much as possible of the other drilling planned for Middle Valley prior to departing this site for Escanaba Trough.

After completing operations at BH1, we will transit to Hole 857D (48°26.517´N, 128°42.651´W, Figs. 1, 5), where a second instrumented CORK was installed during Leg 139. During the transit, we intend to deploy a second PUPPI at a location along a line between Sites 858 and 857 about 400 m north of Site 857. Upon arrival at Site 857, a third PUPPI will be deployed. At Hole 857D, the CORK, data logger and thermistor string will be recovered, and a temperature log and down-hole fluid samples will be collected. The high temperatures expected in the hole will be lowered by circulation while drilling for approximately 36 hours with the RCB/MDCB, allowing us to deepen the hole by as much as 200 m. Circulation of cold seawater in the borehole will induce a transient overpressure of ~1MPa relative to in situ pore pressure. If the rocks on the ridge axis are in a tensional state near failure by normal faulting, then the increased pore pressure should induce localized failure detectable by an OBS array scheduled for deployment prior to drilling. Calculations based on measured pore pressure and permeability indicate that the overpressure induced by introduction of cold seawater into Hole 857D during drilling may be detectable in Hole 858G. This represents the first active hole-to-hole hydrologic experiment conducted on the scale of a seafloor hydrothermal system. We will also attempt to record this pressure pulse with the three PUPPI´s deployed in an array between holes 857D and 858G. Since an agitated sea state diminished the quality of the logging data collected from Hole 858G during Leg 139, we will run a full suite of logs in the deepened hole. We expect to run an FMS log as well to help define the structural complexity at this site. Finally, the hole will be CORKed with a new, longer thermistor string, thereby completing an important unrealized objective of Leg 139.

Our plan for the operational time remaining after completion of this portion of the drilling program will need to be highly flexible and will be determined by 1) the amount of time remaining before we must move to Escanaba Trough and 2) the results of drilling at BH1. The investigations we wish to conduct relate to the formation of hydrothermal mounds in the Dead Dog vent field and the lateral variations in the composition and form of the Bent Hill massive sulfide deposit. The following is an ideal scenario assuming that all preceding operations are concluded in a timely fashion.

Following a transit to Site 858 (48°27.336´N, 128°42.600´W, Figs. 1, 5), we will begin a short camera survey to locate Site DD1. Our strategy for investigating the formation of the hydrothermal mound within the Dead Dog vent field is to drill 3 to 4 holes separated by ~25 m each along a transect down the flank of one of the larger mounds. Each of these APC/XCB/MDCB holes will penetrate ~50 m, with particular attention to recovering the hard layer encountered at 30 mbsf at this site during Leg 139. An extensive data set including ~200 heat flow measurements and 20 sediment cores sampled for pore water was obtained within the immediate vicinity of the Dead Dog vent field in the summer of 1995. Evaluation of this data prior to the cruise may argue that the transect of holes should be moved from Dead Dog Hill to either Chowder Hill mound or the Ropos vent field (Fig. 4) if it is determined that they represent better targets for accomplishing the objectives of drilling in this area. Regardless of which mound is chosen for operations, the scientific objectives and drilling strategy will remain the same. All of the mounds are within a few hundred meters of each other, and are considered to be a single drilling site. The proposed transect will include drilling in the top, flank, and periphery of the mound in order to test the subseafloor inflation model for the formation of these mounds by evaluating the composition of the sediment that occurs directly beneath and on the flanks of an active hydrothermal mound. Pore-fluid and temperature gradients will also be measured to evaluate the direction and magnitude of fluid flow in the shallow subsurface. If time permits, the transect will be continued beyond the edge of the acoustic side scan sonar reflector that defines the presently active vent field (Fig. 4).

A second objective of drilling within the Dead Dog vent field is to establish the presence, continuity, and nature of a suspected “caprock” horizon underlying the vent field. Drilling on Leg 139 encountered, but did not recover, a lithified layer at approximately 30 m depth throughout the present extent of the vent field. This layer may be controlling lateral gradients in pore-fluid composition that appear to be supported by lateral fluid flow at approximately this depth. The absence of, or permeable path ways through this layer may also control the location of the individual vent sites. Authogenic cementation of the sediment by either carbonate or silica are though to be the likely cause of this apparent hydrothermal caprock. Hydrothermal caprocks appear to be an important component of near surface fluid flow and localization of ore deposition in ancient hydrothermal deposits, but it is difficult to unambiguously establish the time of formation or genetic importance of such features in on land analogs. Recognition of this horizon (based on Leg

139 rate of penetration) allows us to target recovery of the rocks and to evaluate gradients in the pore-fluid composition at this potential barrier to hydrological flow.

While completion of BH1 will accomplish our highest priority goals for investigating the Bent Hill massive sulfide deposit, other important objectives at the Bent Hill site include examining the lateral extent of sulfide mineralization, the compositional variations in the sulfide, the timing of hydrothermal activity recorded in the sediments, and the tectonic controls on fluid flow. These objectives will be addressed by drilling a transect of holes across the western edge of the Bent Hill deposit starting from BH1 (Fig. 7). The total number, spacing and depth of the holes in this transect will need to be determined by the results of drilling at BH1 and the amount of time left for drilling operations at the Middle Valley site. The first site (BH3) will be located ~50-100 m west of BH1 and will be drilled by APC/XCB to a depth of 50 to 200 m, dependent on recovery. Each of these holes will require a short camera survey for precise site location. The nature of the recovered material and the drilling conditions will determine if we should step inward toward the center of the deposit or move to more distal sites. It will also determine whether the APC/XCB system is the appropriate drilling technology for sampling the sediment buried fringe of the deposit, or whether we should use the RCB to core through the buried sulfide mound. The most westerly hole in this transect (BH6) is targeted at a buried fault (Site 856 fault) that may have served as a conduit for hydrothermal flow, but this hole, which is approximately midway between Sites 856 and 857 will also serve as a reference hole for evaluating the physical properties of the Middle Valley sediments away from the thermal anomalies of hydrothermal upflow zones. If time permits, we will drill an APC/XCB hole (BH8) on the north flank of a second mound of massive sulfide that occurs approximately 300 m south of BH1 (Sunnyside Up deposit, Fig. 7). Pore-water profiles and fluid inclusions in hydrothermal minerals formed in the zone of hydrothermal fluid upflow that formed this massive sulfide mound may help constrain the stability of vent fluid compositions with time and may give important clues to the origin of salinity variations in hydrothermal vents, which remains one of the important unanswered questions in the geochemistry of these systems.

An alternate site to be drilled, as time and conditions warrant, aims to extend the N-S transect begun on Leg 139 across the Bent Hill deposit. Proposed Hole BH7 is located approximately half way between the Bent Hill and Sunnyside Up deposits (~100m south of BH1) and completes the transect BH1, BH7, BH8 (north to south). This Hole is intended to provide constraints on the geometry, extent, and timing of the sulfide mineralization and alteration. It should also provide the least hydrothermally disturbed section of the sediment column overlying the footwall of the Site 856 fault.

In order to complete the drilling objectives at Escanaba Trough we will need to leave the Middle Valley drill sites on or about 28 days into the cruise. After recovering the PUPPI´s, a two day transit from Middle Valley to Escanaba Trough (40°57.50´N, 127°30.50´W) will put us on location for Site ET7 (Fig. 10). This hole will be drilled to establish the sedimentary sequence away from the NESCA volcanic/hydrothermal center. A reference hole is needed to provide the necessary background information to evaluate the sedimentary and thermal history in an area away from a hydrothermal upflow zone. Determination of the nature of the igneous basement at a site away from the igneous intrusions that define the volcanic/hydrothermal centers is important to our understanding of the larger scale thermal and hydrologic structure of sediment-covered spreading centers. The reference hole will be sited along seismic line 89 05 (Fig. 11), which shows relatively little disturbance of the sediment and along which a heat flow profile was collected.

Other important questions regarding the sedimentary history of Escanaba Trough will also be addressed at this site. The only previous drilling in Escanaba Trough was DSDP Site 35 approximately 35 km south of the NESCA area, but this site was located east of the spreading axis. Site 35 was drilled to 390 mbsf without reaching basement, but only 95 m of the interval was cored. The turbidite sequence records the sedimentary record of glacial activity and sea level variations during the Pleistocene. Leg 5 scientists recognized a major change in provenance between the sediments recovered from the lower and upper parts of this hole, defining a change in source from sediments derived from the Klamath Mountains to Columbia River drainage, respectively (Vallier et al., 1973). A second area of investigation into the sedimentary history of Escanaba Trough involves the controversial “transparent” layer present in all seismic profiles across the Trough (Morton and Fox, 1994; Davis and Becker, 1994a). This layer occurs at approximately 100 ms depth and is about 50 ms thick. Davis and Becker (1994a) have interpreted this zone as a homogeneous sandy layer related to the Bretz floods caused by the catastrophic draining of ice-dammed Lake Missoula at approximately 13,000 ka. Normark et al. (1994), however, interpret this zone as a muddy interval formed during an interglacial high-stand of sea level. Either interpretation has ramifications for the large scale hydrology of the Escanaba Trough and can be tested by subseafloor sampling. The former scenario would imply that this unit could be an aquifer for transport of hydrothermal fluid to sites of cross-stratal permeability, such as faults or volcanic highs. The second scenario would suggest that this unit may be an aquiclude that seals the hydrothermal system. Hole ET7 will be logged with the standard suite of logging tools, including FMS.

We will then proceed to the ET1-4 (Figs. 10, 12) transect across the Central Hill massive sulfide deposit with the highest priority again to drill through the massive sulfide deposit and into the alteration zone near the center of the hydrothermal upflow zone. Drilling objectives at this site are similar to those at the Bent Hill deposit and we hope to establish the causes of the major compositional differences between the deposits at Middle Valley and Escanaba Trough. Our drilling strategy will be to APC/XCB a series of shallow exploratory holes and will, therefore, be targeted primarily at the sediment-covered areas of the seafloor between exposed mounds of massive sulfide. We wish to establish the extent, composition, and drillability of the massive sulfide in this area prior to starting a deeper drill hole. Drilling on the exposed massive sulfide outcrops will not be possible using the APC/XCB system and we may be forced to switch to the RCB system during the exploratory phase of drilling to enable us to drill on the outcropping massive sulfide in order to determine the best site to initiate a hole designed for deeper penetration.

The exploratory drilling will provide important information on the mineralogy, composition, and extent of massive sulfide mineralization in the shallow subsurface at this site, and will contribute to some of our high priority goals. In order to achieve all the goals for this site we will need to establish a reenterable drill hole that penetrates through the massive sulfide deposit and recovers altered rock from the hydrothermal upflow zone. This hole (ET5) will most likely be drilled with the RCB system and initiated by installing a length of drill-in casing. In order to address the questions regarding the compositional differences between the Escanaba Trough and Middle Valley deposits it will be necessary to examine the nature and composition of the rocks underlying the deposit. Our contingency plan, in case establishing a deep hole in this environment proves difficult, is to move to the sediment-covered edges of the deposit and attempt to intersect the flanks of the alteration zone. The complex geology at this site precludes accurate estimation of the required depth of penetration at this site. It is our intent to drill deeply enough to warrant running a full suite of logs in this hole, including the GMT, for comparison to the Bent Hill deposit, and drilling will be terminated at the appropriate stage to enable logging of the hole prior to departing the site for the San Diego port call.

In the event that time is available after the conclusion of ET5 operations, we propose to offset to a location over the flat top of the recently uplifted SW Hill (ET6). This hill is similar to Bent Hill in Middle Valley, but is larger and rises more than 120m over the surrounding turbidite plain. Massive sulfides have been observed on every camera and submersible track that have crossed the basal scarp that defines the hill. Drilling at SW Hill could test the hypothesis that laccolithic intrusion is responsible for uplift of these hills, which are common in Escanaba Trough.

LOGGING AND DOWNHOLE EXPERIMENTS

Logging and downhole experiments are critically important to the scientific objectives of Leg 169, particularly as core recovery may be poor, based on the previous coring experiences in Middle Valley during Leg 139. One of the first priorities of the leg will be to remove and reinstall CORKs already present in Holes 858G and 857D. Temperature measurements and fluid sampling with minimum disturbance will be part of these two operations. A full logging program will be run at Hole 857D.

Tools planned for possible use in all holes (Table 2) include the full set of Schlumberger tool logs, several downhole temperature tools and a high temperature borehole fluid sampler. In addition, a packer/flowmeter might be used in Hole 857D, depending on borehole temperatures and such constraints as whether or not the side-entry-sub (SES) is required in order to cool the hole during logging. Unless the holes can be kept cool enough by the down-hole flow of ocean bottom water that may be induced by drilling, the SES is expected to be used in most of the sites as the temperatures will presumably exceed the operational limits of the standard logging tools. Following preliminary temperature measurements, the logging suites will include sonic/resistivity, density/porosity and FMS, as well as a geochemical string in high-priority sites ET5 and BH1 to assess compositional variations throughout these massive sulfide deposits and the underlying altered rocks. If the holes cannot be kept cool enough for the standard Schlumberger tools, a hostile environment gamma ray/density/porosity combination tool can be deployed which can be valuable for characterization of the different lithological units.

The main objectives of the downhole program will be to assess the changes in physical properties resulting from hydrothermal alteration and enhanced diagenesis, as well as how they relate to existing hydrological models. In addition to defining structural and lithological boundaries as a function of depth, the logging program will attempt to establish hole-to-hole correlations to determine lateral stratigraphic variations in active hydrothermal systems, as well as direct correlations with discrete laboratory data. Also, sonic velocities and densities will provide the necessary information for the calculation of synthetic seismogram models, and a direct correlation with high resolution seismic data obtained prior to Leg 139.

SPECIAL SAMPLING PLAN/STRATEGY

Water sampling

Observations from the Alvin submersible demonstrated that Hole 858G is now a producing hole; the CORK seals have apparently failed and hydrothermal fluid is venting from inside the reentry cone. Sampling undiluted hydrothermal fluid in the borehole below the level of casing represents one of the goals of this expedition, and will require particular care to minimize the potential for mixing with cold sea water. We expect the temperature of this fluid to be in excess of 200°C, and perhaps as high as 280°C. Temperatures this high exceed the operational limits of either the WSTP (~120°C) or the Fisseler water sampler (~85°C). The only tool available to collect an uncontaminated, high temperature water sample from the borehole is the Los Alamos dewared high temperature water sampler.

Thin section preparation

Accurate descriptions of the mineralogy present in massive sulfide and sulfide mineral-bearing samples requires polished thin sections for reflected light petrography. Particular care must be taken when these sections are prepared to avoid preferentially plucking phases from the thin section billets and to preserve textural relationships between minerals with high polishing hardness (pyrite, arsenopyrite) and low polishing hardness (galena, silver-rich sulfosalt minerals, clay minerals in the gangue material). Production of high quality polished thin sections of material containing minerals with differing polishing properties is an art. In practice, this requires careful attention to detail and slow polishing with little vertical pressure applied to the sections. Preparation of high quality polished sections of sulfides, therefore, takes considerably more time than required for standard thin section preparation. This may result in the necessity for the Shipboard Laboratory Specialist assigned to the thin section laboratory to be dedicated to thin section preparation during operations at some sites. In order to effect this, members of the Shipboard Scientific Party may be requested to help with core handling to allow the Shipboard Laboratory Specialist the time required for sample preparation.

Geochemical analyses

Nonroutine shipboard analyses will include atomic absorption analyses of sulfide rock and sediment samples for Cu, Pb, Zn, Fe, and Ag. This will require digestion of the samples with Aqua Regia. We also expect to analyze sulfide rock and sediment samples for bulk compositions by X-ray fluorescence. Adequate standards will need to be obtained to cover the expected range of compositions of these mineralized samples. Calibration early in the leg will require an allotment of time from the Shipboard X-ray Laboratory Specialists.

Bacteriological sampling

In addition to sampling biota that may be present on the recovered CORKs and thermistor strings, sample collection from recovered core must be designed to minimize the chance of contamination. This aseptic sampling must be done as soon as possible after recovery of the cores and may include A) taking whole round intervals, and/or B) sampling plugs of material removed from the center of the core on the catwalk.

Pore-water sampling

Thermal and chemical gradients in the active hydrothermal areas are very steep. In order to characterize these steep gradients, it will be necessary to take whole round samples for pore fluid compositions from closely spaced intervals in the uppermost portions of some holes. For the highest temperature sites, sampling frequency may exceed one pore fluid sample per section.

Core and sample handling

Sulfide minerals, in particular pyrrhotite, are subject to rapid oxidation. Core containing significant amounts of sulfide will be stored in D-tubes sealed in tight air bags that have been flushed with N_2 gas to minimize degradation of the cores. Moisture accelerates the oxidation of sulfide-rich cores, so efforts should be made to store the cores with as little contained moisture as is practical. Similarly, samples collected for post-cruise shorebased studies should be dried and sealed prior to shipping.

Transfer of seismic data at sea

A new seismic survey in the area of operations will be run just prior to arrival of the JOIDES *Resolution* on site. The chief scientist of the survey operation has offered to hold the RV *Sonne* on location until our arrival, so that these data can be transferred to the *Resolution* for use in specific site location as required.

Launching and recovery of instruments

A unique experiment in the operational strategy for this expedition is the measurement of a transient pressure pulse measured at one CORKed hole, when a nearby hole is unsealed and deepened. In addition to measurements in the borehole, we hope to deploy an array of three Pop-Up Pore Pressure Instruments between the holes. PUPPI´s are pressure sensing probes, to be deployed either over the side or from the moonpool of the JOIDES *Resolution*. The design of the probe is such that it is a free-fall, programmable memory tool, with a probe that penetrates 3 m into the seafloor sediment. The device records differential pore pressure between two ports on the probe. When measurements are complete, a coded acoustic signal severs the data logger from the probe, and the data logger floats to the sea surface for recovery. The transient overpressure caused by circulating cold seawater into an unCORKed borehole should be reflected in the pore pressure data recorded by this PUPPI array. Installation and recovery of the PUPPI´s will be an operation similar to deployment and recovery of site transponder beacons, where after release on dGPS coordinates, the PUPPI´s are tracked until emplaced, and recovered by either hook or Zodiac after acoustic release prior to leaving Middle Valley.

In the event pre-cruise evaluations, and or operations during the cruise, suggest that the permiability of the sediments is so low as to hinder recording of the expected pressure pulse. The deployment strategy outlined above may be revised, and we may elect to deploy the PUPPI´s adjacent to the APC Holes DD1-DD4 in the Dead Dog area.

REFERENCES

Ames, D.E., Franklin, J.M., and Hannington, M.D., 1993. Mineralogy and geochemistry of active and inactive chimneys and massive sulfide, Middle Valley, Northern Juan de Fuca Ridge: an evolving hydrothermal system. *Can. Min.*, 31: 997-1024.

Butterfield, D.A., McDuff, R.E., Franklin, J., and Wheat, C.G., 1994. Geochemistry of hydrothermal vent fluids from Middle Valley, Juan de Fuca Ridge. In Mottl, M.J., Davis, E.E., Fisher, A.T., and Slack, J.F., (Eds.), *Proc. ODP, Sci. Results*, 139: College Station, TX (Ocean Drilling Program), 395-410.

Campbell, A.C., German, C.R., Palmer, M.R., Gamo, T. and Edmond, J.M., 1994. Chemistry of hydrothermal fluids from the Escanaba Trough, Gorda Ridge. *In* Morton, J.L., Zierenberg, R.A., and Reiss, C.A., (Eds.), Geologic, Hydrothermal, and Biologic Studies at Escanaba Trough, Gorda Ridge, Offshore Northern California: *U.S.G.S. Bull*. 2022, Chapter 11, 201-221.

Currie, R.G., and Davis, E.E., 1994. Low crustal magnetization of the Middle Valley sedimented rift inferred from sea surface magnetic anomalies. *In* Mottl, M.J., Davis, E.E., Fisher, A.T., and Slack, J.F., (Eds.), *Proc. ODP, Sci. Results*, 139: College Station, TX (Ocean Drilling Program), 19-28.

Davis, E.E., and Becker, K., 1994a, Thermal and tectonic structure of the Escanaba Trough: New heat-flow measurements and seismic-reflection profiles, *In* Morton, J.L., Zierenberg, R.A., and Reiss, C.A., (Eds.), Geologic, Hydrothermal, and Biologic Studies at Escanaba Trough, Gorda Ridge, Offshore Northern California: *U.S.G.S. Bull*. 2022, Chapter 3, 45-64.

Davis, E.E., and Becker, K., 1994b, Formation temperatures and pressures in a sedimented rift hydrothermal system: Ten months of CORK observations, Holes 857D and 858G, ODP Leg 139. *In* Mottl, M.J., Davis, E.E., Fisher, A.T., and Slack, J.F., (Eds.), *Proc. ODP, Sci. Results*, 139: College Station, TX (Ocean Drilling Program), 649-666.

Davis, E.E., and Fisher, A.T., 1994, On the nature and consequences of hydrothermal circulation in the Middle Valley sedimented rift: Inferences from geophysical observations, ODP Leg

139. *In* Mottl, M.J., Davis, E.E., Fisher, A.T., and Slack, J.F., (Eds.), *Proc. ODP, Sci. Result*s, 139: College Station, TX (Ocean Drilling Program), 695-720.

Davis, E.E., and Villinger, H., 1992, Tectonic and thermal structure of the Middle Valley sedimented rift, Northern Juan de Fuca Ridge. *In* Mottl, M.J., Davis, E.E., Fisher, A.T., and Slack, J.F., (Eds.), *Proc. ODP, Sci. Results*, 139: College Station, TX (Ocean Drilling Program), 9-41.

Davis, E.E., Mottl, M.J., Fisher, A.T., et al., 1992. *Proc. ODP, Init. Repts.*, 139: College Station, TX (Ocean Drilling Program).

Denlinger, R.P., and Holmes, M.L., 1994, A thermal and mechanical model for sediment hills and associated sulfide deposits along the Escanaba Trough, *In* Morton, J.L., Zierenberg, R.A., and Reiss, C.A., (Eds.), Geologic, Hydrothermal, and Biologic Studies at Escanaba Trough, Gorda Ridge, Offshore Northern California: *U.S.G.S. Bull*. 2022, Chapter 4, 65-75.

Goodfellow, W.D., and Franklin, J.M., 1993. Geology, mineralogy, and chemistry of sediment-hosted clastic massive sulfides in shallow cores, Middle Valley, northern Juan de Fuca Ridge. *Econ. Geol.*, 88:2033-2064.

Goodfellow, W.D., and Peter, J.M., 1994. Geochemistry of hydrothermally altered sediment, Middle Valley, northern Juan de Fuca Ridge. *In* Mottl, M.J., Davis, E.E., Fisher, A.T., and Slack, J.F., (Eds.), *Proc. ODP, Sci. Results*, 139: College Station, TX (Ocean Drilling Program), 207-290.

Koski, R.A., Benninger, L.M., Zierenberg, R.A., and Jonasson, I.R., 1994. Composition and growth history of hydrothermal deposits in Escanaba Trough, Southern Gorda Ridge. *In* Morton, J.L., Zierenberg, R.A., and Reiss, C.A., (Eds.), Geologic, Hydrothermal, and Biologic Studies at Escanaba Trough, Gorda Ridge, Offshore Northern California: *U.S.G.S. Bull.* 2022, Chapter 16, 293-324.

Morton, J.L., and Fox, C.G., 1994. Structural setting and interaction of volcanism and sedimentation at Escanaba Trough: Geophysical results. *In* Morton, J.L., Zierenberg, R.A., and Reiss, C.A., (Eds.), Geologic, Hydrothermal, and Biologic Studies at Escanaba Trough, Gorda Ridge, Offshore Northern California: *U.S.G.S. Bull. 2022*, Chapter 2, 21-43.

Morton, J.L., Zierenberg, R.A., and Reiss, C.A., 1994. Geologic, Hydrothermal, and Biologic Studies at Escanaba Trough: An Introduction. *In* Morton, J.L., Zierenberg, R.A., and Reiss, C.A., (Eds.), Geologic, Hydrothermal, and Biologic Studies at Escanaba Trough, Gorda Ridge, Offshore Northern California: *U.S.G.S. Bull.* 2022, Chapter 1, 1-18.

Normark, W.R., Gutmacher, C.E., Zierenberg, R.A., Wong, F.L., and Rosenbauer, R.J., 1994. Sediment fill of Escanaba Trough. *In* Morton, J.L., Zierenberg, R.A., and Reiss, C.A., (Eds.), Geologic, Hydrothermal, and Biologic Studies at Escanaba Trough, Gorda Ridge, Offshore Northern California: *U.S.G.S. Bull. 2022*, Chapter 6, 91-130.

Rohr, K.M.M., and Schmidt, U., 1994. Seismic structure of Middle Valley near Sites 855-858, Juan de Fuca Ridge, *In* Mottl, M.J., Davis, E.E., Fisher, A.T., and Slack, J.F., (Eds.), *Proc. ODP, Sci. Results*, 139: College Station, TX (Ocean Drilling Program), 3-18.

Tivey, M.A., 1994, High-resolution magnetic surveys over the Middle Valley mounds, northern Juan de Fuca Ridge, *In* Mottl, M.J., Davis, E.E., Fisher, A.T., and Slack, J.F., (Eds.), *Proc. ODP, Sci. Results*, 139: College Station, TX (Ocean Drilling Program), 29-38.

Vallier, T.L., Harold, P.J., and Girdley, W.A., 1973, Provenances and dispersal patterns of turbidite sand in Escanaba Trough, northeastern Pacific Ocean. *Mar. Geol.*, 1: 67-87.

Zierenberg, R.A., and Shanks, W.C., III, 1994, Sediment alteration associated with massive sulfide formation in Escanaba Trough, Gorda Ridge: The importance of seawater mixing and magnesium metasomatism, *In* Morton, J.L., Zierenberg, R.A., and Reiss, C.A., (Eds.), Geologic, Hydrothermal, and Biologic Studies at Escanaba Trough, Gorda Ridge, Offshore Northern California: *U.S.G.S. Bull*. 2022, Chapter 14, 257-278.

Zierenberg, R.A., Koski, R.A., Morton, J.L., Bouse, R.M., Shanks, W.C., III, 1993, Genesis of massive sulfide deposits on a sediment-covered spreading center, Escanaba Trough, 41°N, Gorda Ridge. *Econ. Geol.*, 88:2069-2098.

Zierenberg, R.A., Morton, J.L., Koski, R.A., and Ross, S.L., 1994, Geologic setting of massive sulfide mineralization in the Escanaba Trough. *In* Morton, J.L., Zierenberg, R.A., and Reiss, C.A., (Eds.), Geologic, Hydrothermal, and Biologic Studies at Escanaba Trough, Gorda Ridge, Offshore Northern California: *U.S.G.S. Bull*. 2022, Chapter 10, 171-197.

SITE TIME ESTIMATES

LEG 169--SEDIMENTED RIDGES II

Victoria to San Diego, 20 August to 17 October 1996

Site Name	Latitude N Longitude W	Water Depth (m)	Penetration (mbsf)	Location	Operations	Transit 10.5 kt (days)	CoringTime (days)	Log (days)	Total (days)
Transit Saanich Inlet to Victoria: Dep 0600 20 Aug -- Arr 1200 20 Aug						0.3			0.3
Port Call for Scientific Party: Sci Arr 19 Aug -- Dep 1200 21 Aug						1.0			1.0
Hole 858G	48°27.36´N 128°42.53´W	2415	0	beside Dead Dog Hydro-thermal Mound	Remove CORK, T log,sample, replace CORK	0.9	3.8		4.7
BH-1	48°26.02´N 128°40.85´W	2435	200 sed 50 bsmt	Bent Hill Hydro-thermal Mound	RCB 50 m Pilot Hole DIC 50 m, RCB 250 m,Log	0.1	0.6 3.1	2.0	0.7 5.1
Hole 857D	48°26.5´N 128°42.65´W	2420	200 bsmt	1 nmi South of Dead Dog Mound & 858G	Remove CORK, T log, sample,drill 1 bit, packer, reinstall CORK w/ instr.	0.1	6.1	2.0	8.2
DD-1	48°27.35´N 128°42.60´W	2410	50 sed	Dead Dog Hydro-thermal Mound	APC, XCB 50 m	0.1	0.9		1.0
DD-2	48°27.35´N 128°42.60´W	2425	50 sed	Dead Dog Hydro-thermal Mound	APC, XCB 50 m,WSTP	0.1	0.9		1.0
DD-3	48°27.35´N 128°42.55´W	2425	50 sed	Dead Dog Hydro-thermal Mound	APC, XCB 50 m,WSTP	0.1	0.9		1.0
BH-3 to 6	48°26.02´N 128°40.93´W	2450	200 sed	Bent Hill Hydro-thermal Mound	APC, XCB 200 m APC, XCB 200 m APC, XCB 200 m	0.1	1.7 1.4 1.6		1.8 1.4 1.6
Transit: Depart 20 Sept						1.8			
ET-7	40°57.50´N 127°30.50´W	3340	600 sed 50 bsmt	Escanaba Trough	APC, XCB 650 m.Log		6.1	1.7	7.8
ET-1 to 4	41°00´N 127°29.00´W	3240	200 sed 50 bsmt	Escanaba Trough	APC, XCB 250 m APC, XCB 250 m	0.2	2.7 2.6		2.9 2.6

Site Name	Latitude N Longitude W	Water Depth (m)	Penetration (mbsf)	Location	Operations	Transit 10.5 kt (days)	CoringTime (days)	Log (days)	Total (days)
ET-5	41°00´N 127°29.00´W	3250	200 sed 200 bsmt	Escanaba Trough	APC, XCB 220 m,FFF, RCB 600 m,Log	0.1	7.9	2.0	0.1 9.9
Transit to San Diego: Dep 0800 14 Oct -- Arr 0600 17 Oct						2.9			2.9
					Est Time=	8.1	41.7	7.7	57.5
					Available Time =	6.0	52.0		58.0

ALTERNATE SITES

Site Name	Latitude N Longitude W	Water Depth (m)	Penetration(mbsf)	Location	Operations	Transit 10.5 kt (days)	Coring Time (days)	Log (days)	Total (days)
BH-2	48°26.02´N 128°40.89´W	2440	200 sed 20 bsmt	Bent Hill Hydro-thermal Mound	APC, XCB 220 m	0.1	2.0		2.1
BH-4	48°26.02´N 128°41.02´W	2460	250 sed	Bent Hill Hydro-thermal Mound	APC, XCB 250 m	0.1	2.2		2.3
BH-5	48°26.02´N 128°41.18´W	2465	400 sed	Bent Hill Hydro-thermal Mound	APC, XCB 250 m	0.1	3.0		3.1
BH-6	48°26.02´N 128°41.39´W	2460	450 sed 20 bsmt	Bent Hill Hydro-thermal Mound	APC, XCB 470 m,Log	0.1	3.9	0.8	4.8
BH-7	48°25.95´N 128°40.90´W	2460	200 sed	Bent Hill Hydro-thermal Mound	APC, XCB 200 m	0.1	1.7		1.8
BH-8	48°25.85´N 128°40.90´W	2445	200 sed 20 bsmt	Bent Hill Hydro-thermal Mound	RCB 50 m Pilot Hole DIC 50m,RCB 200m,Log	0.1	0.6 3.4	 0.8	0.7 4.2
ET-2	41°00´N 127°29.00´W	3250	200 sed 20 bsmt	Escanaba Trough	APC, XCB 220 m	0.1	2.9		3.0
ET-3	41°00´N 127°29.00´W	3255	200 sed 20 bsmt	Escanaba Trough	APC, XCB 220 m	0.1	2.5		2.6
ET-4	41°00´N 127°29.00´W	3260	200 sed 20 bsmt	Escanaba Trough	APC, XCB 220 m	0.1	2.5		2.6
ET-6	40°95´N 127°30.05´W	3170	500 sed 20 bsmt	Escanaba Trough	APC, XCB 520 m	0.1	4.4		4.5

TABLE 1. SCIENTIFIC OBJECTIVES FOR TWO LEGS OF DRILLING ON SEDIMENTED RIDGES.

GENERAL SCIENTIFIC OBJECTIVE	LEG 139 SITES	RESULTS FROM LEG 139	LEG 169 SITES	SPECIFIC OBJECTIVES FOR LEG 169
Large Scale Hydrology				
Reaction Zone	857C-D	Pore-fluids match vent composition, determined alteration mineralogy	857D, 858G	Sample borehole fluids after unCORKing holes.
Active Upflow Zone	858A-G	Localized by basement high, nearly isothermal, determined alteration mineralogy	BH8 ET1-5	Determine relationship of active fluid flow to alteration of sulfide mounds
Paleo Upflow Zone	856A-B	Distal hydrothermal alteration	BH1-6	Establish controls on fluid flow under Bent Hill massive sulfide
Permeability Distribution	857D 858G	Packer measurements, CORK data	857 D	Hole-to-hole hydrology experi-ment, induced seismicity experi-ment, detailed packer experiment
Permeability Distribution	857D, 858G	Packer measurements, CORK data	857 D	Detailed packer experiment, hole to hole hydrology experiment, induced seismicity experiment
Temperature Structure	All sites	Detailed temperature records	All sites	Detailed temperature records
Small Scale Hydrology	858B-D,F	Lateral flow of hydrothermal fluids, presence of caprock under vent field	DD1-4	Extent and composition of caprock, relation of lateral flow to active vents
Sulfide Genesis				
Localization of Deposits	858G	Localized over basement high	BH1-6 ET1-5	Determine if controlled by basement high or faulting
Size and Geometry of Deposits	856C-G	95 m minimum thickness of massive sulfide deposit	BH1-6 ET1-5	Determine limits of mineralization and alteration
Timing	856B	Uplift of Bent Hill post dates sulfide deposition	BH1-6 ET1-5	Establish depositional history of sulfide deposits
Metal Zoning	856G-H	Extensive recrystallization and metal remobilization	BH1-3 BH8 ET1-5	Establish extent and geometry of mineral zoning
Fluid Composition	856 858	Bent Hill formed by high temperature hydrothermal system distinct from presently active vents, Dead Dog not depositing massive sulfide	BH8 ET-5	Drilling of actively venting massive sulfides to determine geochemical relationship to deposits
Hydrothermal Alteration	857 858	Hydrothermal metamorphism of sediment controls vent composition	BH1-6 BH8 ET1-5	Map extent and nature of high temperature, sulfide depositing hydrothermal system
Source of Metals	856C-G 858B	Bent Hill formed from dominantly basaltic metal source	BH1-6 ET1-5	Contrast Escanaba Trough, which has a dominantly sedimentary metal source, with Bent Hill
Tectonics and Structure				
Spreading Mechanism in Sedimented Rifts	857C-D	Basement is sill-sediment complex, similar to initial rift sequences	857D 858G BH1-6 ET1-5	Investigate mechanism of sill emplacement and sediment deformation, induced seismicity experiment
Relation of Fluid Flow to Faulting			BH5-6	Establish relative timing of fault movement and fluid flow
Sedimentation and Diagenesis				

GENERAL SCIENTIFIC OBJECTIVE	LEG 139 SITES	RESULTS FROM LEG 139	LEG 169 SITES	SPECIFIC OBJECTIVES FOR LEG 169
Reference Sediment Section			ET7	Determine stratigraphy, physical properties, response to sea level outside of thermal effects of vents
Diagenetic Reactions	All sites	Established porewater, organic geochemistry, sulfur isotope profiles, carbonate nodules record thermal gradient	All sites	Determine porewater, organic geochemistry, sulfur isotope profiles, use carbonate nodules to establish paleo-thermal gradient

TABLE 2. PROJECTED LOGGING PLAN

Site/Hole	Measurements	Time (days)
Hole 858G	Temperature, fluid sampler	0.5
Hole 857D	Temperature, fluid sampler, full Schlumberger suite, (± packer and flowmeter)*	2.0
BH1	Full Schlumberger suite, geochemical (± temperature)†	2.0
ET7	Full Schlumberger suite, (± temperature)†	2.0
ET5	Full Schlumberger suite, geochemical (± temperature)†	2.0

* Depending on hole conditions and time constraints.
† Might be required at the beginning of the logging program if excessively high temperatures are expected.

FIGURE CAPTIONS

Figure 1. A) Location map showing tectonic setting of the sediment covered spreading centers at Middle Valley and Escanaba Trough on the Juan de Fuca-Gorda spreading system. Modified from Davis, Mottl, Fisher, et al. (1992)
B) Bathymetry of Middle Valley (Davis and Villinger, 1992) shown as contours drawn at 10 m intervals. Areas of proposed drilling sites are the Dead Dog vent field (Site 858, DD1-4) in the area of active venting and Bent Hill (Site 856, BH1-6, BH8). Modifed from Mottl, Davis, Fisher, and Slack, (Eds.), 1994
C) Bathymetry for Escanaba Trough shown as 200 m intervals. Black areas are the igneous centers. Proposed drill sites are within the NESCA (northern Escanaba Trough) study area. SESCA is the southern Escanaba Trough study area. Modified from Zierenberg and Shanks (1994).

Figure 2. Triangular diagrams illustrating the A) Pb- and B) Au-rich nature of the Escanaba Trough (ET) massive sulfides relative to samples from Middle Valley (MV) or bare-rock hydrothermal systems. Other abbreviations used: TAG,Trans-Atlantic Geotraverse site; GAL, Galapagos spreading center; EPR, East Pacific Rise; END, Endeavour segment, Juan de Fuca Ridge; AX, axial seamount, Juan de Fuca Ridge; SJDF, southern Juan de Fuca Ridge; GB, Guaymas Basin. Modified from Koski et al. (1994).

Figure 3. Pb isotope composition of sulfide, sediment, and basalt samples for Escanaba Trough and Middle Valley. Escanaba Trough sulfide composition indicates a large contribution of sediment derived lead to the hydrothermal deposit while the Middle Valley sulfides are intermediate between basalt and sediment derived fields. Isotopic data are from Zierenberg et al. (1993) and Goodfellow and Franklin (1993).

Figure 4. Middle Valley. Map of the Dead Dog vent field showing location of the major hydrothermal mounds, active vents and the holes drilled on Leg 139 and proposed sites for holes DD1-4. 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. Middle Valley. East-West multichannel seismic reflection profiles crossing the Leg 139 and the proposed Leg 169 drilling sites (Sites DD and BH). Modified from Davis, Mottl, Fisher, et al. (1992).

Figure 6. Middle Valley. Diagram showing the depth to the basement in the two holes which have been instrumented with CORKs. Basement (shaded) at Site 857 is defined as the top of a sill-sediment complex at 470 mbsf. Basement under Site 858 rises to 250 mbsf and is extrusive basalt (from Davis and Becker, 1994b).

Figure 7. Middle Valley. Map of Site 856 area showing the location of the Bent Hill and the two sulfide mounds to the south. A ridge parallel normal fault bounds the west side of the sulfide deposits, Bent Hill, and similar uplifted sediment hills that occur

south of the map area. Proposed sites BH1, BH2-6, and BH8 are shown. Modified from Goodfellow and Peter (1994).

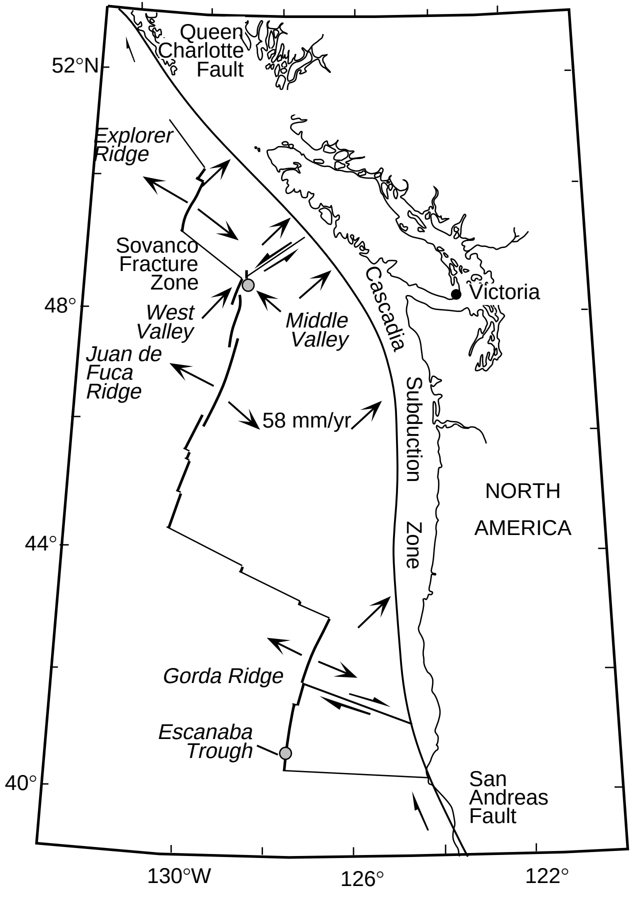
Figure 8. Middle Valley. North-south cross section (5X vertical exaggeration) of Site 856 area showing the exent of penetration of massive sulfide deposit south of Bent Hill and the location of basaltic sills beneath Bent Hill. Modified from Davis, Mottl, Fisher, et al. (1992).

Figure 9. Escanaba Trough. Map of the southern portion of the Gorda Ridge spreading center showing the sediment-filled portion of the Escanaba Trough (light shading), intratrough terraces (intermediate shading) and the volcanic centers (dark shading) that rise through and locally pierce the sediment cover.

Figure 10. Escanaba Trough. Bathymetric map of the NESCA area of Escanaba Trough showing the location of the SW hill, Central Hill, on axis volcanic rocks, sulfide deposits (black), and active vent sites. Location of the proposed sites ET1-5 and ET7 are shown. The location of faults is constrained by the seismic profiles and camera and submersibles scarps. Modified from Zeirenberg et al. (1994).

Figure 11. Escanaba Trough. Heat flow profile along A) seismic line 3 (ET1-5) and B) line 5 (ET7). Modified from Davis and Becker, (1994a).

Figure 12. Escanaba Trough. Detailed map of the Central Hill area of the NESCA site showing proposed drill transect ET1-5 across the hydrothermally active massive sulfide deposits (outlined). Location of active vents, fault scarps, and exposed volcanic rock are based on camera tows and submersible tracks shown as thin lines.



Queen
Charlotte
Fault
52°N
Explorer
Ridge
Sovanco
Fracture
Zone
West
Valley
Middle
Valley
Juan de
Fuca
Ridge
58 mm/yr
Cascadia
Subduction
Zone
Victoria
NORTH
AMERICA
48°
44°
40°
Gorda Ridge
Escanaba
Trough
San
Andreas
Fault
130°W
126°
122°

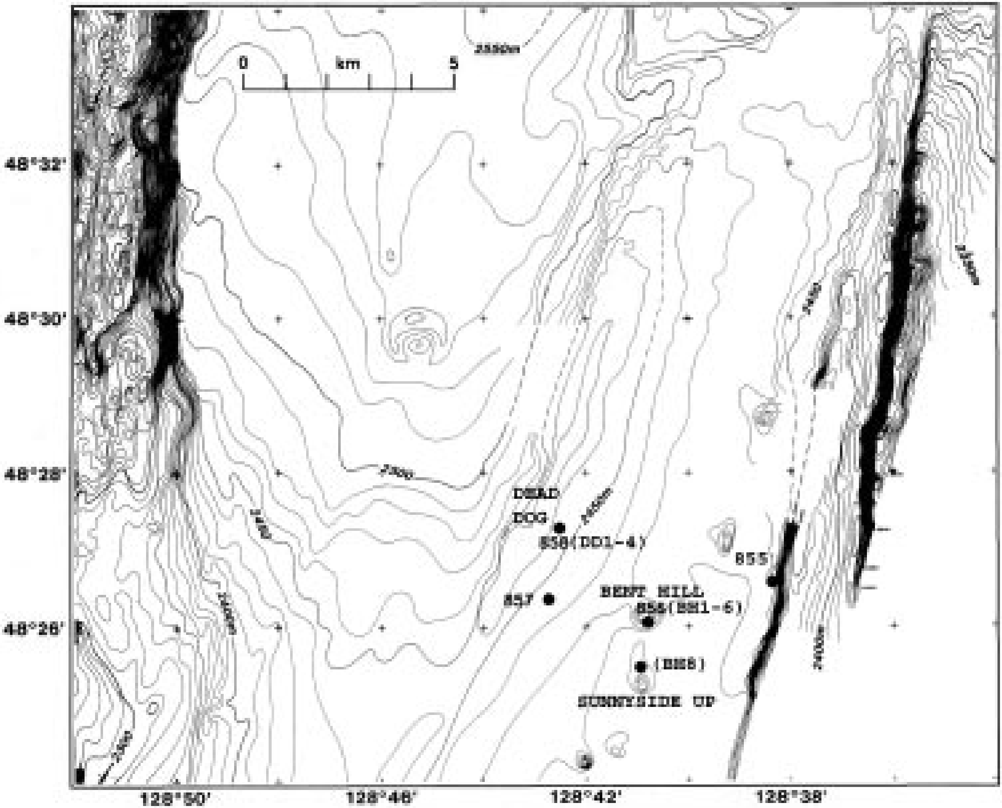

0
km
5
48°32'
48°30'
48°28'
48°26'
128°50'
128°46'
128°42'
128°38'
DEAD
DOG
858(DD1-4)
857
855
BENT HILL
856(BH1-6)
(BH8)
SUNNYSIDE UP

Figure 1C.

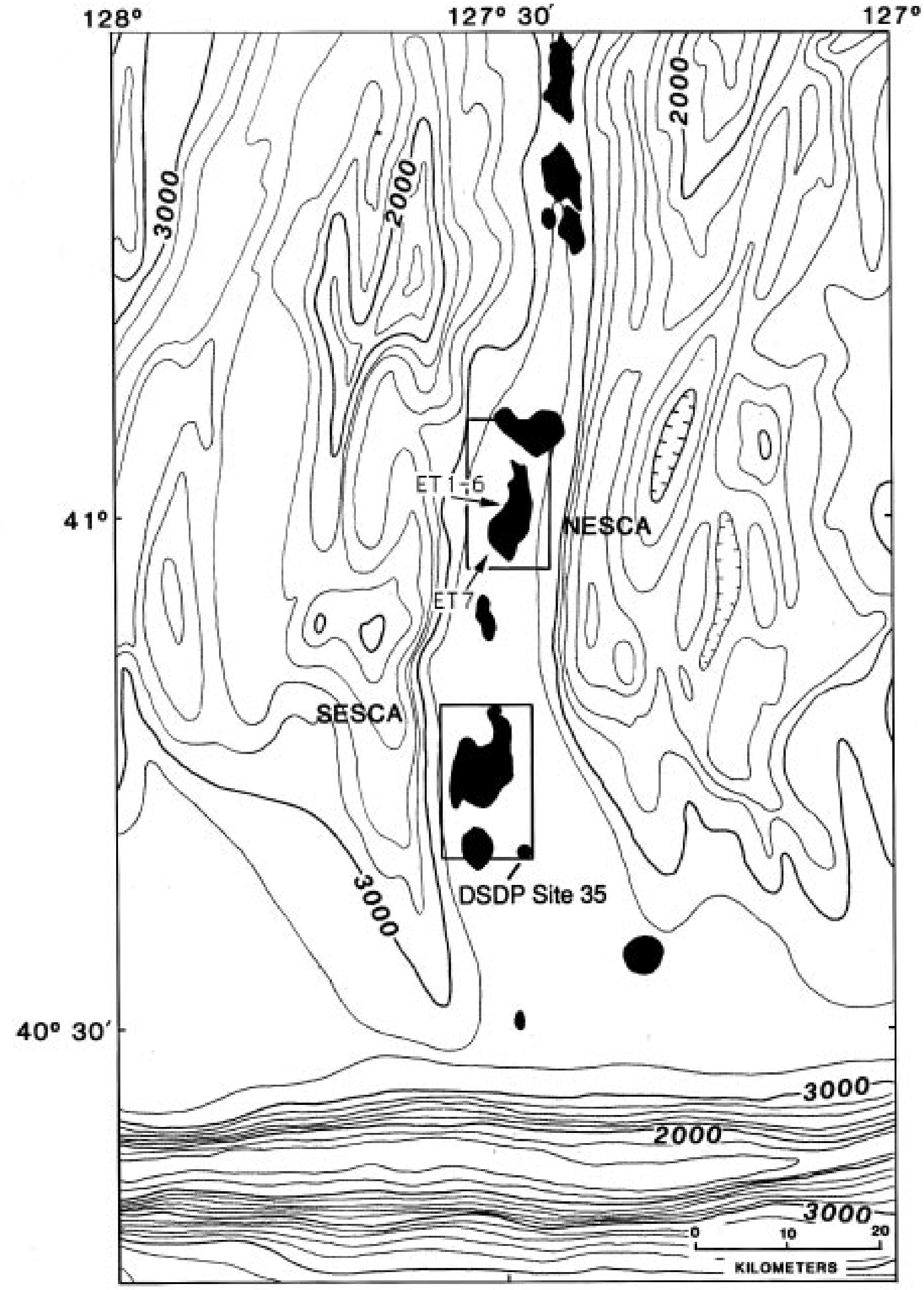
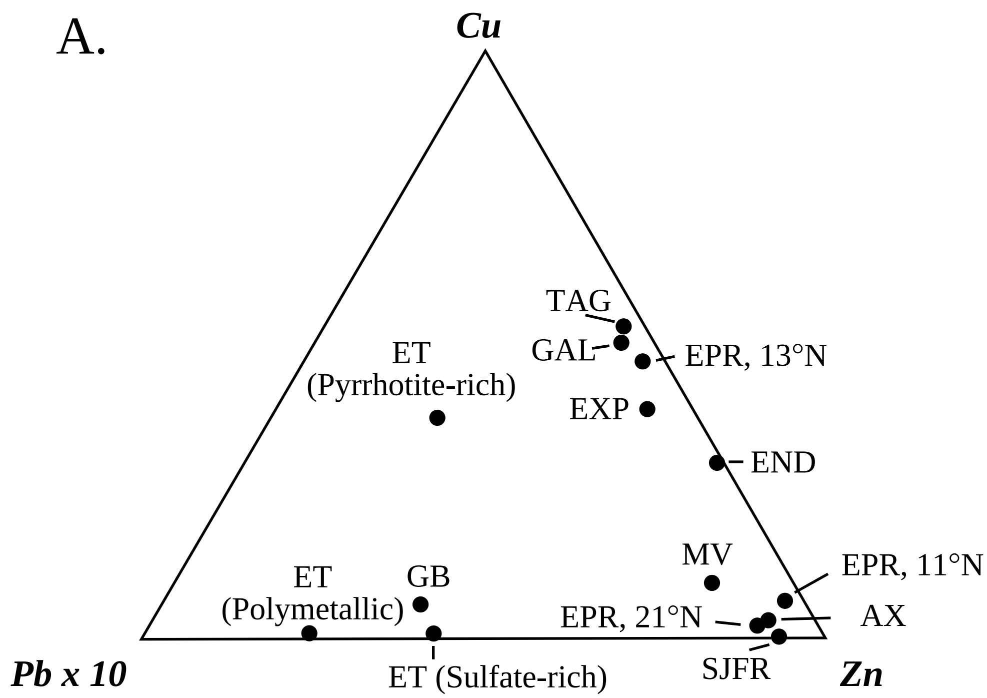

128°
127° 30′
127°
41°
40° 30′
3000
2000
2000
2000
ET 1-6
ET 7
NESCA
SESCA
DSDP Site 35
3000
3000
2000
3000
0
10
20
KILOMETERS

Figure 2.


A.
Cu
TAG
GAL
EPR, 13°N
ET
(Pyrrhotite-rich)
EXP
END
MV
EPR, 11°N
ET
(Polymetallic)
GB
EPR, 21°N
AX
SJFR
ET (Sulfate-rich)
Pb x 10
Zn

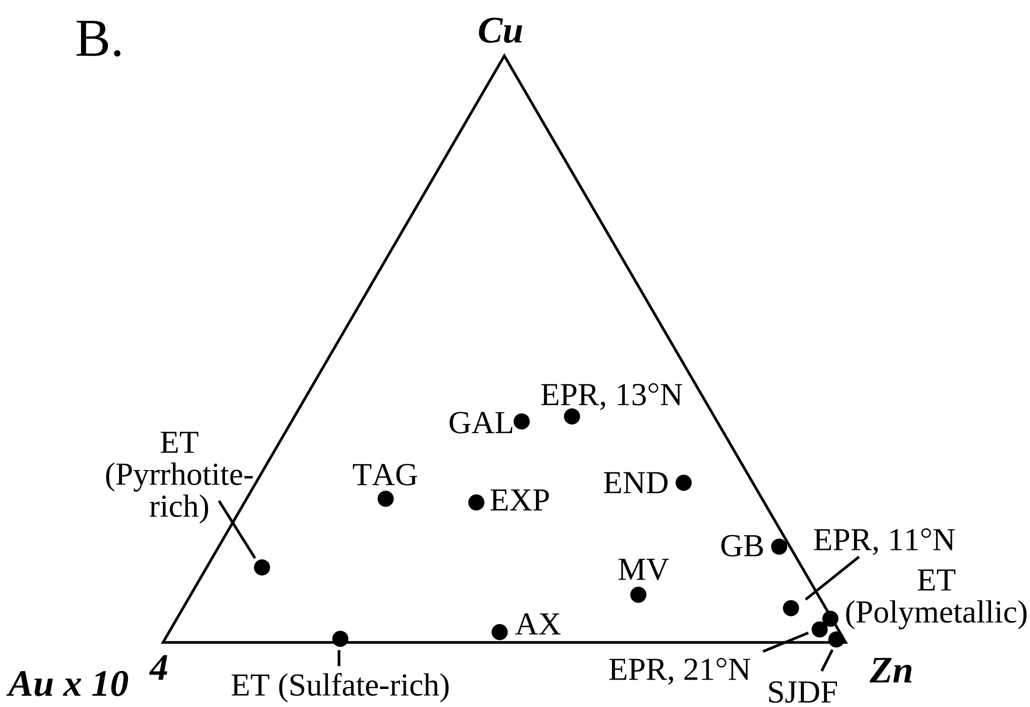

B.
Cu
EPR, 13°N
GAL
ET
(Pyrrhotite-
rich)
TAG
EXP
END
GB
EPR, 11°N
MV
ET
(Polymetallic)
AX
Au x 10
4
ET (Sulfate-rich)
EPR, 21°N
SJDF
Zn

Figure 3.

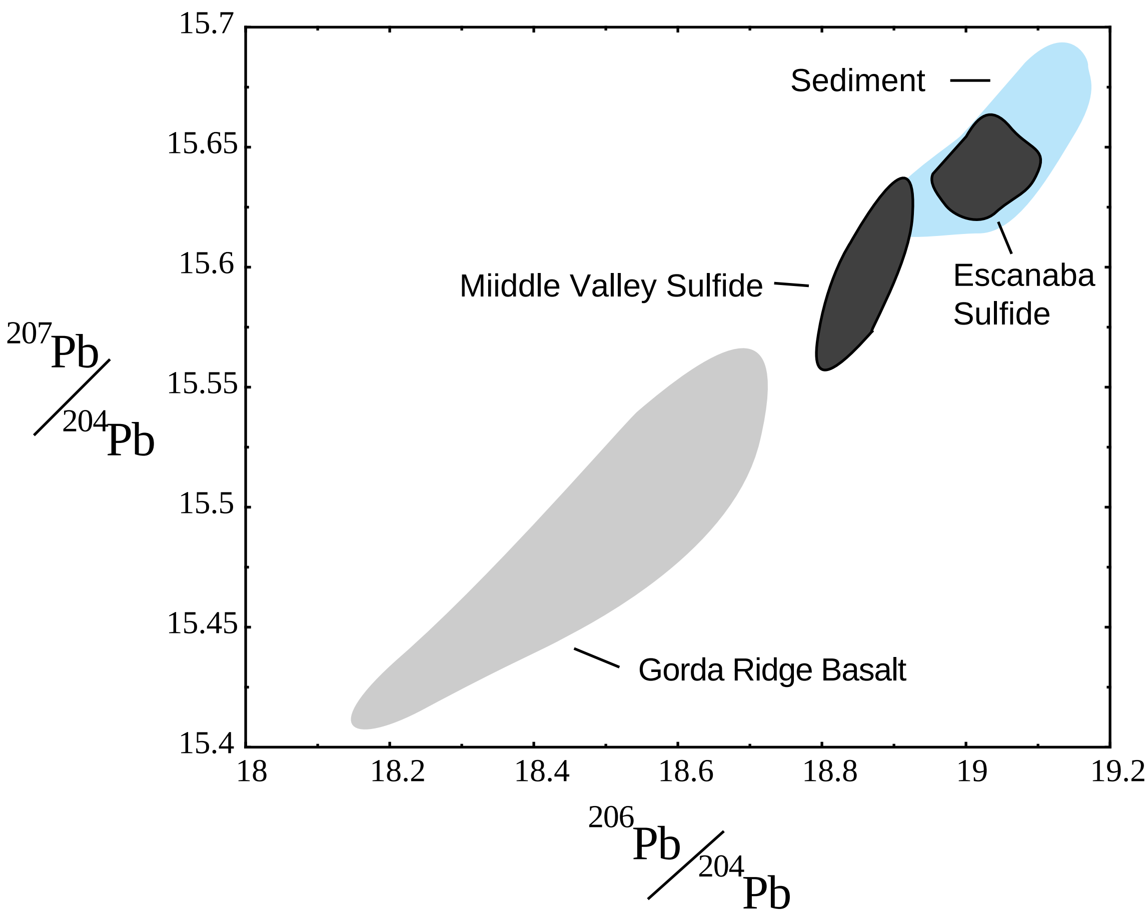

15.7
15.65
15.6
15.55
15.5
15.45
15.4
18
18.2
18.4
18.6
18.8
19
19.2
Sediment
Miidde Valley Sulfide
Escanaba
Sulfide
Gorda Ridge Basalt
207Pb/204Pb
206Pb/204Pb

Figure 4.

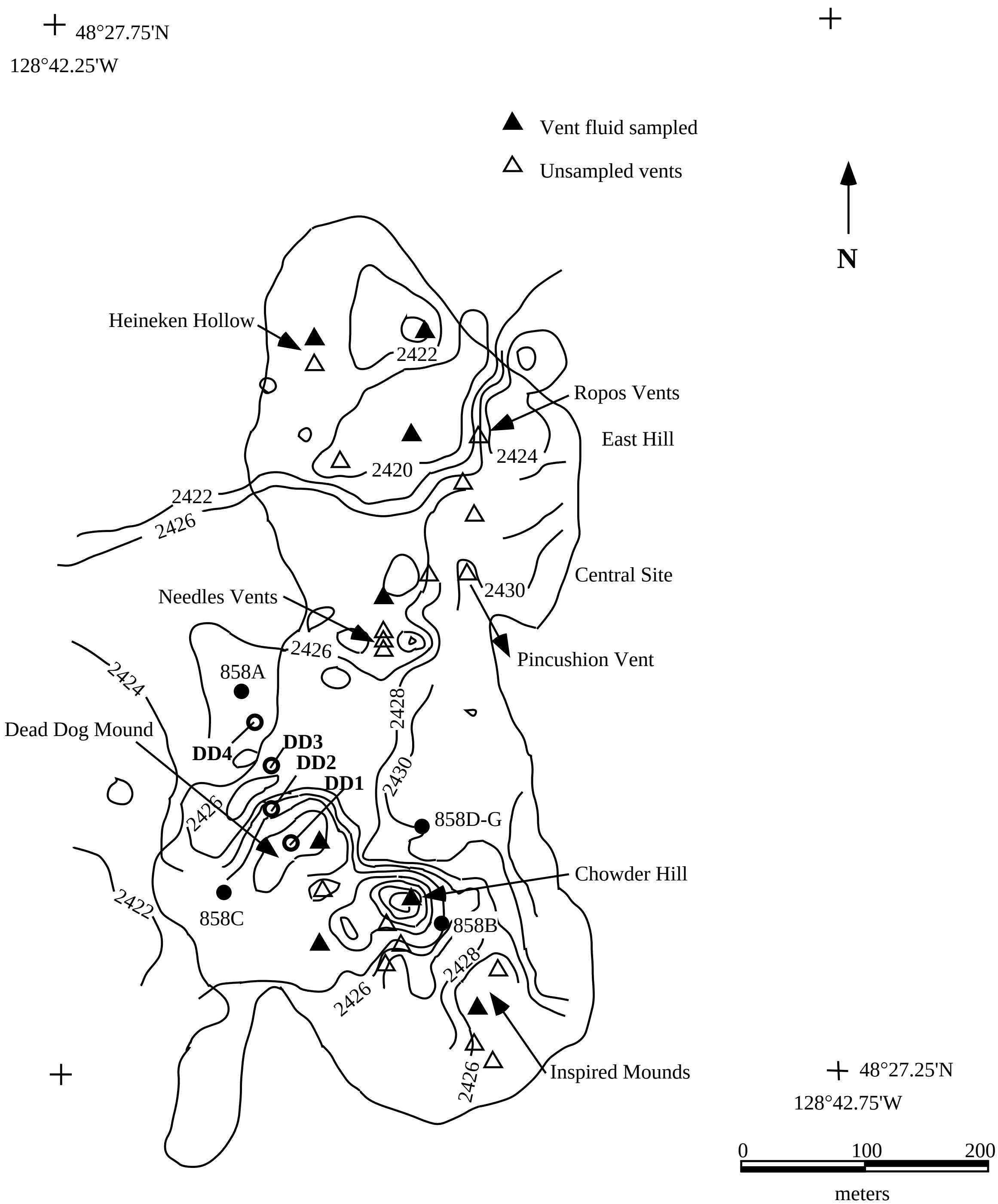

48°27.75'N
128°42.25'W
Vent fluid sampled
Unsampled vents
N
Heineken Hollow
2422
Ropos Vents
East Hill
2424
2420
2422
2426
Central Site
2430
Needles Vents
Pincushion Vent
2426
858A
2424
2428
Dead Dog Mound
DD3
DD4
DD2
DD1
2430
2426
858D-G
Chowder Hill
2422
858C
858B
2428
2426
Inspired Mounds
2426
48°27.25'N
128°42.75'W
0
100
200
meters

Figure 5.

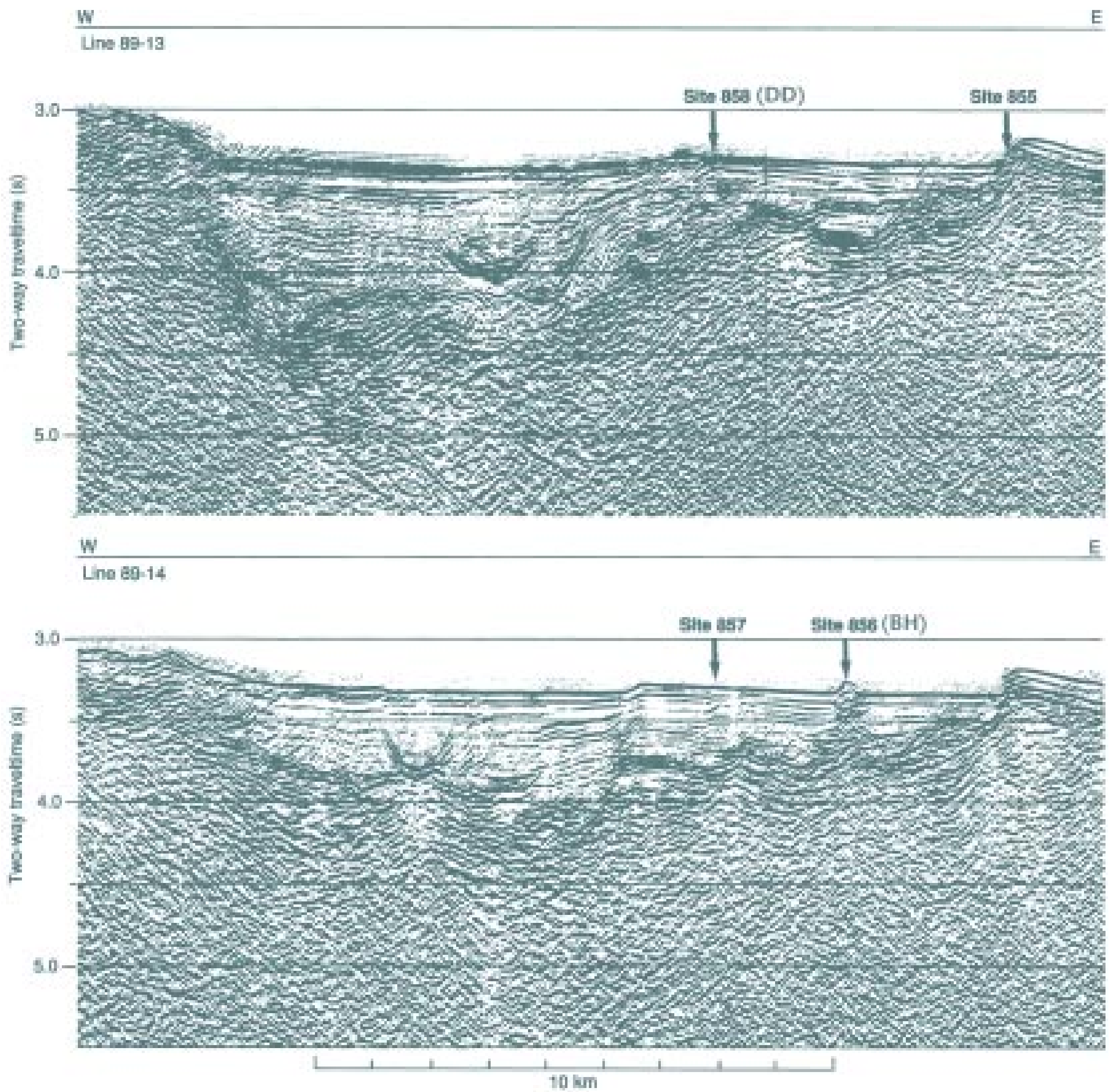

W
E
Line 89-13
Site 858 (DD)
Site 855
3.0
4.0
5.0
Two-way traveltime (s)
W
E
Line 89-14
Site 857
Site 856 (BH)
3.0
4.0
5.0
Two-way traveltime (s)
10 km

Figure 6.

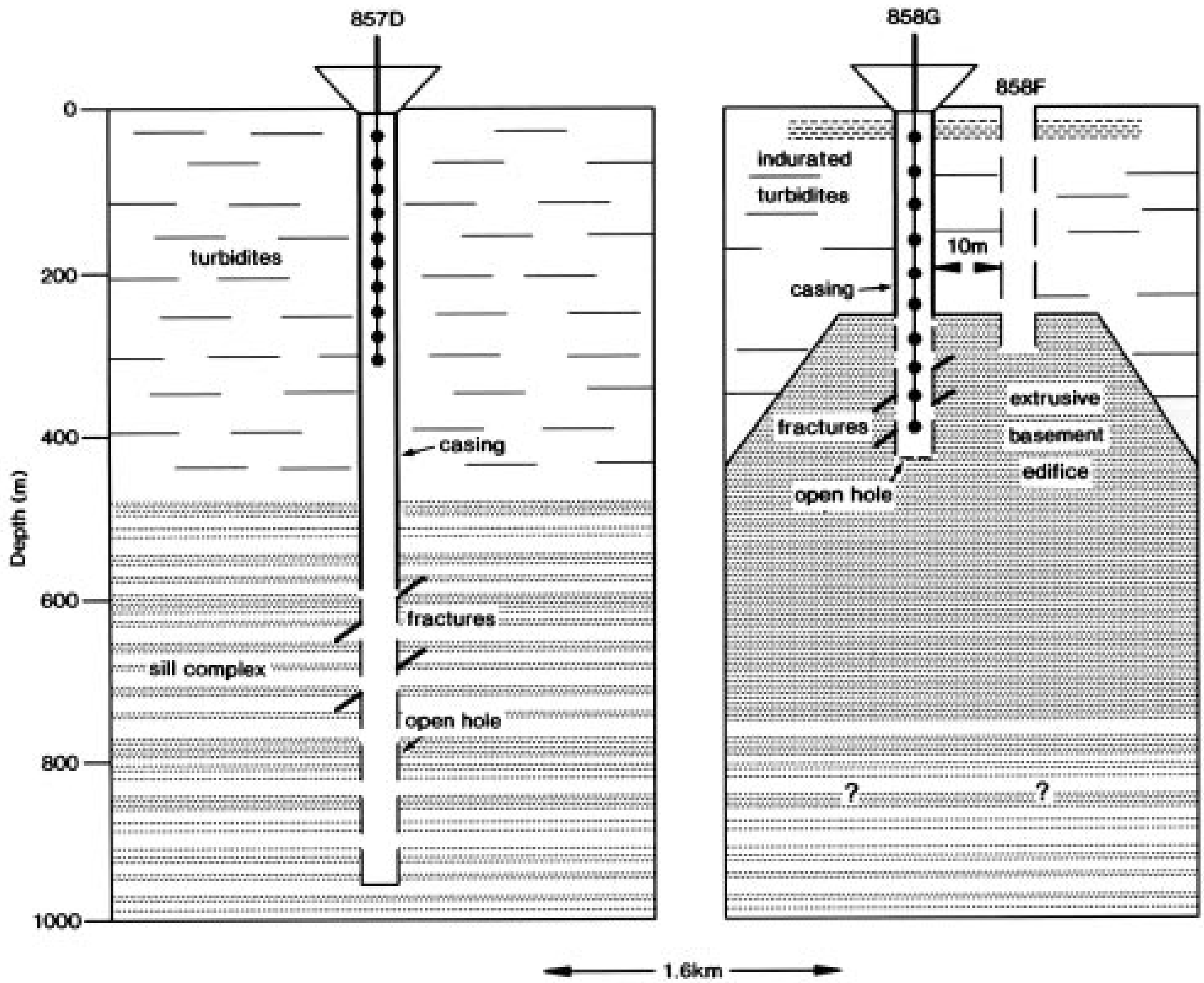

857D
858G
858F
0
200
400
600
800
1000
Depth (m)
turbidites
casing
fractures
sill complex
open hole
indurated
turbidites
10m
casing
fractures
open hole
extrusive
basement
edifice
?
?
1.6km

Figure 7.

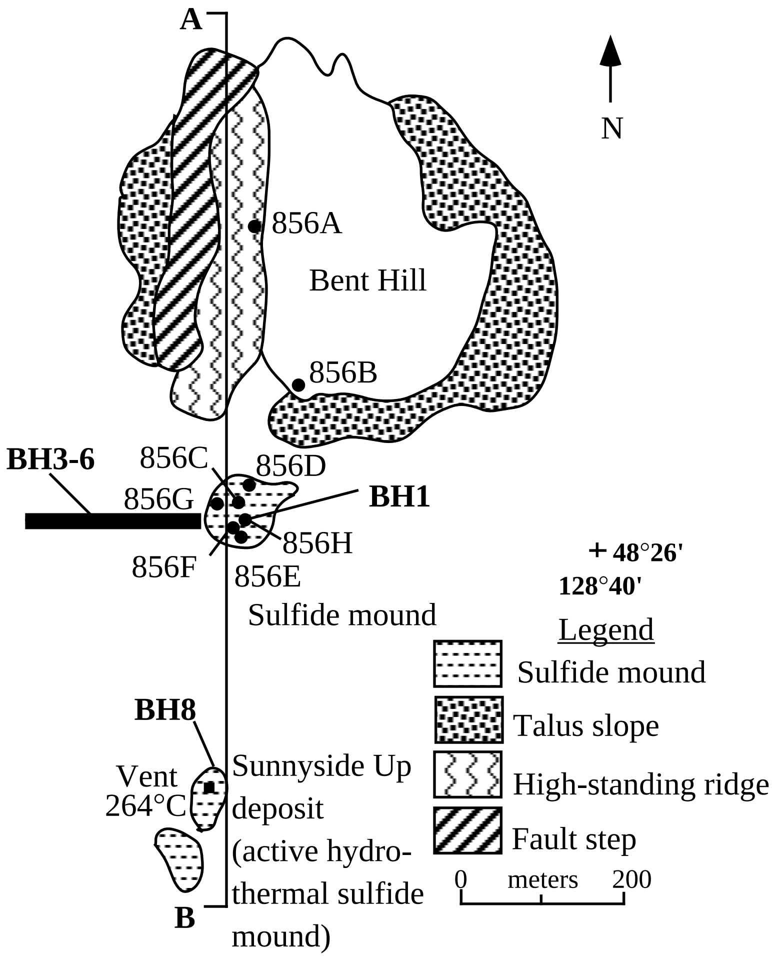

A
B
N
856A
Bent Hill
856B
BH3-6
856C
856D
856G
BH1
856H
856F
856E
Sulfide mound
+ 48°26'
128°40'
Legend
Sulfide mound
Talus slope
High-standing ridge
Fault step
0 meters 200
BH8
Vent
264°C
Sunnyside Up deposit (active hydro-thermal sulfide mound)

Figure 8.

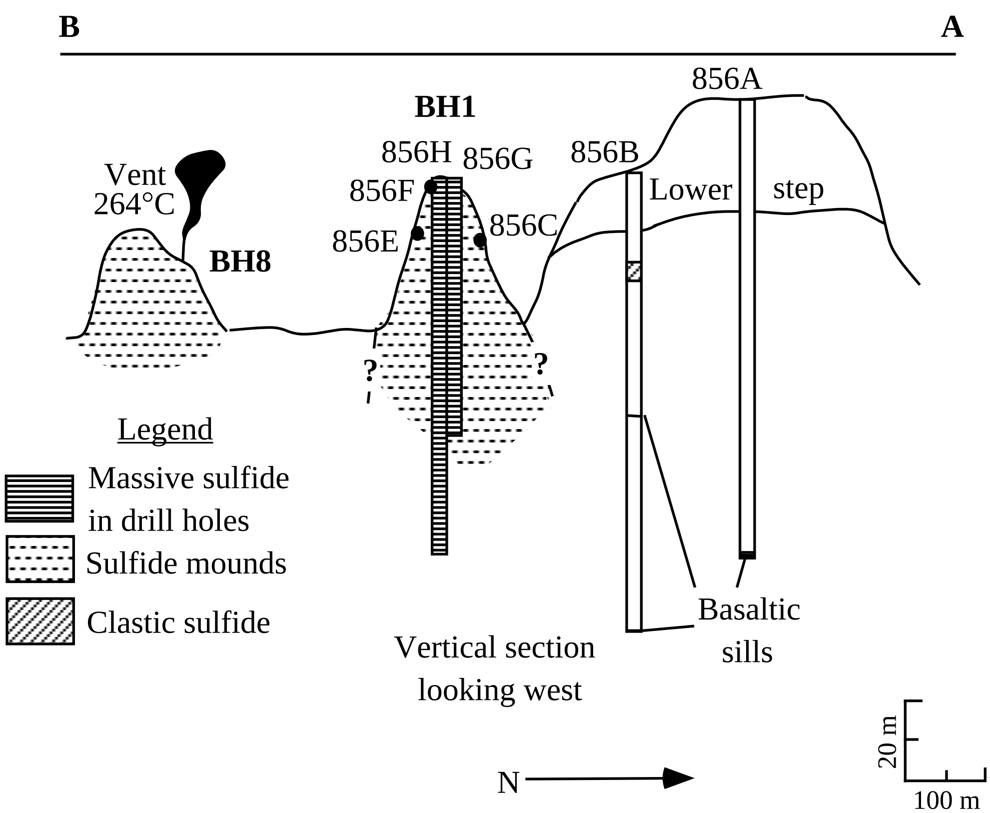

B
A
856A
BH1
856H
856G
856B
Vent
264°C
856F
Lower
step
856C
856E
BH8
?
?
Legend
Massive sulfide
in drill holes
Sulfide mounds
Clastic sulfide
Basaltic
sills
Vertical section
looking west
20 m
N
100 m

Figure 9.

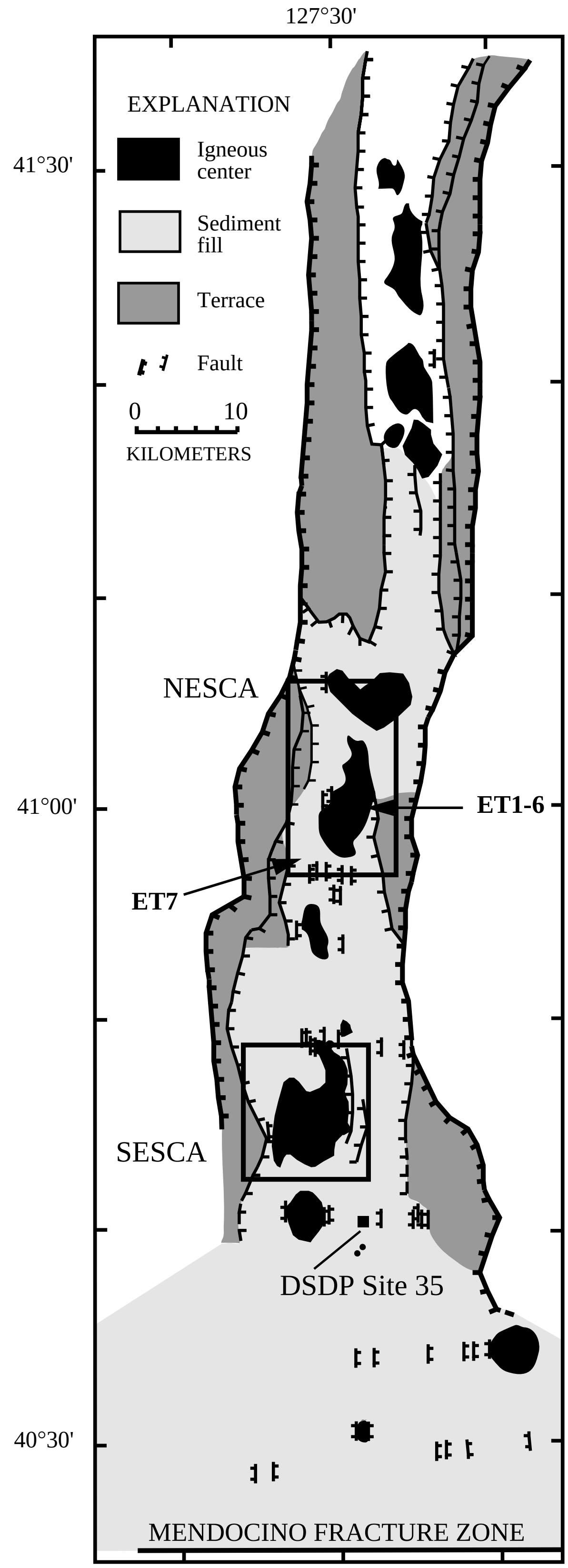
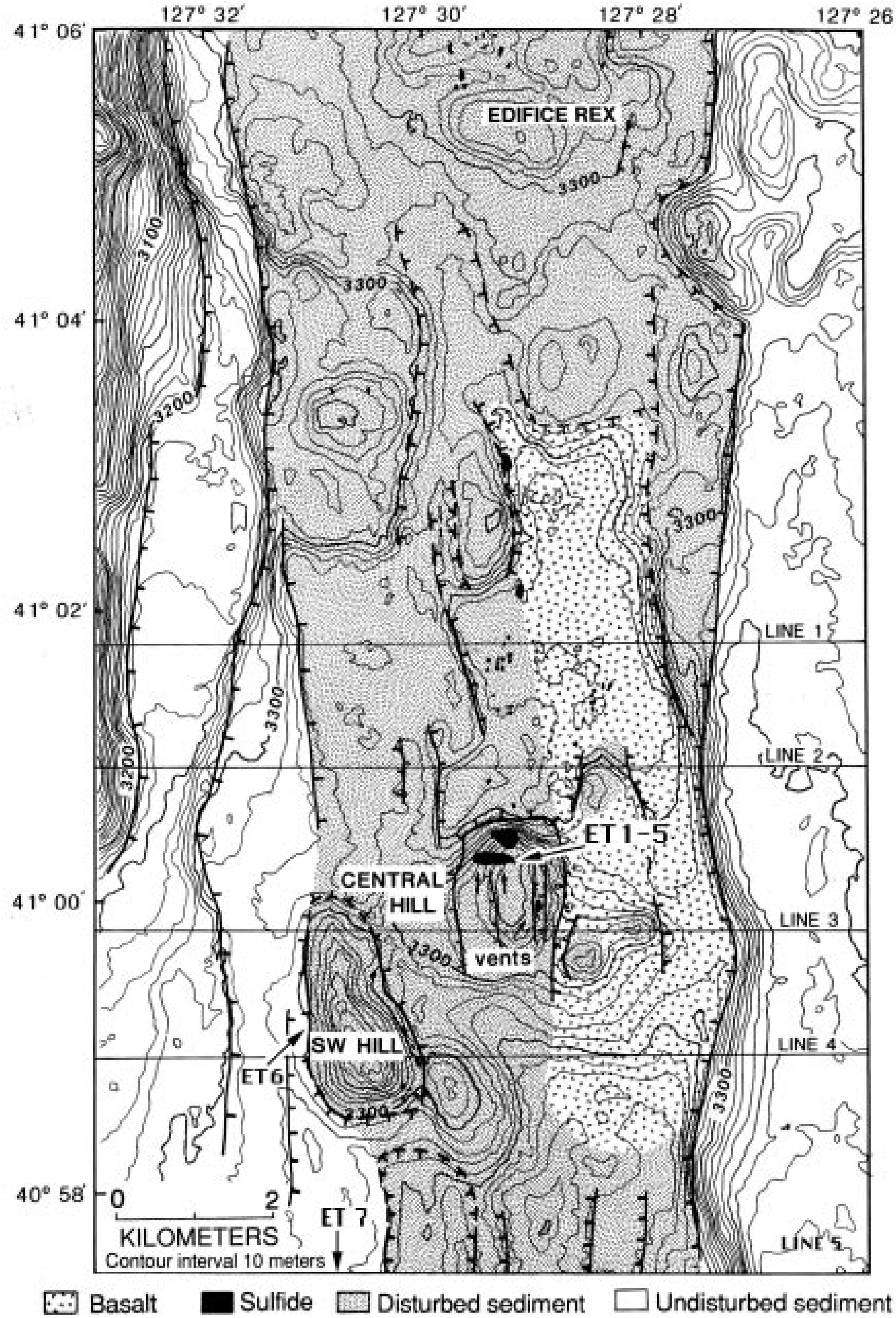
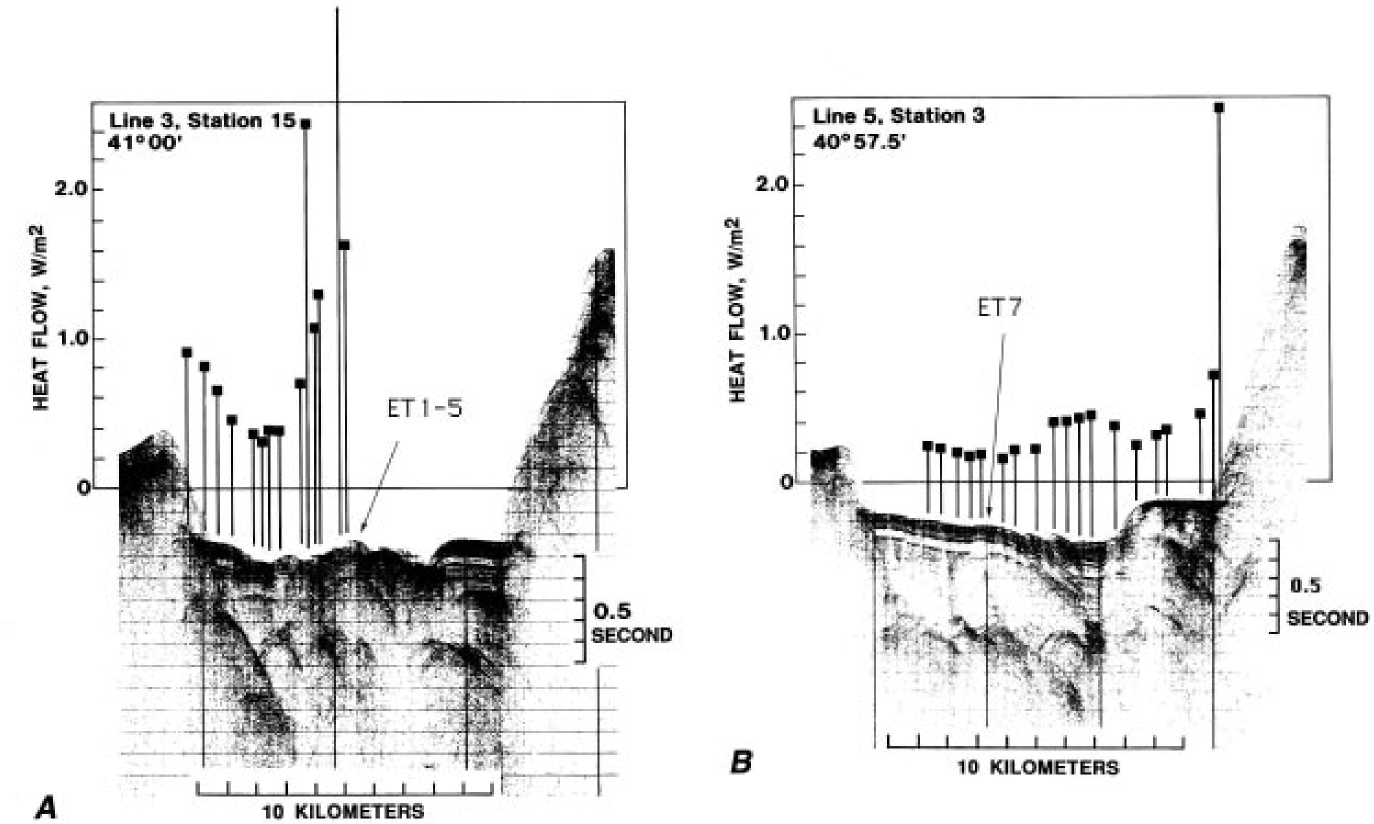

127°30'
EXPLANATION
Igneous center
Sediment fill
Terrace
Fault
0
10
KILOMETERS
41°30'
NESCA
41°00'
ET1-6
ET7
SESCA
DSDP Site 35
40°30'
MENDOCINO FRACTURE ZONE

Figure 10.

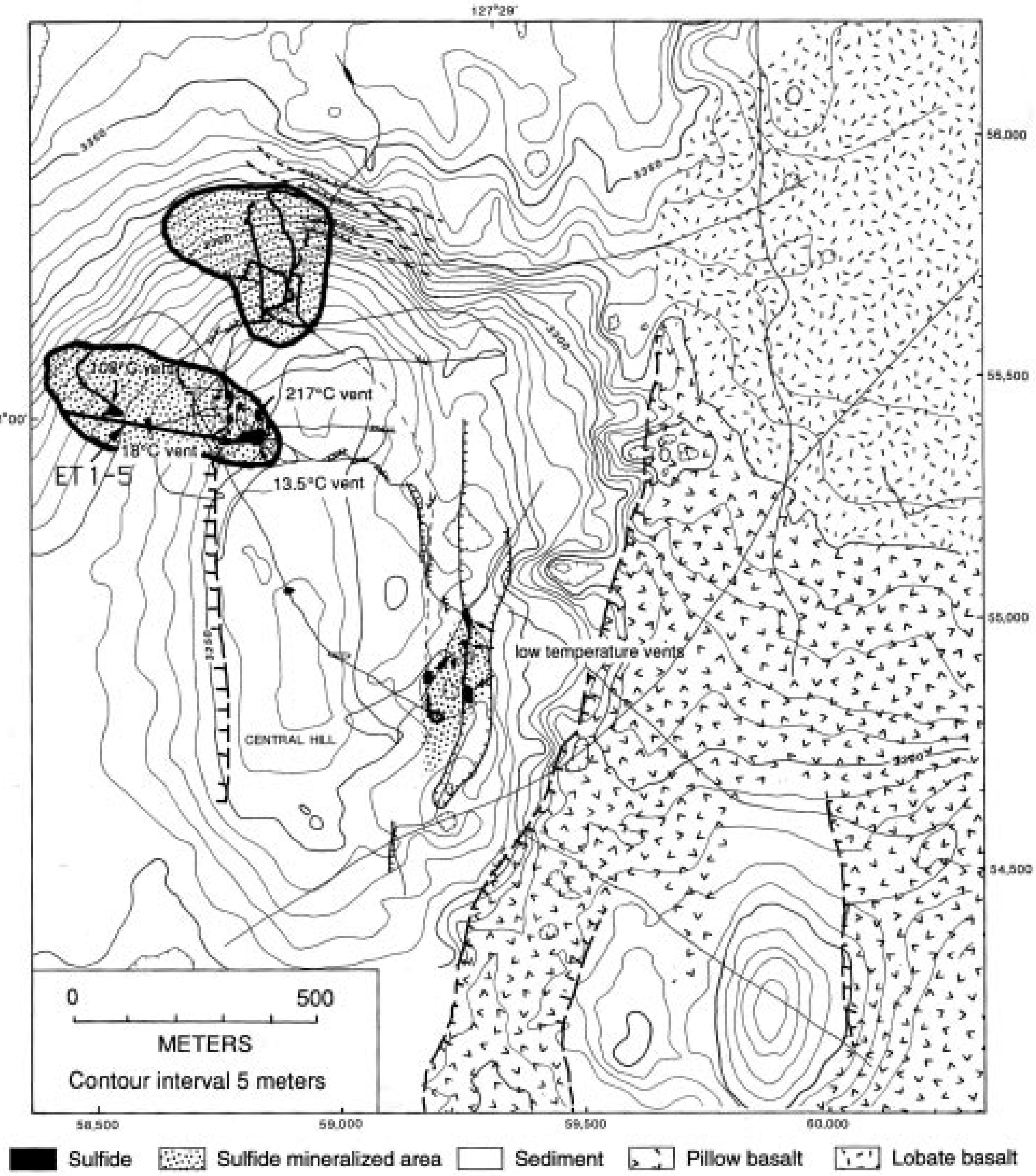

127° 32′
127° 30′
127° 28′
127° 26
41° 06′
41° 04′
41° 02′
41° 00′
40° 58′
EDIFICE REX
3300
3100
3200
LINE 1
LINE 2
LINE 3
LINE 4
LINE 5
ET 1-5
CENTRAL HILL
vents
SW HILL
ET6
ET 7
0
2
KILOMETERS
Contour interval 10 meters
Basalt
Sulfide
Disturbed sediment
Undisturbed sediment



Line 3, Station 15
41° 00'
HEAT FLOW, W/m2
2.0
1.0
0
ET1-5
0.5
SECOND
10 KILOMETERS
A
Line 5, Station 3
40° 57.5'
HEAT FLOW, W/m2
2.0
1.0
0
ET7
0.5
SECOND
10 KILOMETERS
B

Figure 11.

Figure 12.


127°29'
41°00'
109°C vent
217°C vent
18°C vent
ET 1-5
13.5°C vent
CENTRAL HILL
low temperature vents
0
500
METERS
Contour interval 5 meters
56,000
55,500
55,000
54,500
58,500
59,000
59,500
60,000
Sulfide
Sulfide mineralized area
Sediment
Pillow basalt
Lobate basalt

SITE INFORMATION

Site: Hole 858G, Dead Dog hydrothermal area
Location: Middle Valley, Juan de Fuca Ridge, northeast Pacific Ocean
Priority: 1
Position: 48°27.360’N, 128°42.531’W
Water Depth: 2426 m
Sediment Thickness: 26 m
Total Penetration: No new penetration
Seismic Coverage: Single channel line 89-20

Objectives: UnCORK, reCORK

Drilling Program: None

Logging and Downhole Operations: Temperature log, high temperature water sample,

Nature of Rock Anticipated: None

Site: BH1, Bent Hill massive sulfide deposit
Location: Middle Valley, Juan de Fuca Ridge, northeast Pacific Ocean
Priority: 1
Position: 48°26.020'N, 128°40.859'W
Water Depth: 2434 m
Sediment Thickness: 13 m
Total Penetration: >250 m
Seismic Coverage: Multichannel line 89-14

Objectives: Deepen Hole 856H, or a new hole through the massive sulfide deposit and the underlying alteration zone

Drilling Program: Reentry open and unobstructed Hole 856H with either MDCB or RCB. Alternatively, Drill-in a casing to isolate the upper part of the formation and MDCB or RCB to T.D.

Logging and Downhole Operations: Temperature log, full Schlumberger suite, FMS, geochemical log

Nature of Rock Anticipated: Massive sulfide, interbedded hydrothermally altered basalt, and hemipelagic and turbiditic sediment.

Site: Hole 857D
Location: Middle Valley, Juan de Fuca Ridge, northeast Pacific Ocean
Priority: 1
Position: 48°26.517’N, 128°42.651’W
Water Depth: 2432 m
Sediment Thickness: 580 m
Total Penetration: 936 to >1050 mbsf
Seismic Coverage: Multichannel line 89-14

Objectives: UnCORK, deepen and reCORK Hole 857D, conduct hole-to-hole hydrologic experiment

Drilling Program: Run-in MDCB/RCB to present T.D. of 936 mbsf, drill for 36 hr as deep as possible

Logging and Downhole Operations: Temperature log, water sample, full Schlumberger suite, ± packer/flowmeter experiment

Nature of Rock Anticipated: Silicified, hydrothermally altered and metamorphosed interbedded turbidites and hemipelagic sediment alternate with basalt

Site: DD1-4, Dead Dog hydrothermal area
Location: Middle Valley, Juan de Fuca Ridge, northeast Pacific Ocean
Priority: 1
Position: 48°26.517'N, 128°42.651'W
Water Depth: 2420 m
Sediment Thickness: 250 m
Total Penetration: ±50 m
Seismic Coverage: Multichannel line 89-14

Objectives: Sample the principal area of hydrothermal activity in Middle Valley to test the subsurface inflation model of hydrothermal mound growth.

Drilling Program: APC/XCB/MDCB on top, flank, and periphery of an actively venting hydrothermal mound.

Logging and Downhole Operations: None

Nature of Rock Anticipated: Semimassive sulfide and hydrothermally altered hemipelagic and turbiditic sediment

Site: BH3-6, Bent Hill massive sulfide deposit
Location: Middle Valley, Juan de Fuca Ridge, northeast Pacific Ocean
Priority: 1

Position: 48°26.02'N, 128°40.86'W

Water Depth: 2450

Sediment Thickness: 200 m

Total Penetration: 200 m

Seismic Coverage: Multichannel line 89-14

Objectives: Constrain geometry and composition of lateral massive sulfide mineralization and alteration, intersect Site 856 fault zone

Drilling Program: APC/XCB

Logging and Downhole Operations: None

Nature of Rock Anticipated: Hydrothermally altered hemipelagic and turbiditic sediment and semimassive sulfide

Site: BH8, Sunnyside Up hydrothermal mound

Location: Middle Valley, Juan de Fuca Ridge, northeast Pacific Ocean

Priority: 2

Position: 48°25.85’N, 128°40.90’W

Water Depth: 2445

Sediment Thickness: 200 m

Total Penetration: 220 m

Seismic Coverage: Multichannel line 89-14

Objectives: Drill through the hydrothermally active sulfide deposit south of Bent Hill to determine composition and thickness

Drilling Program: RCB through surface or near periphery of mound

Logging and Downhole Operations: None

Nature of Rock Anticipated: Massive sulfide and hydrothermally altered hemipelagic and turbiditic sediment

Site: ET7

Location: Escanaba Trough, southern Gorda Ridge, northeast Pacific Ocean

Priority: 1

Position: 40°57.5’N, 127°30.5’W

Water Depth: 3340 m

Sediment Thickness: 600 m

Total Penetration: 650 m

Seismic Coverage: Single channel, Tully, 89-04, line 5

Objectives: Reference section through sedimentary sequence

Drilling Program: APC/XCB 50 m through sediment column and 50 m into basement

Logging and Downhole Operations: Full Schlumberger suite

Nature of Rock Anticipated: Interbedded turbidites and hemipelagic sediment, underlain by basalt

Site: ET1-4

Location: Escanaba Trough, southern Gorda Ridge, northeast Pacific Ocean

Priority: 1

Position: 41°00'N, 127°29'W

Water Depth: 3250 m

Sediment Thickness: 600 m

Total Penetration: 200 m

Seismic Coverage: Single channel, Tully, 89-04, line 3

Objectives: Find suitable location for deep penetration hole in an active hydrothermal massive sulfide deposit, determine extent and composition of mineralization and alteration

Drilling Program: APC/XCB

Logging and Downhole Operations: None

Nature of Rock Anticipated: Massive sulfide and hydrothermally altered hemipelagic and turbiditic sediment

Site: ET5

Location: Escanaba Trough, southern Gorda Ridge, northeast Pacific Ocean

Priority: 1

Position: 41°00'N, 127°29'W

Water Depth: 3250 m

Sediment Thickness: 200 m

Total Penetration: >400 m

Seismic Coverage: Single channel, Tully, 89-04, line 3

Objectives: Determine extent and composition of hydrothermal mineralization and alteration in an active hydrothermal massive sulfide deposit, determine depth to and composition of basement

Drilling Program: Multiple reentry, drill-in casing, RCB/MDCB to 400 m or as deep as possible

Logging and Downhole Operations: Temperature log, full Schlumberger suite, FMS, geochemical log

Nature of Rock Anticipated: Massive sulfide and hydrothermally altered hemipelagic and turbiditic sediment, hydrothermally altered basalt

Site: BH2, Bent Hill massive sulfide deposit

Location: Middle Valley, Juan de Fuca Ridge, northeast Pacific Ocean

Priority: 2

Position: 48°26.0’N, 128°40.9’W

Water Depth: 2450

Sediment Thickness: 200 m

Total Penetration: 200 m

Seismic Coverage: Multichannel line 89-14

Objectives: Constrain geometry and composition of lateral massive sulfide mineralization and alteration, part of N-S transect across deposit

Drilling Program: APC/XCB

Logging and Downhole Operations: None

Nature of Rock Anticipated: Hydrothermally altered hemipelagic and turbiditic sediment and semimassive sulfide

Site: BH7, Bent Hill massive sulfide deposit

Location: Middle Valley, Juan de Fuca Ridge, northeast Pacific Ocean

Priority: 2

Position: 48°25.95’N, 128°40.9’W

Water Depth: 2450

Sediment Thickness: 200 m

Total Penetration: 200 m

Seismic Coverage: Multichannel line 89-14

Objectives: Constrain geometry and composition of distal massive sulfide mineralization and alteration, part of N-S transect across deposit, stratigraphic reference section

Drilling Program: APC/XCB

Logging and Downhole Operations: None

Nature of Rock Anticipated: Hydrothermally altered hemipelagic and turbiditic sediment

Site: ET6

Location: Escanaba Trough, southern Gorda Ridge, northeast Pacific Ocean

Priority: 2

Position: 41°00’N, 127°29’W

Water Depth: 3170 m

Sediment Thickness: 500 m

Total Penetration: 520 m

Seismic Coverage: Single channel, Tully, 89-04, line 4

Objectives: Determine structure and uplift history of a large, uplifted sediment hill (SW Hill) associated with massive sulfide formation

Drilling Program: APC/XCB

Logging and Downhole Operations: None

Nature of Rock Anticipated: Hydrothermally altered hemipelagic and turbiditic sediment, hydrothermally altered basalt

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