OCEAN DRILLING PROGRAM

LEG 139 PRELIMINARY REPORT

MIDDLE VALLEY, JUAN DE FUCA RIDGE

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SCIENTIFIC REPORT

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SCIENTIFIC REPORT

Abstract

Leg 139 occupied four sites in Middle Valley of the northern Juan de Fuca Ridge, with the overall objective of elucidating processes and products of hydrothermal circulation in a sedimented spreading center. Site 855 was drilled to determine the role of a valley-bounding normal fault in guiding hydrothermal recharge. Site 856 was drilled into and adjacent to a seafloor sulfide deposit. Work at Site 857, the first of two reentry sites, concentrated on the hydrogeology of a hydrothermal reaction zone, and the structure and composition of a sediment-sill complex. Site 858 was situated close to a high-temperature, hydrothermal vent site; drilling there included 175 m of penetration into the upper part of extremely young igneous crust. Leg 139 featured the successful deployment of a variety of unusual downhole instruments and a complete series of detailed laboratory analyses. Preliminary shipboard studies have highlighted an array of localized and regional processes which transport energy and mass in this setting.

Introduction

Sediment-covered spreading centers provide an unparalleled opportunity for quantitative studies of the fundamental physical and chemical processes associated with submarine hydrothermal systems and metallogenesis. A regionally continuous, relatively impermeable sediment cover over zero-age crust limits the recharge and discharge of hydrothermal fluids, and conductively insulates the underlying igneous basement. Where discharge of fluids does occur, very large hydrothermal sulfide deposits can be produced. The sediments may also preserve a relatively continuous stratigraphic record of magmatic, tectonic, and thermal events, providing clues to the spatial and temporal variability of these processes.

Although a sedimented ridge drilling program will provide information on all of these processes, the highest priority objectives for Leg 139 were:

1. A three-dimensional characterization of the fluid flow and geochemical fluxes within a sediment-dominated hydrothermal system.
2. A systematic investigation of the processes involved in the formation of sediment-hosted massive sulfide deposits.

For most of the length of the Juan de Fuca Ridge, magma is supplied in abundance, and although the spreading rate is only 58 mm/yr, the morphology of this ridge is similar to that of faster spreading ridges. At the northern end of the ridge, at its intersection with the Sovanco Fracture Zone (Fig. 1), the supply of magma is diminished significantly, and a deep extensional rift known as Middle Valley is present (Figs. 2-3). The proximity of this rift valley to the continental margin has caused it to be filled with Pleistocene turbidite sediments. Continuous sediment cover over the full 10-15-km width of the valley between the primary bounding normal faults persists over a distance of 75 km along the axis.

Drilling sites in the valley were chosen primarily on the basis of the structure defined by numerous single- and multichannel seismic lines crossing the valley (Figs. 4-5), and heat flow data (Fig. 6).

There is a general tendency for heat flow to increase toward the center of the valley and away from the normal faults that bound the valley on the eastern side. This may be due to the influence of hydrothermal recharge supplied through the thinner sediments that fill the eastern part of the valley, and through basement exposures along the normal faults themselves.

Sites and Objectives

Site 855 (proposed site MV-7) is located in the easternmost part of Middle Valley along the base of the first major fault scarp that, at this latitude, forms the topographic boundary of the valley (Figs. 2-4). The site, comprising an array of four closely spaced holes, is situated in the hanging wall of the axis-facing normal fault that has produced the scarp. Throw on the fault of about 115 m is greater than the local sediment thickness of about 90 m, so that basement is exposed along the seafloor scarp. The positions of individual holes (Fig. 7) were established with the intention of intersecting the fault at a variety of depths ranging from a few tens of meters to a few hundred meters, and possibly into a variety of combinations of lithologies in contact across the fault, including unconsolidated sediment, consolidated sediment, altered sediment, and basalt. The dip of the fault to be intersected was initially estimated on the basis of (1) seismic reflection data, and (2) the combination of the scarp height defined by the local bathymetry and the plan-view width of the scarp as determined from acoustic image data.

Drilling at this site was intended to provide information about the rates and geochemical consequences of fluid flow in the part of the rift where diffuse or localized drawdown of fluids could occur, and about the influence of a major fault zone on the hydrologic regime. Also the heat flow in this part of the rift (Fig. 6) is less than half that at other sites of the leg. Thus the site provides a reference section of sediment with a low thermal gradient, to which the sections at other sites, where the effects of higher temperatures and upward fluid flow may be present, can be compared.

Site 856 (proposed site MV-2) is located in the eastern part of Middle Valley roughly 3 km west (inside) of the normal fault scarp that forms the eastern topograpic boundary of the valley, and about 4 km east (outside) of the primary structural boundary of the current rift axis. The site is situated over and adjacent to one of a number of small hills that are typically a few hundred meters in diameter and stand a few tens of meters above the otherwise smooth, sedimented rift valley floor. They appear to be of syn- or post-sedimentary volcanic origin, and consist of sections of uplifted sediment typically about 100 m thick overlying bright seismic reflectors that are believed to be sills, or lacolithic plug-like intrusions. Massive sulfide deposits are associated with these hills (Davis et al., 1987). Structures similar to these hills have been observed in other sedimented rifts, including Guaymas Basin (Lawver and Williams, 1979; Lonsdale and Becker, 1985) and Escanaba Trough (Morton et al., 1987; Davis and Becker, 1991; Dellinger and Holmes, 1991; Zierenberg et al., 1991); these examples also have associated hydrothermal mineralization. None of the hills in Middle Valley are currently hydrothermally active, although there is a small vent field roughly 200 m south of the southern flank of the hill where Site 856 is located; there the heat flow through the seafloor exceeds 4 W/m^2, and 270°C fluid currently is discharging.

An array of shallow holes was completed on and near this hill at Site 856 with the following objectives: (1) to investigate the subsurface structure of this representative feature; (2) to determine the extent and geometry of hydrothermal alteration within the sediment section at various positions and levels beneath the hill; (3) to characterize the composition and distribution of the mineralization beneath, within, and/or above the sediment section; and (4) to establish the genetic relationship between the mineralization and the local volcanic, tectonic, hydrologic, and thermal regime.

Site 857 (proposed site MV-3) is located over a part of Middle Valley where the sediment cover is thick and locally continuous, and the heat flow is high, typically over 0.8 W/m^2. The site is located 1.6 km away from a large hydrothermal vent field, where fluids discharge through the seafloor at temperatures up to 286°C. Because the sediment cover is thick, it was anticipated that the heat transfer at this site should be dominantly conductive. Given the level of heat flow (Fig. 6) the depth at which hydrothermally high (300-350°C) temperatures were anticipated was relatively shallow.

The highest priority objective at this site was to penetrate through the sediment fill of the valley into what may be a regional "reservoir" where high-temperature fluids reside in the upper igneous crust, chemically interact with their permeable host rocks, and supply fluid to remote areas of focused discharge where local permeable conduits allow fluids to penetrate the otherwise thick and impermeable sediment section. Drilling at this site would test this conceptual model for the thermal and hydrologic regime in this sedimented rift and would allow the chemical composition of the water-rock system, and the hydrologic and thermal properties of the sediment and hydrothemal basement, to be determined. This was to be accomplished through a combination of direct sampling of the rock and fluids at various levels in the the formation, discrete and continuous downhole measurements and logging, formation permeability testing, and long-term observations of temperatures and pressures in the formation.

Other objectives at this site included the determination of (1) the degree of alteration of organic and inorganic constituents of the sediment column which probably have been exposed to high temperatures but relatively minor amounts of pore fluid flux, (2) the effect of high-temperature alteration on the physical and magnetic properties of sediment and upper igneous crustal rocks, and (3) the composition and physical nature of the volcanic rock that makes up igneous basement in this sedimented rift.

Site 858 (proposed site MV-1) is located 1.6 km north of Site 857, over an active hydrothermal vent field that extends about 800 m along and 400 m across the strike of Middle Valley. The regional structural setting of Site 858 is similar to that at Site 857; they are both situated about 6 km east of the axis of the rift valley over an uplifted but fully buried basement fault-block. Sediment thickness in the vicinity of Site 858 ranges from 400 to 700 ms, and it was suspected that the discharge was controlled by this local basement topography and the local reduction in sediment thickness. The vent field lies above what appears to be a local basement edifice; several shallow (<300 ms), bright reflectors are seen in both single- and multichannel seismic profiles beneath the site, and the more regional layered seismic stratigraphy is disrupted throughout the section. The amplitude of the seafloor reflection within the vent field is 2 to 3 times higher than that from the surrounding seafloor. Heat flow through the seafloor surrounding the site is typically about 1.0-1.5 W/m^2, slightly higher than that at Site 857. Heat flow increases over a distance of a few hundred meters to values ranging from 4 W/m^2 to over 20 W/m^2 within the field itself. Numerous vent sites have been observed from a manned submersible; fluid temperatures of most vents range between 255 and 265°C.

A number of objectives were to be addressed by drilling and downhole measurements in this active upflow and discharge zone. Most importantly, it was anticipated that observations made at this site could be coupled with the information provided by the deep hole at Site 857 to answer several fundamental questions about the fluid flow regime in the upper crust in this sedimented rift environment. For example, what controls the location, rate, and nature of upflow and discharge? How rapid is the rate of discharge relative to the conductive heat loss in the upflow zone beneath the vent field? How efficiently does the sediment cover thermally insulate and hydrologically isolate the underlying igneous crust? And how efficiently do hydrothermal fluids transport heat and chemical species laterally from one part of the crust to another beneath the sediment "seal"?

Important questions also could be answered about the detailed aspects of upflow at this site. Is there a regional "hydrothermal fluid reservoir" beneath the sediment section that is tapped by the discharge zone, or do fluids ascend from greater depth? How focused is the ascending flow? To what degree do fluids react with the adjacent rock and sediment during their ascent? How much heat is lost during ascent? Is there significant diffuse fluid flow that results in significant alteration of and possibly mineralization within the sediments in the vicinity of the vent field? Does a discharge area such as this host significant subsurface mineralization?

Other more site-specific questions to be addressed by this drilling concern the history of hydrothermal discharge as recorded in the sedimentary section, the influence of high temperatures on diagenesis, hydrocarbon maturation, and sediment and igneous rock physical and magnetic properties, and the nature and composition of the igneous rock that underlies this site.

It was anticipated that all of these questions could be addressed with the combination of an array of relatively shallow holes across the vent field, and a deep reentry hole sited as close to the center of the area of discharge as logistically possible. In addition to drilling and coring, operations would include fluid sampling, discrete and continuous downhole measurements and logging, formation permeability testing, and long-term observations of temperatures and pressures in the formation.

Drilling Results

Site 855

Four holes were drilled at Site 855 to form a transect across the hanging-wall block (Fig. 7). Individual holes were located 40 m (Hole 855B), 70 m (Hole 855A), and 125 m (Holes 855C and 855D) from the base of the scarp. Precise estimates of these ranges were obtained from a Mesotech scanning sonar image made of the scarp from the bottom of the drill string prior to spudding the first hole.

All holes intersected basalt, two in the foot wall (855A and 855B) and two in the hanging wall (855C and 855D). The offsets from the scarp and the depths to basalt (determined by the depth at which the drilling rate abruptly dropped) at Holes 855A (74 mbsf) and 855B (45 mbsf) provide a lower limit of the dip of the fault. The apparent dip is about 45°. Whether this is the true dip, or reflects the average dip of a zone of en-echelon stair-step faults, cannot be ascertained. The depths to basalt at Hole 855C (98 mbsf) and 855D (108 mbsf) are consistent with the reflection time to basement (130 ms) and the acoustic velocities determined for the section.

Drilling conditions and recovery in basalt were poor, with binding and hole collapse typical at all holes. The objective of reaching the normal fault zone at a level of basalt/basalt contact, estimated to be about 35 m sub-basement at the location of Holes 855C and 855D in the hanging-wall block, was not possible. Operations were terminated after 3, 18, 9, and 11 m of basement penetration at

Holes 855A, 855B, 855C, and 855D, respectively. Total penetration depths were not sufficient to permit logging.

Small pieces of basalt were recovered from each hole, with basalt recovery averaging 8%. Given the simple fault geometry inferred, this disposition of the basement samples may allow the basaltic section to be characterized at three levels, one at the top of basement (Holes 855C and 855D), one at roughly 60 m sub-basement (Hole 855B), and one at 100 m sub-basement (Hole 855A). The samples range from porphyritic basalt with large phenocrysts of plagioclase and olivine, to basalt containing only sparse phenocrysts of plagioclase. Relatively fresh glassy margins are present on many samples, although most of the samples show various degrees of low-temperature alteration. No systematic spatial or depth variations are evident.

RCB drilling was done at this site so that objectives in basement could be reached with a single pipe trip. Unfortunately the RCB cores in the unconsolidated sediment section were mechanically disturbed and core recovery on average was only 39%. A single lithologic unit was defined, consisting of dark green to gray clay, silty clay, and quartz-plagioclase sandy silt and silty sand, comprising fining-upward turbidite sequences throughout the cored interval. The sequences ranged in thickness from 13 to 131 cm; Hole 855C cored 28 of these in 98 m. They are readily detected in magnetic susceptibility traces obtained on the multi-sensor track, in which positive peaks correspond with coarse sediments at the base of the units. Clear correlations between local lithology, thermal conductivity, porosity, and remanent magnetization were also defined, despite the coring disturbances.

Pore waters squeezed from the sediments and collected in situ with the WSTP indicate that fluids in basement at all four holes are nearly identical to seawater. Chlorinity, alkalinity, sulfate, Mg, Ca, and silica all display maxima or minima within the sediment section and then return to seawater values near basement. Coupled with the low heat flow found in Hole 855C, these data indicate that seawater is being drawn down into the basalt layer along the outcrop at the fault scarp.

Site 856

Operations at Site 856 began with a north-south transect of APC/XCB holes (Fig. 8). Holes 856A and 856B were located at the center and southern edge of the top of the hill. Coring in the two holes recovered compositionally primitive intrusive rock at depths of 112 and 120 mbsf, respectively. The overlying sediment is an undisturbed section of semi-indurated turbidites, about 20% less porous throughout than the section sampled at Site 855. Heat flow was found to be 0.60 W/m^2 in Hole 856A and 1.52 W/m^2 in Hole 856B. Although high, these values probably do not reflect conditions that existed when the hill was formed and was hydrothermally active. Temperatures at the top of the sill are only 50°C in Hole 856A; they are projected to be about 150°C in Hole 856B. Pore water compositions suggest that currently there is no flow vertically through the sediment section, although the absence of a Pleistocene chlorinity anomaly suggests that seawater has flushed through the sediment at some time during the past 10,000 years. Coarse clastic layers of massive sulfide interbedded with fine sand to silt turbidites were encountered at about 30 mbsf in Hole 856B. Semi-indurated sediment near the bottom of Hole 856B was weakly altered hydrothermally, and mineralized by disseminated barite, pyrrhotite, chalcopyrite, and sphalerite.

The Site 856 transect continued with APC/XCB Holes 856C through 856E, distributed over a distance of 60 m north to south across the southern flank of the hill. Massive sulfide, sulfide sand,

and sulfide clay were encountered at or immediately beneath the seafloor in all of these holes. This material was difficult to penetrate or recover with either the APC or XCB systems; a final attempt (Hole 856F) resulted in no recovery and a bent APC barrel. Having thus defined the minimum extent of this massive sulfide outcrop, it was decided to continue operations at this site with a standard RCB bit to test this technology in massive sulfide and to explore the nature and extent of this hydrothermal deposit at depth. RCB drilling was very successful, and the hydrothermal deposit proved to be much thicker than expected. Hole 856G penetrated 65 m of massive sulfide with 33% recovery before the bit became inextricably jammed by falling rubble. Hole 856H was then started using a section of drill-in casing connected to a free-fall reentry cone. This hole was drilled to 95 mbsf, again with apparently continuous massive sulfide throughout the section, before hole fill prevented further penetration. Core recovery from this hole was 21%.

The massive sulfide recovered from Holes 856G and 856H is composed predominantly of pyrite and pyrrhotite with subordinant amounts of chalcopyrite ($CuFeS_2$) and sphalerite (Zn,FeS). Late-stage alteration has locally formed magnetite and hematite in some samples and apparently resulted in removal of some sphalerite from the upper part of the deposit. Magnetite and hematite alteration decreases downhole, resulting in increasing amounts of primary mineralization with higher zinc and copper contents. Only rare fragments of altered sediment are contained in the massive sulfide, suggesting that most or all of the massive sulfide was deposited above the seafloor. The lack of minerals rich in elements such as Pb, As, and Sb, which typically are enriched in sediment-hosted sulfide deposits, suggests that the major source of metals is the basaltic basement.

In terms of normal logging operations, Hole 856H was not very deep, but because of its unique character, a limited suite of logs was completed. This included several temperature runs, a neutron geochemical log, a sonic velocity log, and an induction electrical resistivity log. Results indicate clearly that no sedimentary or volcanic material had been drilled but not recovered by coring. As expected, the geochemical logs indicate high iron and sulfur, and low calcium and silicon contents. Electrical resistivities are low, ranging between 0.1 and 0.2 ohm-m. The upper 70 m of the hole remained very cool, less than 2.5°C warmer than bottom water at all times during the logging program, indicating downhole flow of water into the formation. Temperatures below 70 mbsf increased with depth to about 25°C at 80 mbsf. The temperature gradient defined between this point and the seafloor, combined with the typical value of thermal conductivity measured on the sulfide core material of over 5 W/m°C, yields a heat flow that is similar to that measured at the seafloor and in Hole 856B, indicating that the thermal regime before drilling was probably conductive.

The total penetration in massive sulfide at both Holes 856G and 856H (up to 95 mbsf) extends to 70 m below the local level of the sedimented valley floor. This suggests either that the hydrothermal deposit fully replaced the sediment in which it lies, or that it was constructed by sulfide precipitation at or near the seafloor while turbidite and hemipelagic sedimentation continued. The massive texture of the sulfide and apparent lack of sedimentary interbeds suggests the latter. A large volume of fluid has clearly been involved in producing the deposit. The conditions that produced this massive sulfide deposit presumably are common in sedimented rift environments in which inherently low-permeability, nearly continuous sediment cover blankets the igneous crust that contains the heat source. This provides a favorable physical and chemical environment for efficient, high-temperature water-rock interaction, and causes discharge to be highly focused.

Site 857

Operations at Site 857 (Fig. 5) began with APC/XCB Hole 857A, which was drilled slightly west of the peak of the heat-flow anomaly to avoid intersecting a bright reflector, inferred to be a sill, at 400 ms in seismic reflection records. This hole was drilled to 112 mbsf. Adjacent APC Hole 857B was drilled to 30 mbsf to provide a mud-line core and additional temperature data within the upper sediment section. From these and thermal conductivity data we determined that heat flow at this location is conductive at a value of 0.709 W/m^2, somewhat lower than we had targeted for this deep-penetration site. For this reason we offset 180 m to the east to drill the RCB exploratory Hole 857C. The conductive temperature gradient measured over the upper 80 m of Hole 857C indicates a heat flow of 0.803 W/m^2.

The sediment section comprises upper Pleistocene interbedded hemipelagic mud and turbiditic silt and sand. The fraction of coarse material increases with depth in the section, as does the sedimentation rate, estimated in the upper tens of meters from two clear biostratigraphic markers, and in the lower part of the section from the inferred age of igneous basement. The sediment becomes increasingly indurated with depth. The induration is caused primarily by the high thermal gradient and the accompanying diagenetic alteration and metamorphism, and in part by metasomatism resulting from diffuse fluid flow. At depths less than about 250 mbsf, carbonate concretions and diagenetic pyrite are common. This assemblage gives way with depth to carbonate-cemented clastic sediment, then to pervasively cemented fine- and coarse-grained sediment, and ultimately to ferroan carbonate. Below 400 mbsf, detrital feldspar is altered to clay minerals, and magnetite is pyritized by H_2S. At shallow depths, the magnetic susceptibility is highly variable; susceptibility peaks result from magnetite concentrated in the basal, sandy parts of turbidite layers. A 3-5-m-thick unit at 15 mbsf bears distinctively low susceptibility, and is strikingly similar to intervals seen at Sites 856 and 858; the cause of this shallow interval of low susceptibility is at this point unknown. On average, the susceptibility decreases steadily from 150 to 250 mbsf and remains low at greater depths because of the increasing alteration of magnetite to iron sulfide minerals.

The first of a series of sills, interbedded with indurated sediment, was penetrated at 471 mbsf. The sills are basaltic in composition, with plagioclase and pyroxene phenocrysts set in a fine-grained, hydrothermally altered groundmass, and are properly described as metadiabase. The dominant alteration assemblage consists of chlorite, epidote, and actinolite. The sills are subvertically fractured and cut with veins of epidote, chlorite, carbonate, pyrite, chalcopyrite, and sphalerite. Hole 857D, a deep reentry hole, was drilled 50 m north of Hole 857C to a total depth of 936 mbsf. The altered sill/sediment sequence intersected in Hole 857C continues with remarkably little systematic change in composition or degree of alteration to the bottom of Hole 587D.

Physical properties reflect clearly the high degree of induration of the sediment. Porosity measured on cored material decreases systematically with depth, from normal values of about 65% near the seafloor to as low as 25% at a depth of 450 m, and there is a corresponding increase in seismic velocity over this same depth interval, from about 1550 m/s to 3000-3500 m/s. The average velocity of the full section of sediment down to the first sill, defined by the 470 mbsf depth to the top of the first sill and the traveltime to the first reflector of 480 ms, is 1980 m/s. Velocities measured transverse to core axes are higher than vertical velocities; anisotropy increases with depth from about 5% in the upper part of the section to 25% at 400-500 mbsf (horizontal values are quoted above). Velocity in the igneous units ranges from 4500 to 6500 m/s. The intrinsic porosity of the igneous rock is low, typically 5% and less, although mineralized and open subvertical fractures are present in the cores. Fractures are also observed commonly in formation microscanner images of Hole 857D. Remanent magnetic intensity of the igneous rocks is low, averaging about 20 mA/m, as is magnetic susceptibility, which averages about 0.5×10^{-3} SI.

Based on variations in drilling rate, it was inferred that thick intervals of sediment were interbedded with the intrusive layers below 470 mbsf, but recovery in the sedimentary intervals was generally poor. Induction, porosity, lithodensity, sonic, natural gamma, and formation microscanner logs run in Holes 857C and 857D reveal the lithologic structure clearly and confirm this inference. Numerous igneous units are imaged clearly in all logs; these range from 1 to 25 m in thickness. The range of thickness of sedimentary interbeds is similar, and the volumetric proportion of igneous to sedimentary rocks is roughly 2:3. In situ sonic velocities determined by the logs are similar to the vertical-component velocities measured on samples. Electrical resistivity of the sediment ranges from about 0.4 to 0.6 ohm-m, and of the igneous layers from 3 to 20 ohm-m. Average values within individual igneous units are resolvably different, and there is a tendency for resistivity to increase into the sill interiors. There is also some tendency for the contrast in physical and electrical properties to be sharper at the bases of the sills than at the tops. The logging data also reveal the thicker layers of sandy and silty turbidites clearly. Further analysis should provide an accurate measurement of the proportions and frequency of the large turbidite layers.

In spite of low porosities, pore waters were extracted from all parts of the section. Higher porosity material was squeezed in the normal manner. Lithified sediment and porous igneous rocks were first shattered, then ground with a quantity of distilled water equivalent to the pore volume, and finally squeezed. Profiles of composition vs. depth reflect mainly reaction and diffusion, although lateral flow is indicated by the occurrences of broad maxima and minima of various chemical species in the vicinity of 300 mbsf. Concentrations of sodium, potassium, and calcium are remarkably similar to those found in vent fluids at the location of Site 858.

Temperature measurements in the open hole at 857C were made while the hole was still recovering from drilling disturbance. A temperature of 222°C measured at 495 mbsf thus provides a minimum estimate for the formation temperature at this depth. An extrapolation of the conductive gradient measured higher in the section provides a maximum estimate of just over 250°C for this same depth. Temperatures in the cased section of Hole 857D, measured 14.5 days after drilling and before the casing shoe was drilled out, showed clear indications of fluid flow down the annulus around the outside of the casing and into the sediment section. Temperatures were much less than 100°C in the upper part of the hole, and were close to those measured in Hole 857C only below 300 mbsf. This implies that much of the cement used to grout the casing was lost to the formation, and that the sediment was sufficiently permeable to accept downhole flow to 300 mbsf.

Hydrologic properties of the formation were determined in the section of hole below the casing in Hole 857D. Packer injection tests, along with a flow-meter log, showed the formation to be extremely permeable. Virtually all of the pressure losses occurred in the pipe and through the packer itself; formation pressures rose little, even at the maximum injection rate of 3000 L/min (150 strokes/min). Much of the flow entered the formation in two discrete zones which were conspicuous in electrical-resistivity and self-potential logs. A packer test in the formation below the deeper zone yielded more "normal" behavior, with pressures responding smoothly during and following injection intervals, although even in this deepest interval the permeability is high. Formation pressures measured while the packer was seated confirmed the high differential pressure that was indicated by loss of circulation pressure during drilling; pressure measured in the formation was over 1 MPa lower than that in the cold hole. Under this differential pressure, the less restricted flow into the formation with the packer released was found to be over 10,000 L/min.

Final operations at Hole 857D involved setting an instrumented reentry cone seal (CORK), which included a 300-m-long, ten-thermistor temperature-sensor string, a pressure sensor, and plumbing for fluid sampling. This will allow pressure and temperature to be monitored as the formation returns to equilibrium conditions.

Site 858

Four APC/XCB holes were drilled in an array crossing the field and onto the flank of the associated thermal anomaly (Figs. 4 and 9). These four holes (858A-D) were drilled to document the local fluid-flow and thermal regimes, and the associated sediment alteration beneath and around the vent field. An exploratory RCB hole (858F) and a deep reentry hole (858G) were drilled approximately in the center of the field to characterize the deeper hydrothermal and geologic structure in the upflow zone and within the upper igneous crust lying beneath the area of discharge. These holes are shown in Figure 9.

Hole 858A was drilled with continuous APC coring to 62.5 mbsf and XCB coring to 339 mbsf. Drilling ended when the penetration rate and recovery dropped below acceptable levels. The hole is located about 100 m west of the vent field area (as defined by seismic, 3.5-kHz, and acoustic side-scan data), and about 150 m west of the nearest currently active vents. Temperatures measured in the upper 110 m of the hole show the thermal regime to be conductive; the thermal gradient is 1.7°C/m.

The next hole in the transect, Hole 858C, was drilled within the distal part of the vent field area (again as defined by high acoustic backscatter and the locally depressed topography), 70 m west of the nearest known vent. Measurements define a temperature gradient of about 3°C/m. APC/XCB cores were collected to a depth of 93 mbsf, by which point the penetration rate and core recovery had deteriorated and drilling was terminated. No indications of focused fluid flow were observed, although a considerable amount of dispersed pyrite and some brecciation were encountered.

Hole 858B, the next hole in the transect, was drilled 140 m east of Hole 858C and only a few meters away from a 286°C hydrothermal vent. A temperature of 197°C was measured at 19.5 m depth in the hole, indicating that the flow feeding the vent is very localized. The hole was drilled to a depth of 39 mbsf, where the core recovery and rate of penetration dropped below acceptable levels. Highly silicified sediment was again encountered near the bottom of the hole.

Hole 858D was drilled at the center of the vent area, about 70 m northeast of the nearest vent (at Hole 858B). Twenty-nine meters of sediment was recovered with APC coring; temperatures >208°C were measured with the WSTP at a depth of 18.5 mbsf. Hard drilling and low XCB recovery began at about 30 mbsf, and drilling was terminated at 41 mbsf. Deep drilling began at this location with RCB Hole 858F, which penetrated 258 m of sediment and into extrusive basalt. Penetration of basalt flows continued in reentry Hole 858G to a total depth of 432.6 mbsf.

Unfortunately, recovery was poor with all coring systems but the APC. Recovery in the sedimentary section from Hole 858F averaged about 3%, and in the igneous section from Hole 858G averaged less than 5%.

Sediment in all holes at this site is hydrothermally altered, as reflected in mineral assemblages, bulk chemical composition, and physical and magnetic properties. The degree of alteration varies laterally and with depth in a way that is consistent with the thermal structure defined by the surface heat flow and downhole temperature measurements. The lateral boundary of the upflow system is very sharp, and upward flow of pore fluid at a rate that can be detected thermally or geochemically is limited to the area beneath the vent field itself. Conditions are thermally conductive, and chemically diffusive or reactive, in Holes 858A and 858C. Within the vent field, it is inferred that the section is virtually isothermal and chemically dominated by advection deeper than a few tens of meters. Lateral flow appears to be significant at various levels in all holes. Extreme alteration may have resulted in the formation of a cap of indurated sediment intersected at 30 mbsf in Holes 858B, 858F, and 858G. This cap may represent a fundamental hydrologic unit beneath the field. Unfortunately, very little of this material was recovered. Electrical resistivity logging in Hole 858F imaged a sequence of turbidite layers that correlates remarkably well with a similar sequence logged in Hole 857C, 1.6 km distant. This is remarkable, in light of the vast difference in thermal and chemical regimes at the two sites, for two reasons: the porosity signature of the turbidite layers has survived hydrothermal induration, and the section has been vertically compressed by less than 10% in the process. Clear correlations can also be drawn between the sections at Hole 858A and Holes 857A and 857C, based on lithologic and biostratigraphic boundaries.

Igneous basement at Site 858 comprises a relatively uniform sequence of basalt flows. Units are defined primarily on the basis of textural variation. Low core recovery limits the degree to which individual flow units could be recognized, although typically one to two chilled margins were recovered in each core. Chemical analysis indicates that the flows may be genetically related to the sills drilled at Site 857. The rocks are highly altered, but vein- and dispersed-mineral assemblages show little indication of the passage of high-temperature (>380°C) hydrothermal fluids. Injection tests showed that this basaltic basement is highly permeable. Measurements with a flow-meter in Hole 858G during a steady injection test showed that most of the flow entered the formation in a discrete layer. Temperature measurements showed clear evidence that downhole flow, forced "naturally" by the cold, high-density water in the hole, entered the formation at the same depth and cooled it. Temperature measurements in Hole 858G indicate as well that drawdown into the sediment section may have been stimulated where Hole 858F penetrated the cap rock.

After completion of all operations at this site, a second instrumented hydrologic seal (CORK) was installed to obviate downhole circulation and to monitor temperature and pressure as the formation returns to equilibrium.

Conclusions

The studies initiated during Leg 139 can loosely be characterized under the broad heading of "crustal hydrogeology." These studies will improve our understanding of how oceanic crust is created and then altered during the early stages of rifting and hydrothermalism at a sedimented spreading center. Although only preliminary work has been completed thus far, we can draw some broad conclusions. Hydrothermal circulation is vigorous in this setting, perhaps even more than anticipated,with fluid flow occurring both in the sediment section and in the upper igneous crust. Flow is highly controlled by structure and lithology, including trough-bounding faults (Site 855), sandy layers within the thick sediment section (Site 857), and fractured or porous zones in the upper igneous crust (Site 858). The environment is conducive to the formation of massive sulfide deposits (Site 856) which, perhaps because of the isolation of fluid conduits through the sediments, are compositionally similar to deposits produced at unsedimented ocean ridges.

Contrasts in material properties and compositions, in combination with localized heat sources, create powerful, nonlinear vertical and lateral pressure, temperature, and chemical gradients; these gradients in turn drive large mass and energy fluxes. Extremely high temperatures are maintained close to the seafloor within tens of meters of active hydrothermal vents, requiring the input of enormous quantities of heat. Hydrothermal basement in this setting may be composed of sediments, a sediment/sill complex, or a sequence of igneous flows and dikes, provided there is sufficient permeability and heat to keep high-temperature fluid moving. The complexity of observed thermal and chemical gradients through the upper oceanic crust at Middle Valley emphasizes the dynamic and transient nature of this hydrothermal system.

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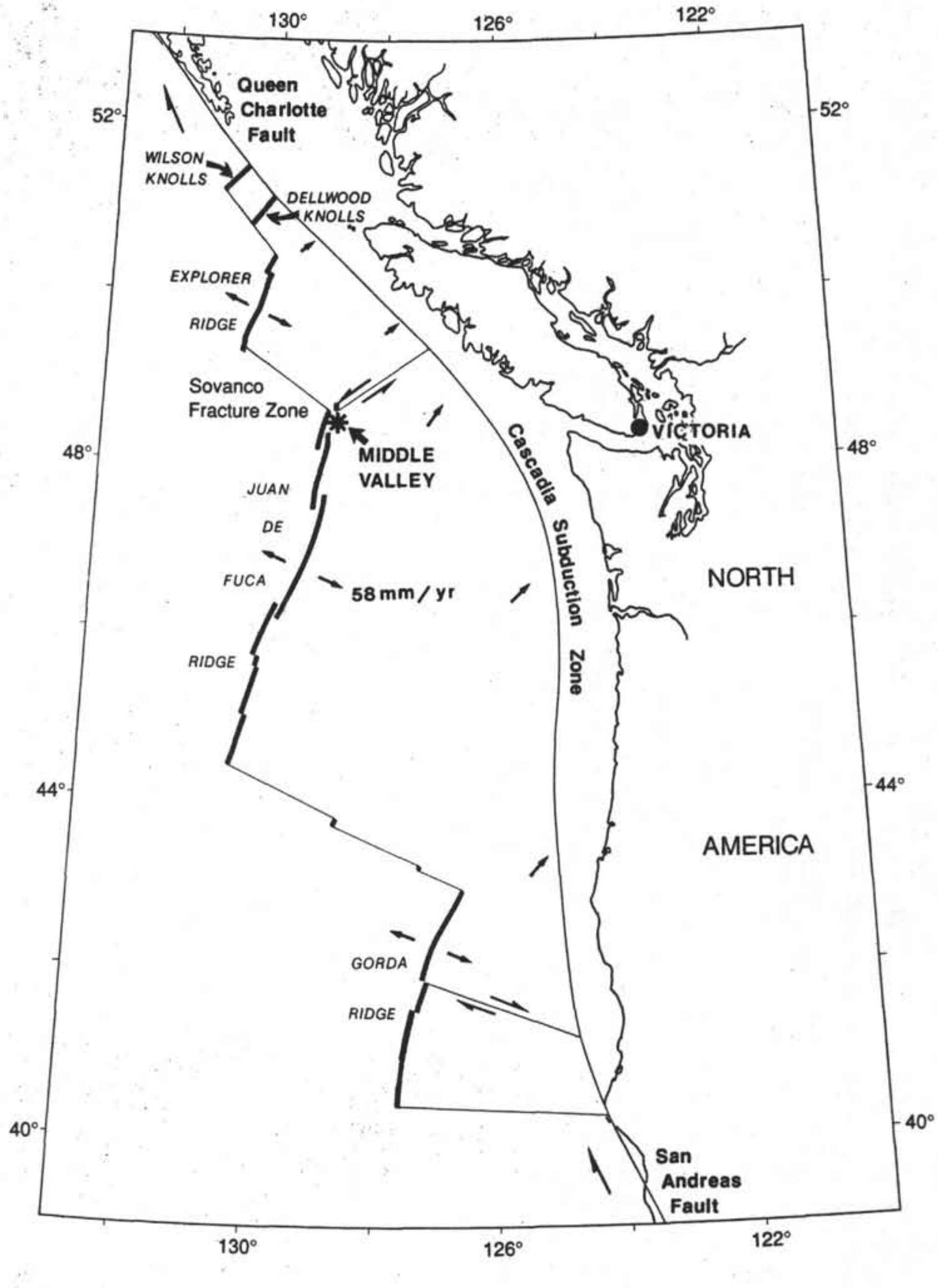


Figure 1. Location map, showing the tectonic setting of Middle Valley.

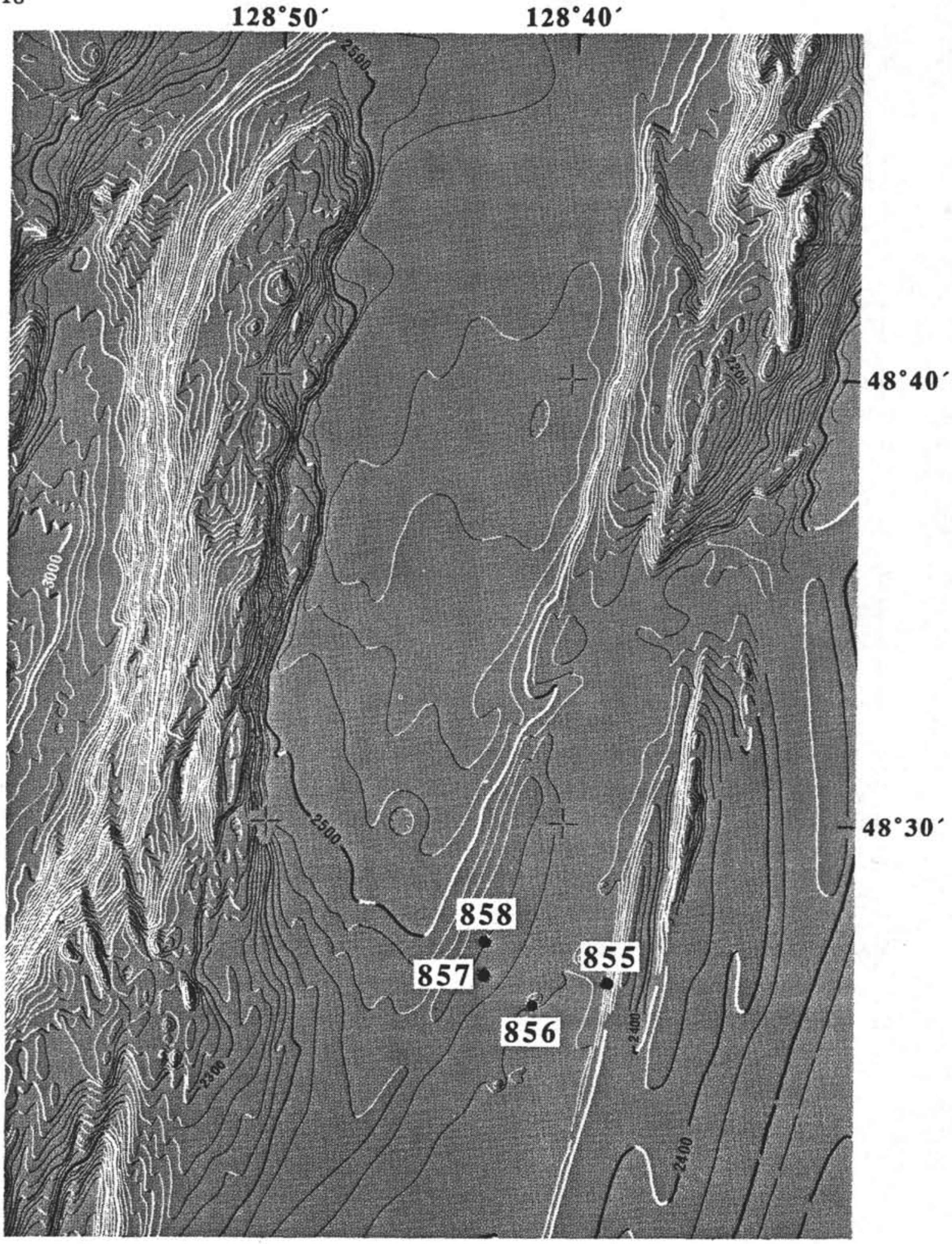


Figure 2. Regional bathymetry of the sedimented rift, Middle Valley, of the northern Juan de Fuca Ridge. Contours are shown at 20-m intervals.

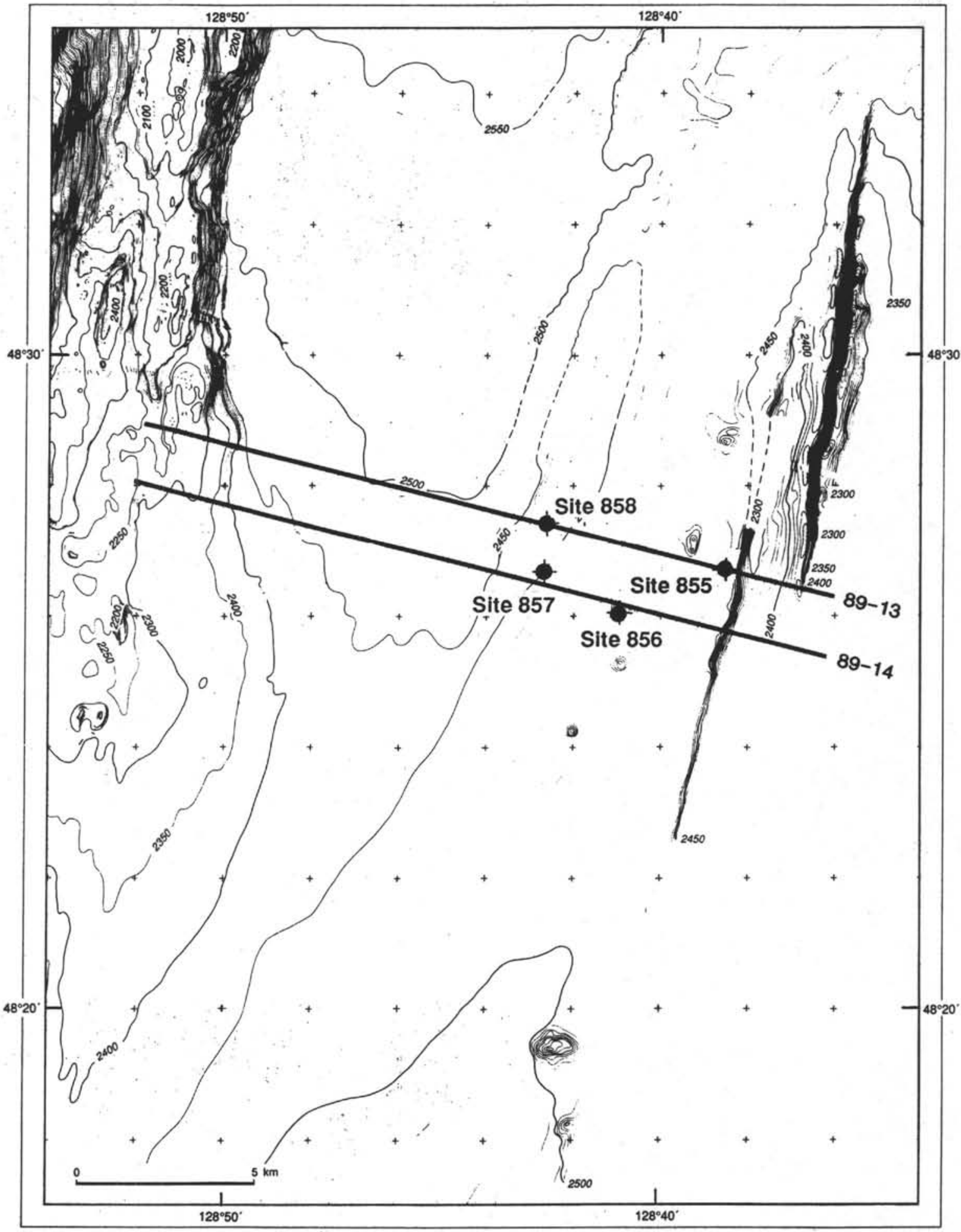


Figure 3. Local bathymetry, shown at 10-m contour intervals, in the vicinity of the sites drilled during ODP Leg 139. The location of the sites and tracklines of the seismic reflection profiles shown in Figures 4 and 5 are included.

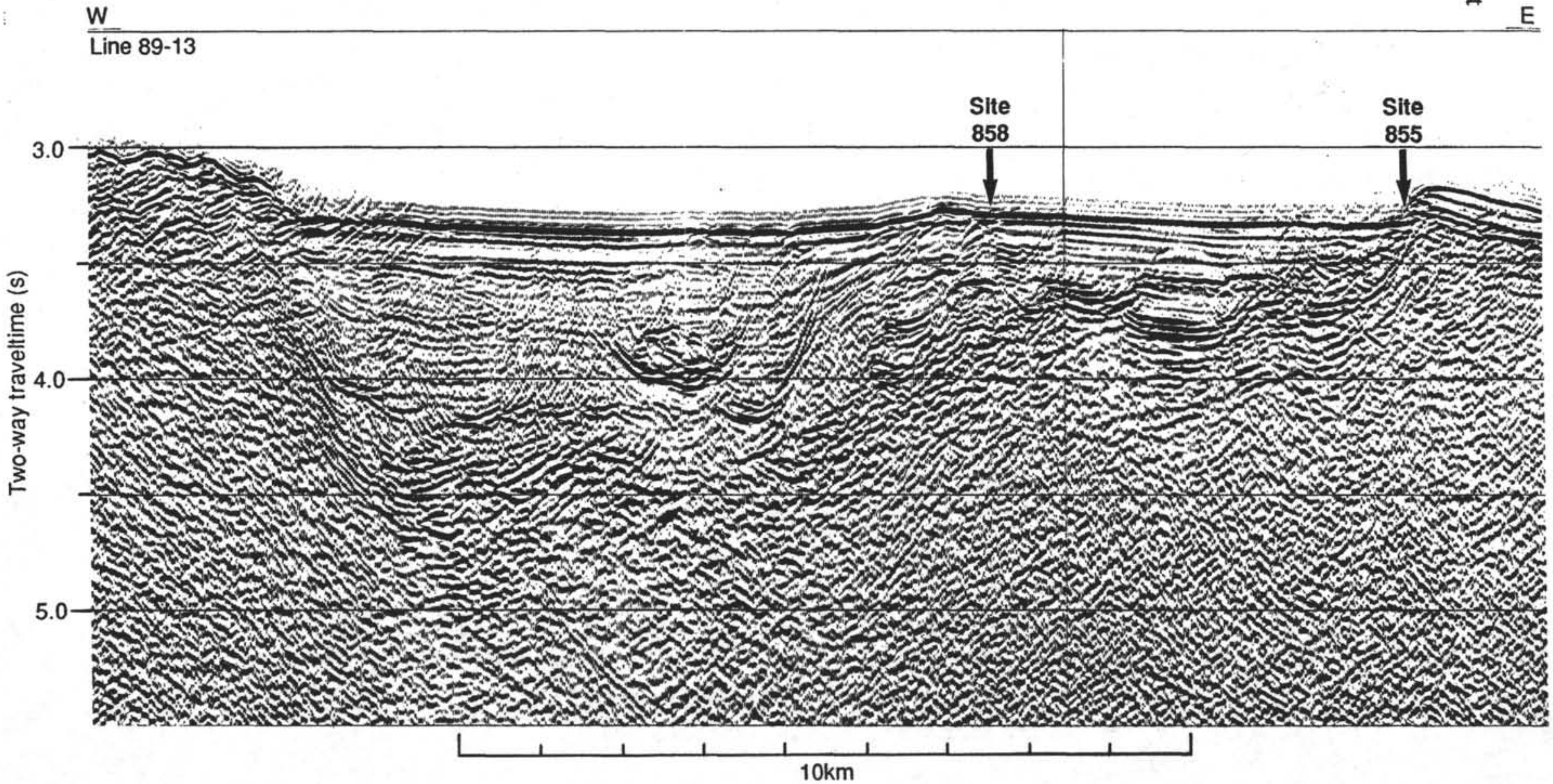


Figure 4. Multichannel seismic reflection profile crossing Middle Valley and ODP Sites 855 and 858.

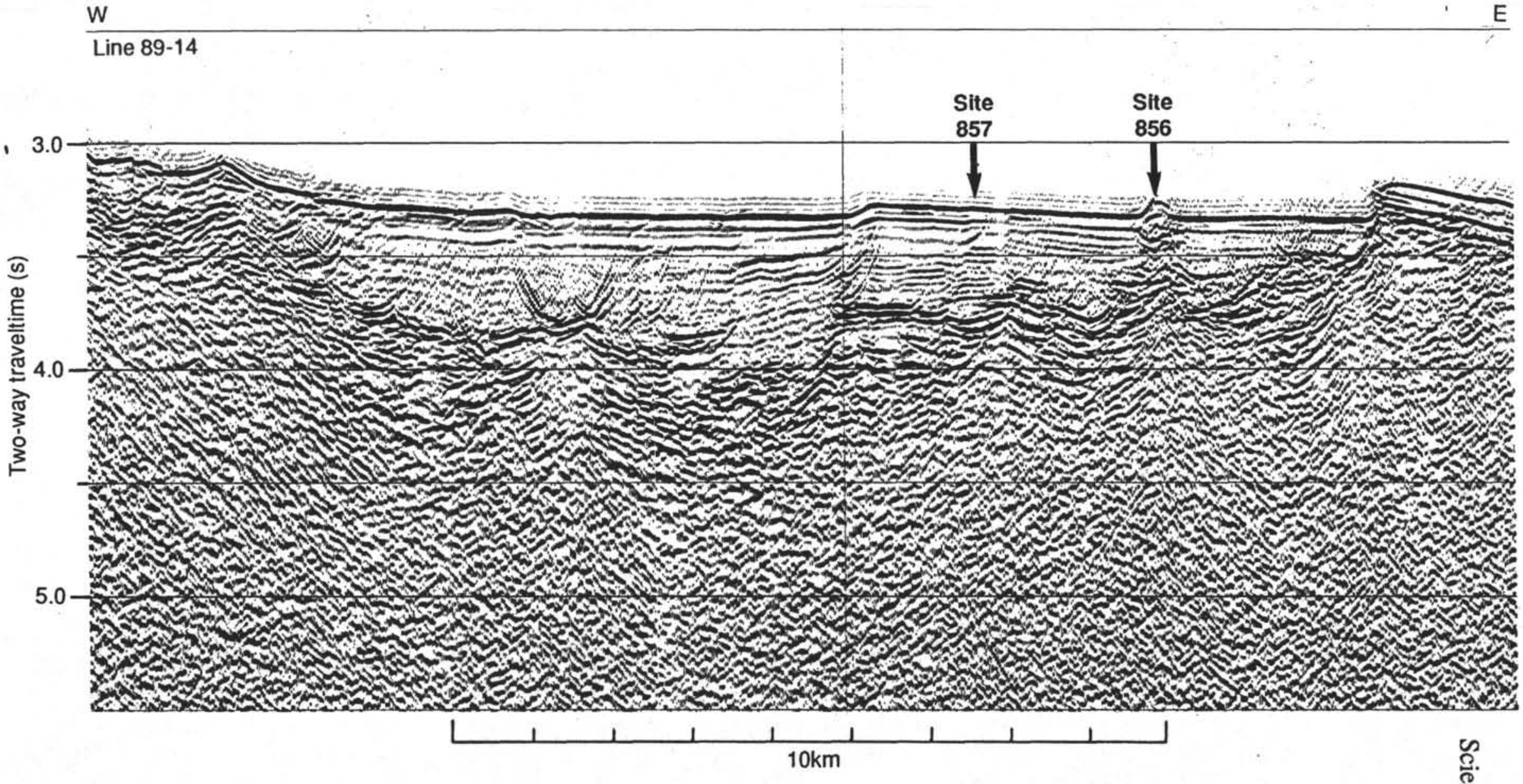
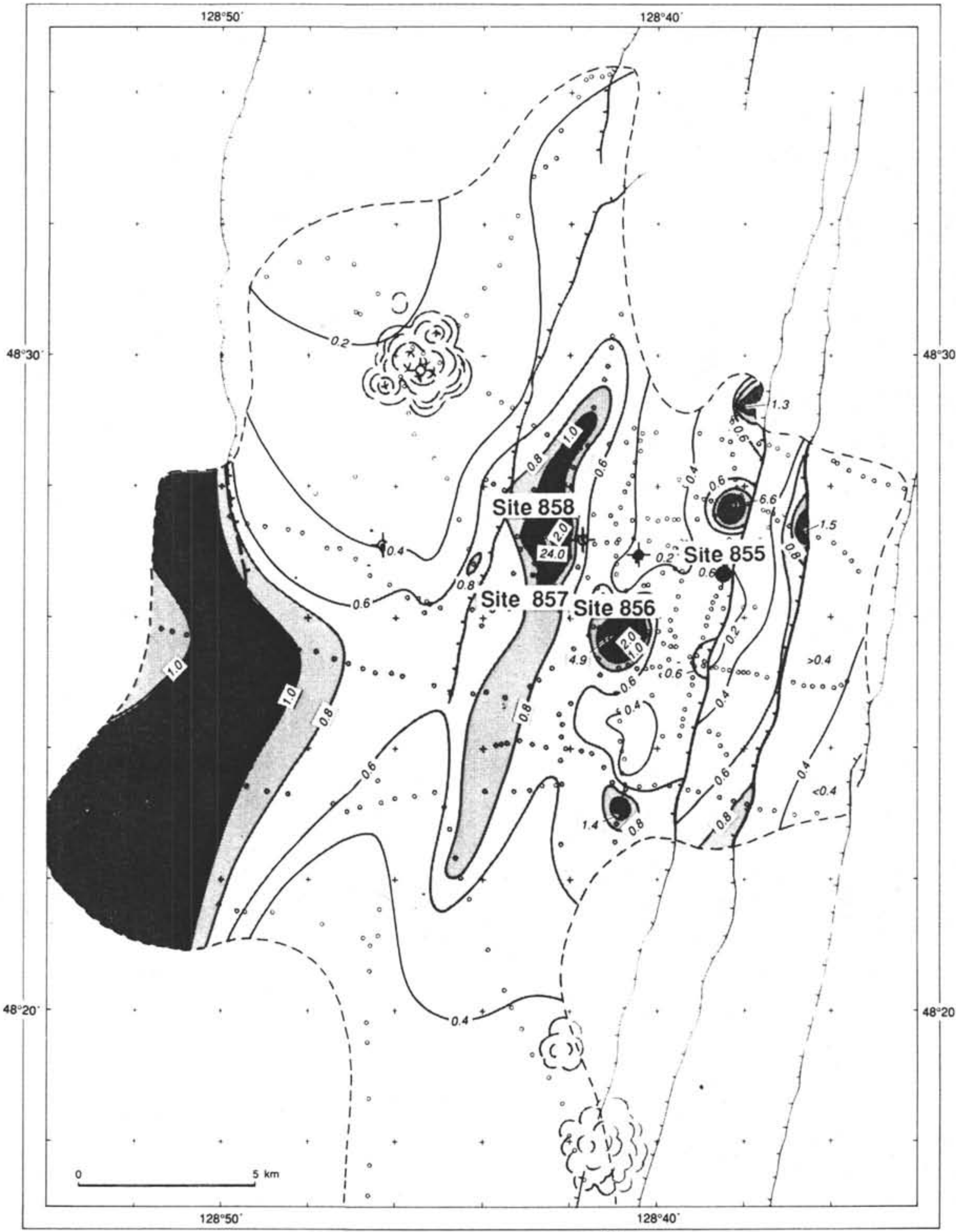


Figure 5. Multichannel seismic reflection profile crossing Middle Valley and ODP Sites 856 and 857.



HEAT FLOW (Wm⁻²)

Figure 6. Heat flow in the southern part of Middle Valley.

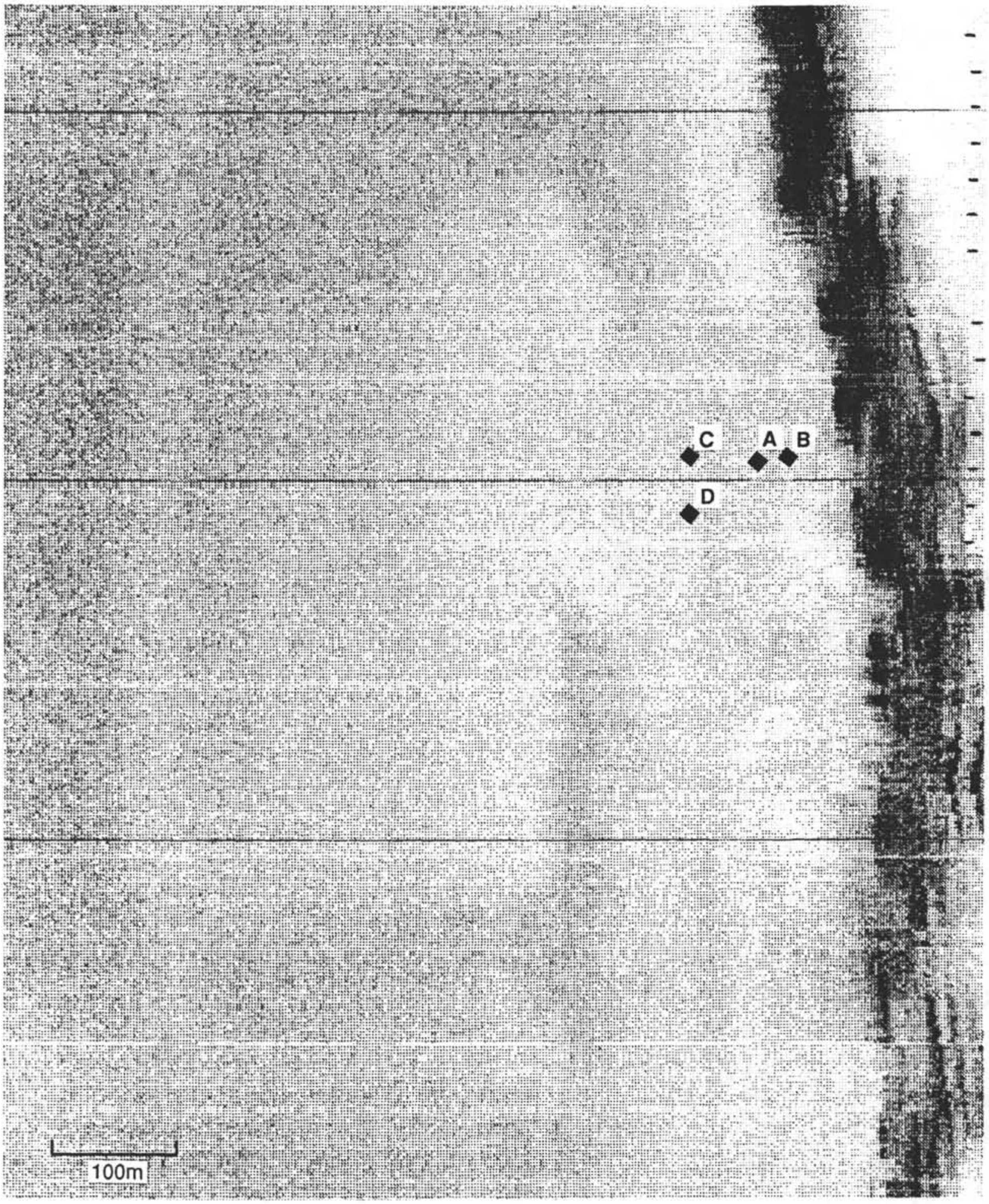


Figure 7. A 30-kHz side-scan acoustic image of the fault scarp where Site 855 was drilled. A - D = Holes 855A - 855D.

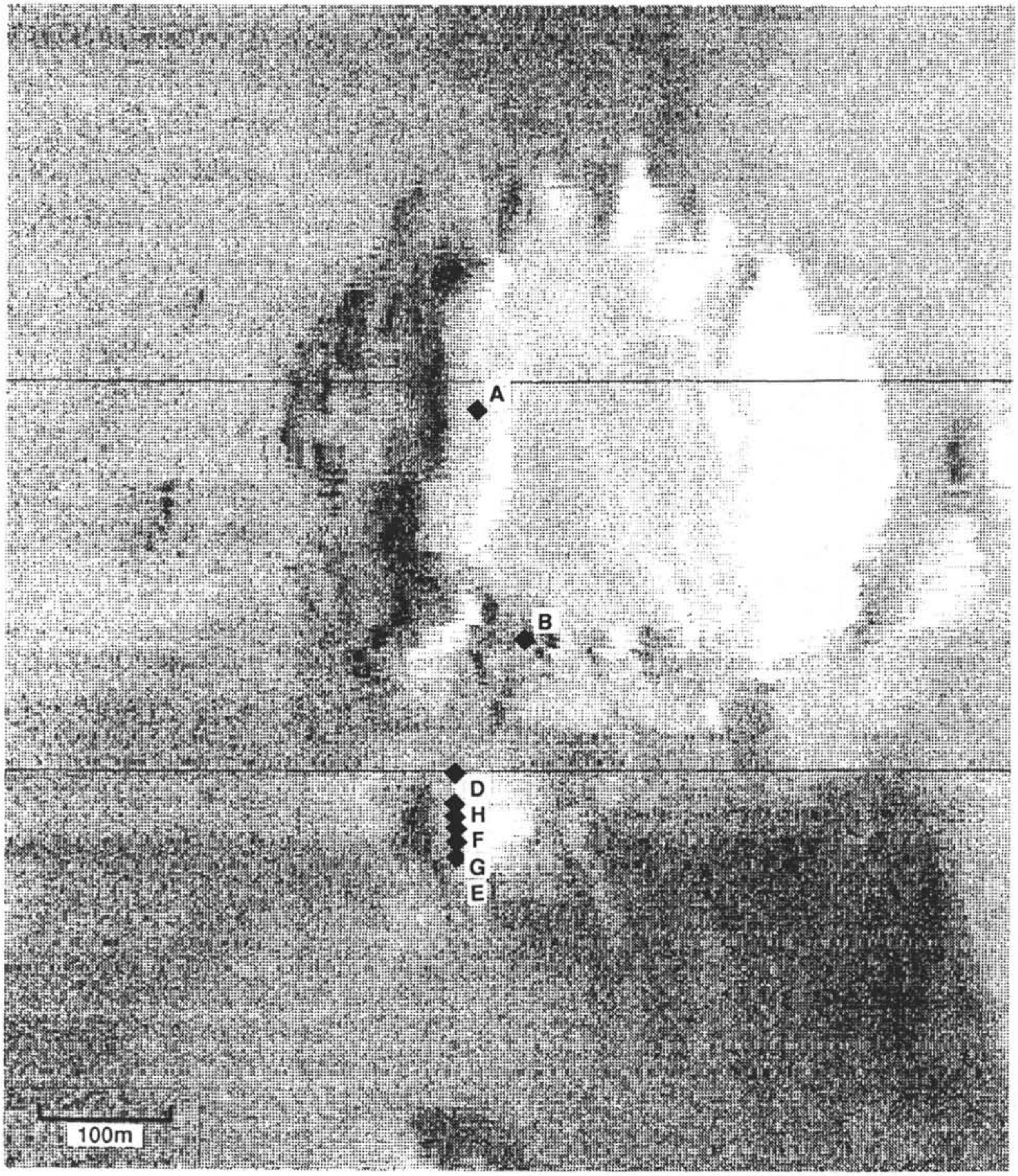


Figure 8. A 30-kHz side-scan acoustic image of the uplifted hill and sulfide deposit where Site 856 was drilled. A - H = Holes 856A - 856H.

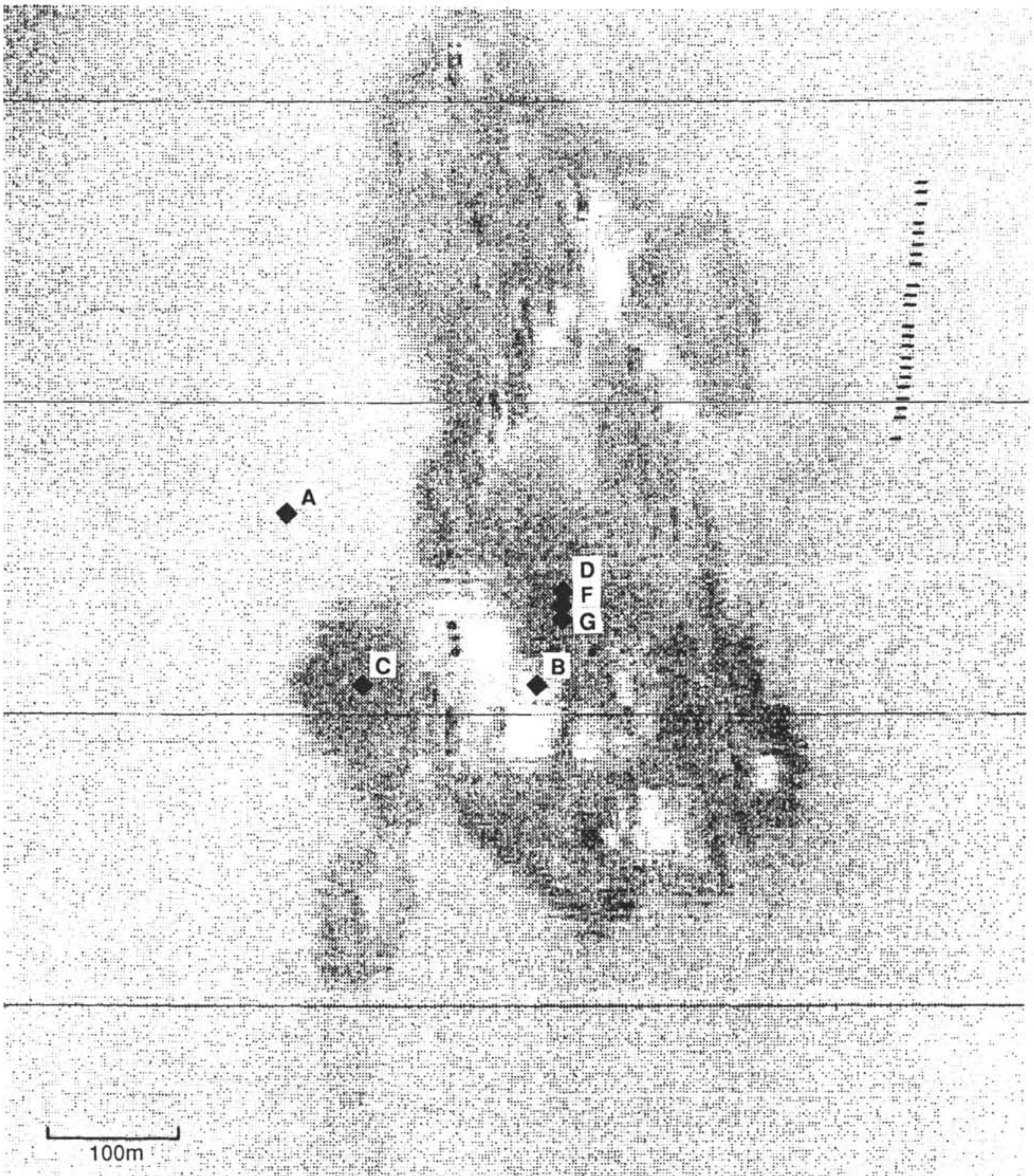


Figure 9. A 30-kHz side-scan acoustic image of the hydrothermal vent field where Site 858 was drilled. A - G = Holes 858A - 858G.

OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 139 of the Ocean Drilling Program were:

Operations Superintendent:	Glen Foss
Development Engineer:	Tom Pettigrew
Schlumberger Engineer:	James Witkowsky

OPERATIONS REPORT

Overview

Leg 139 of the Ocean Drilling Program encompassed an ambitious program of investigating hydrogeologic circulation and its effects on the sediments and underlying rocks in the environment of a sedimented seafloor-spreading ridge. A total of 22 holes were investigated at 4 sites (Sites 855-858). One site was drilled in a suspected "recharge" area (Site 855), with two sites in an area of high heat flow and known hydrothermal venting (Sites 857 and 858), and one site in a deposit of massive sulfide mineralization (Site 856).

Holes at the two high-temperature sites have full dual-casing reentry installations that were left plugged against circulation and equipped with instrumentation for recording downhole temperature and collecting fluid samples. A hole at the third (sulfide) site is complete with a reentry funnel that would permit future investigations.

Notable operational highlights and achievements of Leg 139 included:

A. Successful drilling/logging/coring operations in the highest downhole temperatures to date for DSDP/ODP (estimated 300-350°C);

B. Coring nearly 160 m of massive sulfide deposits in two holes;

C. The first operational deployment (twice) of the circulation-obviating retrofit kit (CORK), with installed instrumentation, to plug reentry cones against fluid flow;

D. The first operational deployment of the pressure core sampler (PCS);

E. The rescue of three important logging tools from downhole distress;

F. Successful operations in a deep hole having extremely high influx of water to a high-permeability zone.

San Diego Port Call

Leg 139 began with the first mooring line at San Diego's Tenth Avenue Marine Terminal at 1530 hr, 4 July 1991. The port call was a major effort in terms of resupply, repair work, and public-relations activities. The final activities of the port call were completion of installation of supplemental air conditioning capacity and arrival of last-minute spare parts. *JOIDES Resolution* departed San Diego at 1700 hr, 10 July.

San Diego to Site 855

The transit up the west coast of the United States was uneventful. The weather was foggy and chilly for the first two days, improving on the third, only to deteriorate into drizzle and rain showers as the operating area was approached. Fortunately there was little wind, and seas were relatively calm, enabling the vessel to make an average transit speed of 11.3 kt directly into the California Current for the 1146-nmi transit.

All the Leg 139 drill sites are located within a few kilometers in the Middle Valley area near the northern end of the Juan de Fuca Ridge. The region is about 95 nmi southwest of Estevan Point, Vancouver Island, and 160 nmi west of Cape Flattery, Washington.

A preliminary survey of the operating area began at 1830 hr, 14 July. New seismic lines were run across proposed sites MV-1, MV-2, and MV-7 with high-frequency sound sources to improve the tie between bathymetry and global positioning system (GPS) navigation. A positioning beacon was launched at 0330 hr, 15 July, to begin site operations.

Site 855 (MV-7), Eastern Boundary Fault

Hole 855A

The site was located on the downthrown limb of the eastern boundary fault of the trough. The drilling objective of Hole 855A was to penetrate the fault plane at relatively shallow depth about 50 m from the base of the fault scarp. Actual selection of the spud location was to be done by locating the escarpment with the Mesotech sonar and offsetting the rig with the dynamic positioning (DP) system to the proper spot. The drill string and VIT frame then were lowered so that spud-in could be observed with the underwater TV camera. The initial spud was made at 1600 hr, at 2455.5 m from the driller's datum at the dual elevator stool (DES).

The first three RCB cores were "punch cores," with recovery averaging 71% for the interval. Continuous circulation was required to achieve penetration on the ensuing cores; recovery dropped to about 22% as a result. Rubbly basalt was encountered at 74 mbsf, and hole problems began immediately. The basalt was considered to be a sill lying above the boundary fault, so coring was terminated at 76.4 mbsf.

One water sampler/temperature probe (WSTP) measurement was attempted at 36 mbsf. Average core recovery for the hole was 45%.

Hole 855B

The rig was offset 30 m to the east (toward the fault scarp) in the hope of penetrating the fault above the level of the basalt sill. RCB cores were taken from the seafloor at 2457 m to 45 mbsf, where hard drilling again was encountered. Drilling was uneven to about 53 mbsf, where the rocks became uniformly hard, though torquing tendencies persisted. Total depth of the hole was 63.3 mbsf. Average core recovery was only 20%, partly because only fragments of basement rock were recovered.

The results of Hole 855B convinced investigators that the basalt in both the A and B holes represented the footwall of the normal fault, which had an apparent dip of about 45°. A location was chosen for Hole 855C that would allow for penetration of the same basalt member both above and below the fault plane and permit study of the faulted zone with cores and logs.

Hole 855C

A positioning offset was entered to locate the new hole 55 m west of Hole 855A. A jetting test was conducted to determine the casing point for a potential reentry hole at Site 855 later in the leg.

RCB core recovery was good to about 66 mbsf, where the requirement for circulation again caused a sharp decrease. WSTP runs were made at 37, 56, 75, and 95 mbsf with generally good results. Hard material was encountered at 98 mbsf, and drilling problems began shortly thereafter. No basement core was recovered from 13 m penetrated. Average recovery for the hole was 55%.

Hole 855D

Hole 855D was spudded at 1945 hr, 17 July. The hole was drilled without coring to 79.5 mbsf, where a WSTP run was made. Continuous RCB coring then began.

The bit deplugger was used to clear an obstruction after no core recovery had been achieved from the first two core attempts. Some sediment core was then recovered, but the familiar torquing/sticking/filling tendencies returned when basalt was encountered, and operations were terminated at 118.6 mbsf. Average recovery for the hole was 5%.

There was little chance of drilling a hole deep enough for logging, and the site was clearly not suitable for a reentry installation.

Site 856 (MV-2), Bent Hill

The drillship got under way at 1300 hr, 18 July, and conducted a precision depth recorder (PDR) survey across proposed sites MV-1 and MV-2, dropping beacons on both sites in order. The vessel then took station on the MV-2 beacon, beginning site operations at ODP Site 856 at 1530 hr.

Hole 856A

An APC/XCB outer barrel and BHA were assembled and run to spud depth. The initial APC core found the seafloor at 2405.8 m. Continuous APC cores were collected to refusal (105,000 lb pullout force) at 79 mbsf with full recovery. The new (Adara) APC temperature shoe was used on Cores 139-856A-3H, -5H, -7H, and -9H and performed flawlessly. XCB cores then were taken to basalt at 114 mbsf, where the hard rock stopped XCB penetration. An experimental hard-formation XCB shoe succeeded in obtaining an additional 1.4 m of basalt core. Average core recovery for the hole was 88%.

Hole 856B

With the bit pulled above the seafloor, the vessel was offset in dynamic positioning (DP) mode 190 m to the south for the second planned hole of the Bent Hill site. APC cores were taken to 62 mbsf, with the APC temperature shoe used on Cores 139-856B-3H, -5H, and -7H before it was discontinued due to high-temperature limitations. The WSTP was run after cores 4H and 9H. A thin basalt intrusion halted APC penetration when a small amount of basalt was recovered in the core catcher. XCB coring continued to basement at 120 mbsf. Average core recovery was 89%.

Holes 856C, D, E

The drillship was offset 120 m south-southwest to the next proposed location, an outcropping of sulfide mineralization. Because the drilling target was located atop a small ridge a few meters in height, a series of APC mud-line cores was used to both define the bathymetry and to sample the seafloor material.

The initial core (139-856C-1H) was shot from 2448 m. Incomplete stroke was indicated, and the recovered core barrel contained over 7 m of clay and sulfide material. Most of the contents apparently had flowed in by "hypodermic" action as the barrel had been picked up by the piston rod. Penetration was estimated at 2 m.

After a further offset of 30 m south, the drill-string weight indicator registered resistance at 2436 m, indicating that the ridge had been found. An APC core from 2435 m again failed to stroke completely. Core barrel 139-856D-1H contained 8.3 m. As more of the material appeared to be "real" core, penetration was estimated at 5 m.

The identical procedure then was repeated with another 30-m south offset. The APC was shot from 2440 m. This time a full stroke (pressure bleedoff) was indicated. The inner barrel contained 2.4 m of oxidized sulfide sediments with evidence of the seafloor interface at the top. The core was designated 139-856E-1H.

Hole 856F

The increase in depth was interpreted to mean that the ridge had been crossed. As the main sulfide accumulation was the primary target, a 15-m north offset was entered to position midway between Holes 856D and 856E. The hole was spudded at a depth of 2434 m with an XCB core. Coring results were unsatisfactory, with recovery limited to a few centimeters of friable massive sulfide material mixed with clay in each of three successive cores. The material had become quite hard after about 5 m, the rate of penetration (ROP) had dropped sharply, and average core recovery was 2% after 23.6 m of penetration. The hole was terminated for a round trip to install the RCB bottom-hole assembly (BHA).

The APC corer was lowered for a single "mud-line" core attempt as soon as the bit cleared the seafloor. Incomplete stroke was indicated when the core was actuated, and the core barrel could not be retracted through the bit with the coring line, indicating a bent barrel. The APC was recovered with the drill string. When it reached the drill floor, the lower portion of the barrel was found to be broken off completely.

Hole 856G

To ensure a favorable spud location, the VIT was deployed with the TV and sonar systems. Sonar was used to locate a level spot on the crest of the ridge. The bit was observed by TV to tag sediment at 2433.5 m. The bit remained in contact with the seafloor, and the drill string was compensated while the VIT was recovered.

With the VIT removed, the drill string could be rotated, and RCB coring began. Again, hard material was encountered after about 6 m. The reason for the inital soft drilling soon became evident, as each of the first two core barrels contained several meters of loose, coarse sand composed of sulfide minerals. The dense sand continued to flow into the hole and cause hole-cleaning problems as coring progressed, but whole core of the massive sulfide deposits was recovered in the ensuing cores. Hole-cleaning problems continued, as considerable amounts of hole fill were present on connections despite frequent mud flushes and high circulation rates.

Following the connection after Core 139-856G-7R, which had reached 65.1 mbsf, circulation was plugged off and the drill string was stuck, both vertically and rotationally. Circulation was regained, but the string remained firmly stuck with the bit at 47.5 mbsf. Circumstances indicated a high probability that the bit was the stuck point. The "rotary" shifting tool (RST) therefore was run on the coring line. The mechanical bit release (MBR) shifted and released routinely, and the BHA came free.

Core recovery for the hole was 33%.

Before the drill string was pulled clear of the seafloor, a marker was fabricated of a glass ball flotation and an anchor of casing. It was stripped over the drill pipe and dropped to mark Hole 856G for future reference.

Hole 856H

The flowing sand and sulfide debris of the uppermost few meters was considered to pose a serious threat to successful deepening of any hole on the sulfide outcrop. As a deeper hole near 856G had high scientific priority and a conventional reentry cone installation was not feasible, the situation appeared appropriate for a short length of drill-in casing (DIC) with a small reentry funnel attached to the top to provide the option for future reentries.

The VIT frame again was deployed to help in pinpointing a spud location near Hole 856G. Seafloor depth of the new hole was 2434.5 m, only 1 m deeper than Hole 856G. The DIC was drilled to 12 m without difficulty and was released with the RST. A 4-m core of pyrite sand then was recovered from the uppermost interval.

Core 139-856H-2R encountered an additional 5 m of easy drilling before the ROP decreased in harder material. There were hole-cleaning problems from the beginning, probably from the soft material below the casing shoe. Remedial measures stabilized the hole until the drilling rate again increased below about 50 mbsf. Hole problems then returned and became worse with depth until the drill string became stuck during the retrieval of Core 139-856H-17R from 93.8 mbsf. Two hours was required to work the drill string free, and efforts to deepen the hole further were abandoned. Core recovery for the hole averaged 20%, all in massive sulfide minerals.

A through-the-bit logging run was then made with the JAPEX "PTF" logging tool. The results prompted interest in further logging, so the bit was pulled clear of the reentry funnel and released to allow the passage of the larger standard Schlumberger tools. The logs recorded that the hole had filled to 70 mbsf with debris and that temperatures had indicated a flow of seawater into the hole.

After the drill string had been recovered, the positioning beacon was acoustically switched to standby status, and offsetting in DP mode to the next site began. At 1845, hr 26 July, after a move of 1.3 nmi, a new beacon was launched at prospectus site MV-3.

Site 857 (MV-3)

Hole 857A

The initial seafloor APC core was "shot" from 2431 to 2440.5 m, and a full core barrel was recovered. At the time, the top of the core was thought to represent the seafloor interface. Continuous APC coring therefore continued until Cores 139-857A-9H and -10H failed to achieve complete stroke. The switch to XCB coring was made at 85 mbsf.

XCB cores were taken to 111 mbsf. Sediments were considered firm enough for RCB coring at that point, and operations were terminated in preparation for the deeper RCB exploratory hole.

Several downhole measurement runs were made in the hole, including the APC temperature shoe, the WSTP, and the pressure core sampler (PCS). Results were mixed. Average core recovery was 86%.

Hole 857B

Closer inspection of Core 139-857A-1H (after the liner was opened) had revealed that the sediment/water interface had not been recovered. A second "mud-line" core was therefore attempted from 7 m shallower than Core 139-857A-1H. The core succeeded in establishing the seafloor depth at 2429.1 m for Holes 857A and 857B, 1.9 m shallower than the earlier depth.

Core 139-857B-2H was then taken for a temperature-shoe measurement at 13 mbsf. The bit was "washed" ahead to 21 mbsf for Core 139-857B-3H and a temperature-shoe reading at 30.5 mbsf. All data were satisfactory, and the drill string again was pulled clear of the seafloor.

Hole 857C

An offset of 180 m to the east was requested by the shipboard scientists to relocate to an area of higher heat flow. When the required move had been completed, Hole 857C was spudded with a seafloor "punch" core that established the seafloor at 2432.5 m. A jet-in test then was conducted to 56.5 mbsf, where increasingly firm sediment signaled the limit for jetting in casing. WSTP probe runs were made at 37.5 and 56.5 mbsf. Continuous RCB coring then commenced.

Hole conditions and ROP remained good through the sedimentary section, though core recovery was disappointing to about 230 mbsf. Recovery then increased in firmer sediment to about 435 mbsf, where brittle or fractured, though highly indurated, sediment was poorly recovered as rubble. At 471 mbsf, an altered basaltic sill was encountered. Spotty recovery in alternating altered intrusive and sedimentary rock units then prevailed until total depth was reached at 568 mbsf.

Coring operations were interrupted at 202 and 285 mbsf for logging runs with the Sandia Laboratories self-contained temperature-recording tool, which was deployed on the coring line through the RCB bit.

In preparation for logging, a wiper trip was made to 75 mbsf and back to total depth, a mud sweep was circulated, and the bit was released with the rotary shifting tool (RST). The open-ended pipe then was pulled back to 75 mbsf for logging operations, and the conical side-entry sub (CSES) was employed to provide the capability of cooling the hole with pump circulation to protect the logging tools and cable.

Successful seismic stratigraphy and litho-density logs were recorded, but the third logging suite, the formation microscanner (FMS), could not be lowered out of the drill string. Attempts to free the tool with the logging winch resulted in the tool becoming stuck in both directions. The problem later was determined to be fouling of the cable and cablehead in the latch sleeve area of the outer core barrel (OCB) as a result of sediment plugging the end of the drill string and the oilsaver packoff in the CSES becoming unseated.

It was necessary to crimp and cut the cable near the cablehead and to trip the drill string to save the logging tool and cable. A free-fall reentry funnel (FFF) was dropped into place to enable reentry for logging, fishing, or plugging of the hole. The VIT also was deployed so that the pipe could be observed as it cleared the FFF. When the drill string had been retrieved, the logging tool was recovered in good condition.

Hole 857D

Construction of the reentry installation began with assembly of the cone and conductor casing. The cone was positioned in the moonpool, four joints of casing and the casing hanger were made up, and the entire assembly was latched to the lower BHA.

Hole 857D was spudded at 0930 hr, 5 August, on positioning offsets 50 m north-northeast of Hole 857C at a seafloor depth of 2431.5 m. The casing shoe was jetted to 48.7 mbsf, where the mud plate of the reentry cone came to rest. A wireline run with the RST released the cone/casing assembly routinely.

Drilling then proceeded toward the total depth of Hole 857C. Hard drilling was encountered at 2895 m, about 8 m higher than in Hole 857C. A strong drilling break occurred just before the planned total depth of 3000 m for the 14-3/4-in. hole, indicating soft and possibly unstable sediment. As several meters of fast drilling were involved, drilling continued to 3012 m (580.5 mbsf) so that an additional joint of casing could be set to isolate the soft interval. The hole was then flushed with drilling mud before the pipe trip began.

Upon recovery of the bit, preparations were made for running the 11-3/4-in. surface casing string. Weather conditions began to deteriorate as the casing operation progressed, and wind gusts to 66 kt produced vessel-motion conditions that approached operational limits. Nevertheless, the 580-m string, including 47 joints of range-3 casing, an expansion joint, and the casing hanger, was assembled without interruption.

Reentry operations were postponed for an hour due to adverse weather/current conditions, and maneuvering required an hour before the stab could be made. When the casing shoe had been lowered to 300 mbsf, the top drive was deployed so that circulation could be used to cool the seals in the float valve and seal nipple during the remainder of the trip. The casing string was latched in, released (with some difficulty due to heave conditions), and cemented into place before the cementing "stinger" was pulled clear of the seafloor for reentry into Hole 857C.

Hole 857C (return)

An hour was required for the offset of 50 m back to Hole 857C and the subsequent reentry into the FFF. Logging attempts with the Sandia temperature tool were made with the pipe at 94, 274, and 474 mbsf, but the logging tool was stopped by bridges on all attempts.

A 30-barrel plug of neat cement slurry then was mixed and displaced into the hole to guard further against any potential communication between Hole 857C and the 857D reentry hole. The drill string was flushed out and tripped for the move to Site 858.

Site 858 (MV-1) - Hydrothermal Discharge Area

Hole 858A

The beacon that had been dropped on proposed site MV-1 during the preliminary survey could not be reactivated acoustically, so the "backup" beacon was launched at 1930 hr, 9 August.

The initial APC core was shot from 2413 m, 6 m above the PDR depth of 2419 m. Depth was established at 2420.1 m on the basis of the core recovered. APC cores with full recovery then were taken to 40 mbsf. Beginning with Core 139-858A-3H, the heat flow shoe was used on every core. Incomplete stroke of the corer began with Core 139-858A-5H. On core 139-858A-7H, the butyrate core liner showed signs of high-temperature failure. Core 8H was taken with a high-temperature "ultem" liner, but the liner was shattered when the core was recovered.

One XCB core then was recovered with full core recovery and was followed by a PCS core. The result was the first fully successful PCS core with a 1/2-m core recovered under pressure. After a WSTP run, XCB coring continued with WSTP runs after each second core to 111 mbsf. Circulating pressures increased progressively on the next few XCB cores, indicating plugged jet nozzles in the bit, and recovery dropped sharply. A drop in pressure on Core 139-858A-17X allowed coring to continue, but core recovery continued to be low in firm claystone/siltstone. Chances of reaching the basement target faded when the ROP decreased with depth, and Hole 858A was terminated at 339 mbsf.

A temperature log then was run with the Sandia temperature tool, and an FFF was dropped so that a return could be made for further logging and/or deepening of the hole with the RCB system. The bit was pulled clear of the seafloor at 2330 hr, 12 August.

Hole 858B

Seven hours was spent in surveying the hydrothermal vent area in the vicinity of proposed site MV-1. A drill location eventually was found about 245 m southeast of Hole 858A and only a few meters from an active vent.

A "mud-line" core measured the depth at 2420.3 m. Incomplete stroke was encountered on Core 139-858B-3H, with gravelly material recovered in the catcher of a 1.7-m core. After a WSTP probe recorded a temperature of 196°C, a short XCB core was tried. The rate of penetration (ROP) was high, and only a trace of sediment was recovered, so the switch back to APC coring was made. Core 5H apparently stroked out during the trip down the pipe, but 7.6 m of sediment was recovered. Core 6H recovered only 82 cm after an incomplete stroke. Attempts to deepen the hole with the XCB met with little success, and coring was terminated at 38.6 mbsf due to poor hole conditions, low core recovery, and low ROP.

The Sandia temperature logging tool was run before the seafloor was cleared. The recorded temperature of about 150°C indicated that hot water was not flowing into the hole.

Hole 858C

A positioning offset of 140 m west then was made to locate the next hole in a zone of heat flow that was intermediate between conditions at Holes 858A and 858B.

The hole was spudded at 0130 hr, 14 August, with an APC core that determined seafloor depth to be 2428.0 m. After two additional APC cores, the PCS was run at 22.5 mbsf. Only water was recovered, apparently because too much pump circulation was used in the soft sediment, but the chamber was pressurized when recovered. APC cores then were taken to 47.5 mbsf. All had incomplete stroke. WSTP probe runs were made at 24 and 47 mbsf. After Core 139-858C-8H recovered gravelly material, a 1.5-m interval was drilled in the hope of extending APC coring past the gravel or hard bed. Core 9H apparently made little penetration, however, recovering only 27 cm. XCB cores then were taken to 93 mbsf, where the objectives were considered to be met.

Hole 858D

The vessel then was offset back to the hydrothermal discharge area to a point about 75 m north-northeast of Hole 858B.

The first APC core found the seafloor at 2426.2 m. Upon recovery of Core 139-858D-2H, the butyrate liner was found to be carbonized and partially melted over the lower half, while the upper half appeared unaffected by the heat. In addition, gas from a core-liner void sent the portable H_2S monitor off-scale, generating an H_2S alert. A PCS core was taken next, recovering sediment core under pressure with gases intact. A WSTP measurement at 18.8 mbsf then registered a temperature of 208°C. Two additional APC cores, with aluminum liners, achieved only incomplete stroke and forced the switch to XCB at 41 mbsf. After two cores with low ROP and recovery, coring was suspended for a round trip and a change to an RCB BHA for the reentry exploratory hole.

"Hole" 858E

Because of the local variability in the geology of the area, a tight pattern of holes in the area of 858D was desired, so no change was made in the positioning offsets.

After inconclusive results on an attempted jet-in test and WSTP run, suspicions of an unplanned reentry into Hole 858D increased. The reentry was confirmed when continued washing ahead contacted solid bottom at the total depth reached by Hole 858D. The bit then was pulled above the seafloor for a valid jetting test.

Hole 858F

Following a 10-m offset to the south, the jet-in test was repeated and indicated that up to 26 m of conductor casing could be emplaced. Though that is a short string, it would be adequate to support a surface casing string up to the anticipated maximum of 200 m in length.

Continuous RCB coring then proceeded, with ROP increased over the XCB system but no improvement in core recovery. After Core 139-858F-5R had been retrieved from 66 mbsf, the bit became plugged. Fairly serious problems were experienced in unplugging the bit and clearing the annulus, which seemed to be packing off around the BHA. The drilling problems eventually cleared up, and coring continued.

Recovery in the sediment section averaged only 2% to 258 mbsf, where hard drilling was encountered. The altered igneous rock produced an increase in core recovery only to about 7%. At 297 mbsf, sufficient "rathole" had been made to confirm a satisfactory casing seat and to ensure a reasonable opportunity for logging the sediment/intrusive contact.

After the hole had been conditioned for logging, a temperature profile log was attempted to confirm whether there was a flow of water into or out of the hole. The self-contained Sandia temperature tool was run on the coring line and apparently reached a depth of 2690 m, 33 m short of total depth. After the logging regimen had been completed, the sinker bars were recovered--without the logging tool attached. The 3/4-in. threaded connection had parted, leaving the entire dewared pressure case in the hole.

Before the borehole was disturbed further, a JAPEX PTF log was recorded, and a water sample was taken with the LANL sampler. The logging tool eventually was fished from open hole (with 19 hr of good data) after three wireline-fishing attempts.

The remainder of the fill was washed from the hole, and another mud sweep was circulated at total depth before the drill string was pulled back to logging depth for the Schlumberger logging program. Successful logging runs were made with the seismic stratigraphy and FMS tool combinations. The geochemistry tool then was deployed but malfunctioned on the trip into the hole. Logging was discontinued when further progress could not be made without considerable delay.

A 35-bbl cement plug then was spotted from about 294 to 220 mbsf. The pipe was then raised to 2527 m, and another 35-bbl plug was set from about 101 to 45 mbsf before the pipe was pulled out of the hole and flushed of cement.

Hole 858G

A short (two-joint) conductor casing string and reentry cone were lowered to seafloor on the drill string, and Hole 858G was spudded at 0600 hr, 21 August, on a 10-m offset south of Hole 858F. Jetting progress stopped with the mud plate of the cone 2.5 m shallower. The cone/casing assembly was released with the RST, and drilling of the 14-3/4-in. hole began.

The bit jets became plugged at 132 mbsf, and a round trip apparently was needed because all ability to circulate was lost. The bit eventually was cleared during last-ditch attempts before it was pulled clear of the reentry cone.

Drilling continued with frequent mud pills as the float valve in the bit sub continued to malfunction and to allow backflow on connections, threatening additional plugging. (On recovery of the bit, the float valve was found to be held open by pieces of cement, which apparently had broken loose from inside the standpipe plumbing.) The 14-3/4-in. hole was terminated at 2702 m to provide for setting surface casing approximately 11 m into hard rock and to leave about 7 m of "rathole."

Following the pipe trip, the surface casing string of 21 joints of 11-3/4-in. casing was made up and hung off in the moonpool. The cementing stinger was assembled and attached to the casing string, and the entire assembly was lowered on the drill string to reentry depth.

After a routine reentry, the casing shoe was lowered to about 24 m short of the intended setting depth. The casing eventually was "worked" the remainder of the distance and released. The cement job was hampered by plugged shipping lines and difficulty in achieving a constant flow of dry cement to the mixer, but the slurry finally was mixed and displaced successfully.

The drill string then was recovered, the Site 858 beacon was switched to standby mode, and offsetting to Site 857 began.

Hole 857D (return)

A routine trip and reentry with an RCB BHA were made after the Site 857 beacon was reactivated and the ship had taken station. A temperature measurement in the equilibrated water column of the cased hole was planned before the casing shoe was to be drilled out, so the logging sheaves were rigged at the time of reentry. A PTF log was recorded as the tool was lowered in the hole. Progress stopped at 510 mbsf, where the tool apparently was set down on cement. The temperature reading was 235°C.

Solid cement was contacted by the bit at 552 mbsf and was drilled easily to the plug and shoe at 573 mbsf. Over 3 hr was required to drill the shoe, but no other problems were experienced as the rathole was cleaned to total depth and 1 m of new hole was made.

Continuous RCB coring then commenced, with a mud flush circulated to clean out any debris from the shoe while the initial core was being cut. The lithology comprised alternating highly altered diabase units and metamorphosed siltstone/claystone strata. Core recovery was fair for the first four cores, then reverted to the poor showing seen previously as the proportion of sediment increased.

A particularly hard igneous unit was penetrated from 607 to 613 mbsf, followed by a sharp drilling break and rapid drilling from about 614 to 619 mbsf. On tripping the core barrel, a major loss of hydrostatic head in the drill string was noted. The water level was checked and found to be 124 m below sea level. Periodic checks during continued coring operations found that the water level gradually returned to sea level over the next 2 days.

Core recovery improved somewhat below about 725 mbsf. Accompanying lower drilling rates supported the appearance of reduced fracturing in the alternating sediments and sills. Coring was interrupted for a bit change at 782 mbsf.

The round trip and reentry were routine and consumed only 13 hr. Hole conditions were excellent, with no "drag" and only 2 m of fill upon the return to total depth. Coring resumed at 0800 hr, 27 August.

There was little change in lithology, drilling parameters, or core recovery from the preceding interval. Coring operations were terminated at 3367.7 m (936.2 mbsf) because basement had not been reached and operating time was running out.

The bit was pulled inside the casing for a JAPEX PTF log to check temperature before the round trip began for the logging BHA. After the reentry, the SES was rigged with the end of the pipe about 85 mbsf. The seismic stratigraphy log was run first, with a good log from total depth to casing. A second run with the FMS tool recorded a good log, but the tool could not be pulled back into the pipe for retrieval. Again it was necessary to rescue the FMS by using the Kinley crimper/cutter tools and tripping the pipe. Two of the contact pads and retractable arms remained in the hole as junk.

The TAM straddle packer (TSP) was made up to the end of the BHA and run to about 100 m into casing after reentry. The first series of permeability tests was aborted when the go-devil became plugged with pipe rust. A second attempt was made after the go-devil was retrieved and redressed, and the pipe was cleaned by pumping a "pig" through it. Successful packer permeability and flowmeter tests then confirmed a formation underpressure of about 150 psi and flow rates into the hole in excess of 2000 gpm. Open-hole permeability tests were then done on the lowermost 180 m of the hole. Permeability was high enough to require the constant-rate injection technique, but was much lower than the zones at about 615 and 670 mbsf.

The lower 3000 m of logging cable was removed to isolate an electrical problem, and the litho-density logging combination was run into the hole. The high temperature at total depth caused thermal failure of the logging cable, and another 200 m had to be removed and the log repeated. A fair-quality log finally was obtained.

With the allotted time for logging having expired, a round trip was made for installation of the CORK and data logger. The CORK and its special BHA then were assembled and run to reentry depth. A routine reentry was made, and the drill-collar "stinger" of the CORK assembly was run a few meters into the casing. The CORK was left suspended above the reentry cone while the 300-m thermistor and fluid-sampling string was deployed, attached to the data logger package, lowered, and landed in the CORK by means of the coring line. When the coring line had been recovered, the CORK was landed in the 11-3/4-in. casing hanger and latched in hydraulically by means of a pump-down ball. With the drill string still attached, a special ROV landing platform was bolted around the drill string and free-dropped to land on the reentry cone. The VIT was lowered for inspection of the platform and CORK installation and for observation as the latch mechanism was "unjayed" to release the CORK from the drill string.

After the VIT and most of the drill string had been recovered, the positioning beacon was released and recovered. Following the pipe trip, the rig was offset to Site 856, where the beacon used earlier at that site also was released and retrieved. Offsetting continued to Site 858, where the beacon left in standby mode 11 days earlier was reactivated by acoustic command at 1130 hr.

Hole 858G (return)

Following a routine reentry, the Sandia temperature logging tool was lowered on the coring line for a log of the undisturbed cased hole. An obstruction in the casing stopped the tool at 162 mbsf. The data showed that the maximum temperature in the hole was about 265°C--at the level of the bit.

RCB coring commenced at 277 mbsf, after 15 m of cement and the casing shoe had been drilled out. The igneous rock (altered basalt, diabase, microgabbro) was highly fractured, contributing to reasonably good ROP (4-15 m/hr), but poor core recovery (4.4% overall). Because projected coring time remaining in the leg was insufficient to wear out the second bit, the journal-bearing bit was pulled from 354 mbsf after just 14-1/2 rotating hours.

The round trip and reentry were routine. Coring operations then continued with a roller-bearing bit until they were terminated at 432.6 mbsf due to expiring operating time.

Planning for the remainder of the leg required hole temperature data, so a temperature log was run with the Sandia tool after the bit had been pulled up to the reentry cone. The temperature tool was stopped by an obstruction at 389 mbsf, and the hole was found to be quite cool to that depth.

Following a wiper trip to total depth, the pipe was round-tripped for the packer BHA. When the pipe reached reentry depth, a pig was pumped through it to remove rust scale. Following a routine reentry, an induction/formation density/gamma-ray log was run, but could not pass the obstruction at 394 mbsf. When the logging tool had been recovered, the drill string was repositioned slightly to place the center of the packer at 107 mbsf. When the downhole pressure recorders were recovered, the pressure records from below the packer showed that water flow had been restricted in the drill string. Some rust flakes also were found in the go-devil passages.

While options were being considered for the remaining operating time, another Sandia temperature log was recorded. The tool reached 399 mbsf and indicated temperatures cool enough for flowmeter and/or additional logging work. As the earlier packer-permeability results were highly suspect, the experiment was repeated after the temperature log. A "slug" test was followed by a series of constant-rate injection tests. Indicated permeability was much higher than on the first try, and injection rates of up to 400 gpm were used. Because high flow rates had been achieved, the go-devil was retrieved and replaced by the electric-wireline-deployed flowmeter and its special go-devil. A series of flowmeter tests then was conducted to determine the location of the permeable zones.

Upon conclusion of the flowmeter measurements, the drill string was tripped for the CORK assembly. Deployment of the CORK, thermistor string, and data logger proceeded extremely smoothly. The CORK was released from the drill string at 0600 hr, 9 September, concluding operations at Hole 858G.

The remaining operating time for the leg was used for a seafloor survey in the vicinity of Site 858 to relate the locations of the boreholes to those of vent fields and other seafloor features. Upon conclusion of the survey, the drill string and positioning beacon were recovered. *JOIDES Resolution* departed the operating area at 0600 hr, 10 September.

Leg 139 ended with the first mooring line at Ogden Point Terminal, Victoria, British Columbia, at 0700 hr, 11 September.

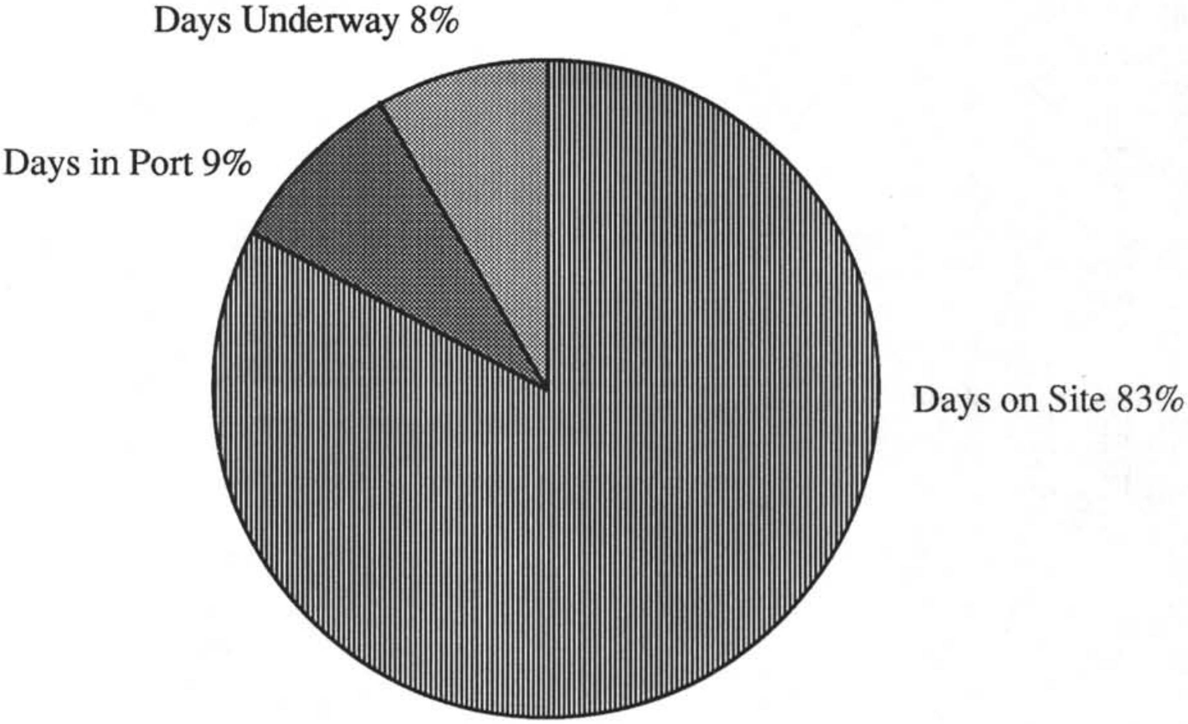
OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 139

Total Days (4 July - 11 September 1991)	68.6
Total Days in Port	6.1
Total Days Under Way	5.6
Total Days on Site	57.0

Trip Time	10.22
Coring Time	21.90
Drilling Time	1.91
Logging/Downhole Science Time	13.83
Reentry Time	1.53
Repair Time (Contractor)	0.10
Casing and Cementing Time	2.54
Downhole Trouble Time	0.99
Wait on Weather	0.04
Other	3.90

Total Distance Traveled (nautical miles)	1453
Average Speed (knots)	10.1
Number of Sites	4
Number of Holes	22
Number of Reentries	13
Total Interval Cored (m)	2656.4
Total Core Recovery (m)	932.9
Percent Core Recovered	35.1
Total Interval Drilled (m)	1030.1
Total Penetration (m)	3686.5
Maximum Penetration (m from drilling datim)	936.2
Maximum Water Depth (m from drilling datum)	2457
Minimum Water Depth (m from drilling datum)	2406

Total Time Distribution



Total Days of Leg = 68.6

OCEAN DRILLING PROGRAM
SITE SUMMARY REPORT
LEG 139

Hole	Latitude	Longitude	Sea Floor Depth (m)[1]	Number of Cores	Interval Cored (m)	Recovered Core (m)	Percent Recovered	Interval Drilled (m)	Total Penetration	Time (hours)
855A	48°26.56'N	128°38.27'W	2455.5	9	76.4	34.0	44.5	0.0	76.4	27.25
855B	48°26.57'N	128°38.25'W	2457.0	8	63.3	12.4	19.6	0.0	63.3	12.00
855C	48°26.57'N	128°38.32'W	2454.5	13	111.0	60.8	54.8	0.0	111.0	24.50
855D	48.26.54'N	128°38.32'W	2454.5	6	39.1	2.0	5.1	79.5	118.6	17.75
SITE TOTALS				36	289.8	109.2	37.7	79.5	369.3	81.5
856A	48°26.20'N	128°40.84'W	2405.8	14	115.7	102.0	88.2	0.0	115.7	25.00
856B	48°26.10'N	128°40.81'W	2430.7	16	121.7	108.3	89.0	0.0	121.7	25.75
856C	48°26.04'N	128°40.86'W	2448.0	1	2.0	7.1	355.0	0.0	2.0	2.00
856D	48°26.03'N	128°40.86'W	2435.0	1	5.0	8.3	166.0	0.0	5.0	0.75
856E	48°26.01'N	128°40.86'W	2447.1	1	2.4	2.4	100.0	0.0	2.4	0.75
856F	48°26.02'N	128°40.86'W	2434.0	3	23.6	0.6	2.5	0.0	23.6	13.75
856G	48°26.02'N	128°40.86'W	2433.5	7	65.4	21.7	33.2	0.0	65.4	38.00
856H	48°26.03'N	128°40.86'W	2434.5	17	93.8	18.4	19.6	0.0	93.8	89.25
SITE TOTALS				60	429.6	268.8	62.6	0.0	429.6	195.25

Hole	Latitude	Longitude	Sea Floor Depth (m)[1]	Number of Cores	Interval Cored (m)	Recovered Core (m)	Percent Recovered	Interval Drilled (m)	Total Penetration	Time (hours)
857A	48°26.50'N	128°42.80W	2429.1	14	110.3	94.7	85.9	1.9	112.2	25.75
857B	48°26.49'N	128°42.80'W	2429.1	3	22.4	23.3	104.0	8.1	30.5	7.50
857C	48°26.48'N	128°42.68'W	2432.5	68	514.7	169.0	32.8	53.0	567.7	208.00
857D	48.26.52'N	128°42.65'W	2431.5	37	354.7	37.4	10.5	581.5	936.2	360.00
SITE TOTALS				122	1002.1	324.4	32.4	644.5	1646.6	601.25
858A	48°27.41'N	128°42.71'W	2420.1	39	339.1	97.8	28.8	0.0	339.1	75.00
858B	48°27.34'N	128°42.54'W	2420.3	9	38.6	31.7	82.1	0.0	38.6	25.00
858C	48°27.34'N	128°42.66'W	2428.0	14	91.6	55.5	60.6	1.5	93.1	22.00
858D	48.27.37'N	128°42.53'W	2426.2	7	40.7	30.4	74.7	0.0	40.7	67.50
858E	48°27.37'N	128°42.53'W	2426.2	0	0.0	0.0	0.0	0.0	0.0	10.00
858F	48°27.37'N	128°42.53'W	2426.2	28	269.1	8.2	3.0	27.8	296.9	110.50
858G	48°27.36'N	128°42.53'W	2426.2	16	155.8	6.9	4.4	276.8	432.6	230.00
SITE TOTALS				113	934.9	230.5	24.7	306.1	1241.0	489.00
LEG TOTALS				331	2656.4	932.9	35.1	1030.1	3686.5	1367.00

[1] Seafloor depths given in meters from the driller's datum at the dual elevator stool (DES).

TECHNICAL REPORT

The Technical and Logistics personnel aboard the JOIDES Resolution for Leg 139 of the Ocean Drilling Program were:

Laboratory Officer:	Brad Julson
Assistant Laboratory Officer:	Don Sims
Yeoperson:	Michiko Hitchcox
Curatorial Representative:	Robert Kemp
Computer System Manager:	Edwin Garrett
Electronics Technicians:	Roger Ball Bill Stevens Mark Watson
Photographer:	Shan Pehlman
Chemistry Technicians:	Ken McCormick Chieh Peng
X-ray Technician:	MaryAnn Cusimano
Marine Technicians:	Bill Bandy Gus Gustafson Kuro Kuroki Jeff Millard Monica Sweitzer

Port Call: San Diego

The ship arrived around 1530 hr, on the fourth of July, a day earlier than originally scheduled. This is the first time since Leg 102 that the ship had had a port call in the continental United States. Almost immediately a truck pulled up loaded with air-conditioning gear, despite it's being a holiday. This temporary A/C gear was hooked to the saltwater cooling lines to act as the air conditioning for the computer room. There was no air conditioning aboard the ship when it arrived because the chill water had been turned off to work on the system. DEC service representatives came and tried to troubleshoot the problems with the computers.

Work was begun on the second day of the port call on the new 25-ton supplemental A/C system that was to be installed on the roof of the lab stack. A Cascade air-breathing system was also unloaded and brought aboard the first night. This system was to be used if excessive hydrogen sulfide fumes were encountered. Two representatives from Safety International came aboard the second day and helped move the parts of the air-breathing system around the ship and install the air lines. Representatives from TOTCO came to check out and help install the H_2S detector system throughout the ship. Leg 138 cores were offloaded.

On the evening of the second day a reunion was held the people associated with the Deep Sea Drilling Project and the Ocean Drilling Program. This took place at Scripps Institution of Oceanography. It was rewarding to see a number of familiar faces that many of us had not seen since the end of DSDP.

SEDCO was also extremely busy during the port call, changing out the guide rails in the derrick. Bentonite was loaded aboard. The cement was offloaded and blended with silica to produce a cement for use in hot holes. Parts were brought out, and the Cyberex was finally brought back online.

More than a thousand people visited the ship while it was in San Diego, and students from as far away as Los Angeles came to tour the facilities. There also was a JOIDES Executive Committee meeting and dinner aboard the ship. The microscopes were all cleaned and recalibrated by a local microscope representative. Late in the port call, Lamont's wireline heave compensator was removed to be rebuilt. A reel of high-temperature logging cable was installed. The ship got under way about 1700 hr on 10 July.

LABORATORY OPERATIONS

Under Way

Geophysical data was collected on two transit lines. Technicians routinely collected bathymetric, magnetic, and seismic data on the two surveys in the vicinity of the sites. Only bathymetric and magnetic data were collected on the long transit from San Diego to the Middle Valley sites. Two 80-in.^3 water guns were used for the site surveys.

Loran-C positioning data were also collected on this leg and compared to the GPS positioning data. This area has a very good signal, and an offset was determined.

Chemistry

The labs on the foc'sle deck were the most heavily used. More chemists sailed on Leg 139 than on any previous leg. Four full-time chemists were in the lab, but a number of other geochemists periodically used the lab. In the organic section of the lab, gas monitoring was carried out at all the holes. Gases were collected and analyzed, and many samples were sent back for isotope analysis. The pressure core sampler was brought out and deployed successfully a number of times. Gas from this tool was collected in the pressure core manifold, which was assembled in the second look lab. Among the gases encountered were carbon disulfide and other sulfide compounds that can be associated with thermal systems. A large extraction program was carried out, and many of the samples were analyzed for inorganic carbon, total carbon, and sulfur. The CNS analyzer was upgraded to handle CNHS.

The inorganic section of this lab was heavily utilized. Two small squeezers arrived for this leg and were helpful in squeezing over 260 samples. H_2S was analyzed in the samples, and clearly indicated how lowering the pH of the water can drive the H_2S out of pore water.

New lamps for additional elements were brought out for the Atomic Absorption analyzer. A larger disk drive was added to the HP1000 computer. An Apple card was installed in the carbonate PCXT so that LOTUS files could be quickly copied to the TMPDAT directory on the DRAKE SHARE and then brought into EXCEL 3.0.

X-Ray Lab

The XRD instrument was thought to have a bad transformer since Leg 138. The wires were unlabeled, and there were three different wiring diagrams in the schematics. After testing, the correct diagram was determined. The goniometer also was found to be in need of re-alignment. Not long after this, the PDP-11, the computer controlling the XRD, failed. It could not be repaired to run analyses from the terminal but the instrument could be operated from the control panel. The XRD was used extensively; more than 450 samples were run.

The XRF tube was changed out and the instrument recalibrated. There was an extensive XRF analysis program carried out on both sediments and hard rocks. Both major elements and trace elements were analyzed. A pressure relief valve was changed out on the Haskris water chiller.

Thin Section Lab

This lab on the foc'sle deck was also heavily used. Thin sections were quite diverse and included basalts, massive sulfides, mud and clay sediments, sandstones, carbonates, and metamorphic rocks of various types.

Physical Properties Lab

Many of the instruments were shut down with the air conditioning system during the final transit of Leg 138. Many of these are difficult to start back up, and the GRAPE was dead when we first tried. The problem was finally isolated to the pre-amp on the detector. Finally, the third amp got the full scale signal quality. The use of aluminum liners for high-temperature coring made the use of the MST challenging. An aluminum standard was placed into an aluminum sleeve and proved adequate for the GRAPE standard. Magnetic-susceptibility values were very low.

Thermal conductivity readings were taken on most of the cores, using both the full-space needle probes and the half-space bath and needles. The new Digital Sediment Velocimeter and the Hamilton Frame were used for velocities. The Hamilton Frame transducers were changed out a number of times. We hope to connect the Hamilton Frame into the Digital Sediment Velocimeter.

Paleomagnetism Lab

This lab had initial problems with the cryogenic magnetometer sensors. These problems were solved, and the lab ran smoothly for most of the leg. Late in the leg, one of the compressors for the cryogenic magnetometer burned out its compressor motor. The compressor was replaced by a spare which was also damaged. With both compressors down, the small amount of liquid helium left in the cryomag boiled off. Two new compressors and liquid helium were ordered for the port call in Victoria.

Downhole Tools

One of the major objectives of this leg was to sample the hydrothermal fluid. The WSTP was returned to the ship after having been refurbished on shore. To prevent trace-metal contamination of water samples, all parts of the WSTP that might come in contact with the water were made from titanium or copper. These parts included tubing and fittings, the filter, and the probe tip. The electronics were replaced with MIL-specified components. There are now two thermistors in the probe tip. One is for low temperature (0-100°C) and the other is for high temperature (60-200°C). O-rings in the bulkheads were replaced with high-temperature Kalrez O-rings. We have modified one of the tools into a temperature-only tool, in which the water filter has been replaced with a machined metal block and the other is the temperature-and-fluid tool.

The DCDL data recorders worked after many attempts on previous legs. There are currently three onboard. Of the 23 WSTP runs, there were only 4 failures. The WSTP tool is officially rated only to about 125°C, but we were able to use it in much hotter places by circulating cold bottom water around the body of the tool that is in the pipe. The thermistors in the probe tip stick out ahead of the bit and are in the hot sediment equilibrating.

This was the first time that the new APC heat flow tool was used. The Adara tool was run 24 times with only 2 failures. This tool is run in the APC shoe and can be used only in soft sediments. It is rated to about 100°C, and one time the tool went into 200°C mud at only 18.8 mbsf. The batteries melted, but the tool came out unscathed; good data was collected.

Another tool that was deployed in the hot water was the Los Alamos water sampler. Although this tool was not used as extensively as was first planned, it was deployed once and did come back up full and under pressure. Three gas samples were taken, using the cylinders provided by LANL as well as numerous vacutainer samples. The vacutainers and one of the cylinder samples were analyzed on board. Two cylinder samples were sent for analysis on shore. Fluids were divided into aliquots for shipboard and shore-based studies. Preliminary shipboard analysis indicated the water to be borehole fluid from a non-producing hole.

A VSP log was planned at one of the sites using an 80-in.^{3} water gun. This was set up but later changed to the 400-in.^{3} water gun. Time ran out and the VSP was not used. The apparatus was taken apart and stowed.

Computers

A DEC representative was in port in San Diego and tried to troubleshoot the problem of DRAKE dropping out of the VAXCLUSTER and freezing. A few changes were made to isolate the problem, but more analysis needed and scheduled for the Victoria port call. One of the disk drives would no longer write to disk, and two RA 90's were rented from a company in Boston. After having problems logging onto the VAX at ODP, the radio operator requested that ODPBLAST be left in the server mode. The Pacific satellite was very busy so the log-on sequence was continually interrupted. This was getting to be very expensive, and the new system keeps the cost down.

This is the first leg without the QMS printers, and there are still some programs that required the code converted to Postscript output.

The PC clones were heavily used on this leg. Most of them now use Windows 3.0, but there were occasional memory problems, and a number of times files saved to a disk in WordPerfect running under Windows were corrupted. A good graphics program for the PC's is needed. HIJACK was a program sent out during the Atlantis II rendezvous that helps address this problem. On the MAC's, Norton Utilities was received and worked very well. EXCEL 3.0 and WordPerfect 2.0 were installed on the computers at the end of the leg. A new version of Retrospect was also received and used to back up the DRAKE SHARE VOLUME.

Miscellaneous

About midway through the leg, we had a rendezvous with the Atlantis II, mother ship for the Alvin. We transferred one of our scientists over there for a few days. Supplies were received.

Another ongoing project is the conversion of the Sub Sea Shop. On this leg a lot of time and effort went into painting the entire overhead, welding up the interior struts, installing the sheet metal finish, and painting the floor. The ducting could not be completed because the blower motor was not onboard. Consequently, the ducting was been tied off to the rail for the next leg.

The Cyberex was down a good part of the leg, and regulated power was provided by the motor generator system. The temperature in the underway lab was initially very high but returned to normal after the thermostat was replaced.

Midway through the leg the elevator began to bounce as it arrived at bridge deck. The cable had stretched to the point that the counterweights were bouncing on the back springs at the bottom of the elevator shaft. There didn't appear to be any damage to the cable, and the tightening nuts were adjusted and the elevator was back in service.

HYDROGEN SULFIDE MONITORING

The leg was well prepared for hydrogen sulfide (H_2S) fumes if they were encountered. A number of individuals had been sent for H_2S training in Canada as well as in Texas. A Cascade air-breathing system was installed in San Diego during the port call. This consisted of two compressors mounted on a skid in a shelter. High-pressure air lines connected the compressors to a series of air-bottle racks. The first one in line was a 2-bottle rack that acted as a buffer to fill the other 3-bottle racks and guarantee that the other racks were always pressured up in this dynamic system. Each bottle rack had a number of regulators that were connected by air lines to manifolds stationed in convenient locations. Up to six workpack units were attached to each manifold by way of 50-ft hoses. The workpacks are gas masks/regulators in harnesses connected to 5-min-egress air cylinders that could be used to get out of a location in an emergency. These were usually connected to the manifolds by way of air lines and were designed to work over long periods of time. Each workpack was in a small metal box situated near work areas. The three main bottle racks were situated in strategic areas of use: by the drill floor, lab stack, and catwalk; the small one was designed for the core roof if cores needed to be cut out in the open air. The old DSDP core cutter was shipped out to use outside if the cores had H_2S concentrations too high for use in the lab stack. There were also twenty 30-min SCBA's located in key areas for use if there was an H_2S spill and areas had to be searched that were not near hose lines.

The H_2S detectors and sensors consisted of two types. The fixed sensor/detector system was a remote system with stations again mounted in strategic areas. These areas consisted of the drill floor, the H_2S van, the catwalk, the air intakes to the lab and quarters, the core lab, and the hold and lower 'tween reefer where the cores could be stored. The lower 'tween reefer also had a digital readout mounted in the reefer so the air quality could be monitored without having to go inside. These detectors each had two sensors, flashing lights, and alarms, and they sent a signal to the control panel, which was mounted on the bridge. The bridge was continuously manned and could respond instantly. Each sensor had a small antenna and broadcast to the main antenna atop the DP room, which was connected to the control panel on the bridge. The other type of detector was a small, hand-held unit. Many of these had small hand pumps with tubing that could be inserted into small areas for detection of H_2S. They were portable with warning alarms. These were used to do the initial check of the core barrel as it was pulled from the pipe, and the liner when it was extracted from the core barrel.

Among the other H_2S precautions were blackboards to be used for communication if H_2S was present; acid suits if the potentially acidic samples came up in the core liners; aluminum core liners to be used if the water got too hot and melted the butyrate liners; and an H_2S scrubbing system in the core lab. The scrubbing system consisted of two wide, low boxes with slits cut through the top. Core racks were mounted on top of these boxes, and the split cores were laid out for sampling and description. The H_2S fumes were heavier than air and so were sucked down through the slits into the boxes by a blower motor connected with hoses that blew the fumes out a porthole. The natural-gas analyzer gas chromatograph in the chemistry lab had been fitted with a more sensitive detector board to monitor the H_2S in gas samples. We also had onboard chemicals to analyze the H_2S in the pore waters.

There was an additional 25-ton A/C unit installed to provide positive pressure to keep H_2S out of the lab stack. There were four large 24-in. and 36-in. fans that could be stationed in convenient areas to dissipate H_2S concentrations.

Wide plastic strips were hung from the doors in the cutting room to try to contain the fumes there. These plastic strips are similar to those seen in cold walk-in reefers. Wind indicators were stationed in numerous areas so everyone could see at a glance what the wind was doing in each area. A 20-ft van was purchased to store cores that had H_2S concentrations too high to be brought into the lab stack. The cores could degas to a safe level in the van then be moved to the regular reefers. If H_2S levels remained high, the cores could be sent to the repository in the van. The van was never used.

All personnel received H_2S training during the transit to the first site. This training consisted of classroom-type training with workbooks as well as hands-on training with the apparatus. Everyone was shown the emergency layout of H_2S detectors and breathing apparatus. It was also mandatory that everyone put on and breathe through a workpack and a SCBA breathing apparatus. Midway through the leg we had a refresher course, when everyone again had to put on both types of breathing gear. There were weekly H_2S drills, when the majority of the people went upwind to the briefing areas, which were the lifeboat stations, while the METS and disaster team performed coordinated exercises re-creating simulated H_2S disasters.

Despite all the planning, the amount of H_2S encountered was very low. For the first half of the leg the only H_2S encountered was an occasional whiff that was too low to be detected on any of the monitors. Our coring strategy was to start with cooler holes and slowly work our way to the high-temperature holes that were likely to contain significant amounts of H_2S. At Site 858, which was located over an active hydrothermal vent, the sediment temperatures got very hot. Butyrate core liners were melting. Extruded aluminum core liners were substituted and felt warm when they were pulled from the core barrel. These aluminum liners presented new problems. You could not see through them to determine where the core started and stopped or where the gas pockets were. A "Sawzall" was used to cut the liners into lengths. Archive and working halves had to be labeled, since there were no indicating lines.

A gas pocket that was bubbling as it degassed was encountered. When the portable indicator tube was put right into the crack, the lights went off scale. Unnecessary people were ushered off the catwalk, all technicians were suited up in workpacks, and work proceeded. Gas samples were taken in vacutainers to get an idea of the concentration. The highest was about 1300 ppm. The H_2S was degassing extremely fast. The water was not acidic as originally thought but actually slightly basic. This did not cause the H_2S to come out as had been feared. Consequently, within minutes, the majority of the H_2S had degassed to low levels.

H_2S levels high enough to produce an alert happened only at three holes, and these only happened in a couple of the cores at each hole. The sediment became indurated fairly quickly, and we had to switch to rotary drilling.

The aluminum liners presented other problems. These liners had to be split using a special pneumatic saw purchased for this work. The cores also had to go through the MST track. A special GRAPE standard was made for the aluminum core liners. Magnetic-susceptibility measurements were not very accurate in the aluminum liners. Holes were drilled for thermcon needles and measurements.

A potential problem associated with vent cores was radioactive radium^{226} which can be found in barite layers near vents. Barium sulfate formed in vent areas has a half-life of 7000 years so would have been found only in the upper three to four cores. A hand-held geiger counter and a hand-held scintillation counter were used to measure cores immediately after they were cut. No radioactivity was encountered. Another possible risk was the fact that radon gas is a byproduct of radium decay. Again, this was not encountered. The sulfides that were drilled were stored in special tri-laminated foil bags. After the core half was put in this bag, the bag was evacuated and then refilled with nitrogen to form an inert atmosphere. These were then sealed and put in the D-tubes. Any cores that had H_2S were marked with yellow caution stickers to alert workers at the repository.

LABORATORY STATISTICS

General Statistics:

Site	4
Hole	22
Cored Interval (M)	2654.4
Core Recovered (M)	932.9
Maimum Penetration (M)	936.2
Number of Samples	>10,000

Samples Analyzed:

Inorganic Carbon ($CaCO_3$)	275
Total Carbon-CNHS	297
Water Cemistry (the suite includes, pH, Alkalinity, Salinity, Sulfate, Silica, Magnesium, Calcium, Chlorinity, Potassium, Phosphate, Ammonia)	260
Gas Samples	326
Thin Sections	154
XRD	451
XRF	
Majors	193
Traces	214
MST runs	980
Cryomag Runs	554
Phys Props Velocity	1131
Thermal Conductivity	448
Index Properties	473

Underway Geophysics:

Bathymetry, Magnetic (Miles)	1387
Seismic (Miles)	46

Down Hole Tools:

APC	24
WSTP	23