OCEAN DRILLING PROGRAM

LEG 139 SCIENTIFIC PROSPECTUS

Sedimented Ridges I

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

Abstract

The primary objectives of ODP Leg 139 are to characterize the fluid flow and geochemical fluxes within a sedimented rift hydrothermal system, and to investigate the processes involved with hydrothermal discharge and associated alteration and mineralization. To address these objectives, a two-leg program has been designed. This first leg (Leg 139) will establish an array of several holes to characterize the hydrothermal regime on a "basin" scale, and begin a program of detailed drilling in two zones of mineralization and discharge. Deepening of one or more of the reentry holes established during this leg and more detailed drilling within the discharge zones will be carried out during a second leg, not yet scheduled by the JOIDES Planning Committee. High temperatures will be encountered in many of the holes. This will provide operational challenges, although it is anticipated that most of the objectives of the program can be realized through a carefully designed drilling and logging strategy that requires the use of only a few special tools.

Background and Objectives

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 this drilling program are:

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.

Leg 139 will address both of these objectives but will concentrate principally on the first. A second leg in Middle Valley and the Escanaba Trough, which has been planned but not yet scheduled, will concentrate primarily on the second objective.

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 and 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.

Heat flow measurements in the valley (Fig. 4) have been combined with estimates of sediment thickness from seismic reflection data (Fig. 5) to give estimates of temperatures at the sediment/basement interface (Fig. 6). Figure 7 shows magnetic-field contours of the investigated area. There is a general tendency for basement temperatures 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. Estimated temperatures also decrease in the northern part of the survey area, where high sedimentation rates may cause the simple estimates of basement temperature to be erroneously low, and in the southern part of the area, where the sediments are probably too thin to prevent advective heat loss. Elsewhere, temperatures range from ~150° to 350°C. At a few isolated points, estimated temperatures exceed 350°-400°C. These estimates are probably erroneously high. Fluid discharge through the sedimentary section is known to occur at two of these locations, at temperatures up to 286°C, and thus the assumption of conductive heat transfer used to calculate temperature profiles from the surface heat flow measurements breaks down.

At the present time, the most vigorous hydrothermal discharge occurs above a small buried basement edifice, which is the location of proposed site MV-1 (Figs. 3 through 6, 8b, 11a). This area is associated with conductive heat flow values ranging from 2 to over 20 W/m^2. Numerous isolated chimneys vent high-temperature fluids, and areas with active vent fauna communities have been observed. These and other small sulfide outcrops occur in a rift-parallel zone roughly 800 m long and 300 m across, with 10 m of relief (Figs. 3, 8b, 11a). Detailed piston coring shows that the amount of sulfide deposited at the seafloor in this area is minor, although large lateral gradients in the degree of alteration of the upper 4 m of sediment are present. Cores recovered from the center of this zone are highly altered and have been dewatered by heating to the point that sediments from depths of less than 3 m are semi-indurated. Sediments just tens of meters away are relatively unaltered. The hydrothermally altered sediments are weakly mineralized with disseminated pyrite and contain secondary carbonate concretions. The lack of surficial topography suggests that the basement edifice predates and is simply buried by the overlying sediment section. The amount of burial is poorly constrained by the seismic data (Figs. 3, 8b, 10a, 11b); a maximum estimate is 120 m.

A second area of current hydrothermal discharge occurs just south of a large sediment/sulfide dome, referred to below as Bent Hill (also the location of proposed site

MV-2). Bent Hill is a circular feature ~600 m in diameter that rises 40-50 m above the relatively flat floor of Middle Valley, with a less prominent elongate feature ~10 m high situated ~300 m to the south (Figs. 3, 8b, 10a, 11b). Several domes having similar morphology and dimensions occur in this part of the valley (Fig. 11). All appear to be the result of lacolithic intrusions within the sediment section. Photography and sampling show the domes to be ringed by outcrops of semiconsolidated mud and minor occurrences of massive and dispersed sulfides. The southern flank of Bent Hill is covered by an area of outcropping pyrrhotitic massive sulfide. These outcrops extend southward along the less prominent elongate mound toward an area of localized high heat flow and current venting (Fig. 11). Although the sulfides overlie an area with high projected temperatures at the sediment/basalt interface, the major-element composition of the sulfides (Pb-poor), the Pb isotope ratios of sulfide, and the Sr isotope ratios of barite are consistent with formation from a fluid that equilibrated with predominantly basaltic source rocks.

Drilling Strategy

To address the scientific goals of the sedimented ridge drilling program, three types of holes will be drilled:

1. Non-reentry holes that will be drilled down as close to the sediment/basement interface as possible (to 500 mbsf). The unconsolidated and semiconsolidated sediment in the upper part of the section will be cored by APC/XCB tools; the highly indurated sediments expected in the lower part of the sedimentary section will be RCB-cored.
2. Reentry holes that will penetrate into basement, and be cased at least partially to basement. These holes will be drilled at least a short distance (~50 m) into basement during Leg 139; at least one will be deepened substantially into basement (>500 m) during the proposed second leg to this area.
3. Shallow (<100 m), closely spaced holes across sulfide bodies to sample and define their structure in three dimensions.

In order to characterize the fluid flow and geochemical fluxes in the Middle Valley hydrothermal system an array of eight sites has been selected, including three alternate sites (Table 1). The highest priority is MV-3, a basement reentry site which has the objective of drilling into the high-temperature reaction zone of this active system. A reentry hole at MV-3 is targeted to drill ~50 m into basement during Leg 139 and will penetrate a well-defined heat flow high near, but not directly on, an active vent area. Complementing this site is an array of four additional sites designed to define the three-dimensional pattern of fluid flow over a 100-200 km^2 area. The main objective of holes at these sites is to characterize the hydrogeology of this hydrothermal system following drill penetration into a few tens of meters of permeable basement.

The proposed sites are located in areas of high and low heat flow within both active discharge and potential recharge zones. Three of these sites will include holes that will be outfitted with reentry cones for potential subsequent deepening into basement to address both magmatic and hydrothermal problems. At four of the five sites an extensive program of logging, fluid sampling, and borehole experiments is planned, and the three reentry holes will be sealed for hydrogeological and geochemical monitoring and sampling. Locations of these sites are shown on the maps in Figures 3 through 6 and 11, and along single- and multi-channel seismic profiles in Figures 8 through 10.

To begin the investigation of the processes and products of hydrothermal discharge, detailed arrays of shallow holes will be drilled at two sites, MV-l and MV-2. Where the sediment is sufficiently compressible, drilling will begin with APC coring. In many locations, indurated sediment or massive sulfide may outcrop at the seafloor, and XCB or RCB drilling will have to commence immediately. It is planned that acoustic beacons will have been well located with respect to a previously established acoustic transponder array that was used for acoustic and visual mapping of the areas. Thus, holes can be precisely sited without using a TV camera.

Site Descriptions

Proposed sites MV-l and MV-2 are located in currently active hydrothermal discharge areas. MV-1 will be the location of a basement reentry hole. Vents here are discharging water at up to 286°C and local basement temperatures are estimated to be in excess of 300°C. Measured heat flow ranges from 2 to 24 W/m^2. Depth to basement in the vicinity of the vent field is ~400 m. Directly beneath the peak of the heat flow anomaly and the hydrothermal field, a local basement edifice rises to within about 120 m, or less, of the seafloor; above that level sediment reflectors are disturbed, but it is not clear whether this is due to hydrothermal induration (the surficial sediments are highly indurated in this area) or to the presence of volcanic rock.

Proposed site MV-2 is located in an area where massive sulfide deposits occur in near-surface sediments on the southern flank of Bent Hill. The mound is cored by a small reflective structure 120 m below the surface. The drill site is located just north of the conductive heat flow peak at ~5 W/m^2, where an active chimney has been sampled. The underlying sediment is relatively undisturbed to the depth of the small sill or volcanic edifice inferred to be at about 120 mbsf. Basement depths in the vicinity are ~250 m.

Proposed site MV-3 is located within the same thermal anomaly as site MV-1 but where no local basement edifice is visible. Heat flow at the site is ~1.0 W/m^2, sediment thickness is ~470 m, and the temperature at basement is estimated to exceed 300°C. It is anticipated that the deep hole at this site will penetrate a section of sediment where temperatures are high but where conductive heat transport dominates, and intercept a "reservoir" zone of high-temperature fluid in basement. This site is also a candidate for later, deep reentry basement penetration.

Alternate site MV-4 is located where basement temperatures are also expected to be high and fluid flux through the sediments low. This site lies near the center of the rift valley where the heat flow is about 0.4 W/m^2, the sediment thickness is 650 m, and the basement temperature is estimated to be over 200°C. Site MV-4 is about 4 km away from sites MV- 1 and MV-3.

Alternate site MV-5 and primary sites MV-6 and MV-7 are located between the high-temperature discharge site at MV-l and the normal faults which bound the valley. Basement temperatures decrease systematically toward the faults (minimum estimates: 150°C at MV-5, 80°C at MV-6, and 60°C at MV-7). This pattern could result from hydrothermal recharge of seawater through the basement outcrops at the normal fault scarps that bound the valley, and perhaps through the thinner sediments that fill this part of the valley.

Alternate site MV-8 is located over a recent and clearly imaged sill that has intruded the upper part of the sediment section in the center of the valley. Either the emplacement of the sill or deeper volcanic activity has deformed the sediment surface; this places the age of the activity at less than 8 ka. No heat flow anomaly is observed over this structure, which constrains the age to be younger still. The depth to the sill, which is the target at this site, is roughly 500 mbsf. Although the surface heat flow is relatively low, the temperatures at the level of the sill may be in excess of 300°C.

Expected Results

A great deal of information about the hydrologic system active in Middle Valley should be gained with this array of sites. The influence of sediment thickness on regional recharge can be determined by sampling and logging sediment sections that are away from discharge sites and that have a wide range of thickness (as little as 250 m at proposed site MV-7, 400 m at MV-5, and 650 m at MV-4). The importance of local recharge at fault scarps can be investigated by determining fluid chemical gradients and physical conditions in basement along the profile from site MV-7 to site MV-3. Temperatures, permeabilities, fluid chemistry, and pressures at all of the diverse sites will provide important new constraints for models of hydrothermal flow in basin settings. Observations in possible high-temperature fluid reservoir zones at sites MV-3 and MV-4 and directly beneath discharge sites MV-l and MV-2 will provide important information about the source region for the fluids that produce massive sediment-hosted sulfides. The role that intrusive and extrusive volcanics within the sediment section play in enhancing permeability can be examined at sites MV-1, MV-2, and MV-5. The influence of faults on permeability can potentially be examined if holes at site MV-7 can be drilled to intersect the eastern boundary normal fault.

In addition to these objectives, the suites of shallow holes to be drilled at discharge sites MV-1 and MV-2 will address problems associated with sulfide deposition. These include the temporal and spatial variations in depositional mechanisms within the sulfide mounds and in the subsurface, and the nature and consequences of subsurface flow of hydrothermal fluid and heated pore fluids entrained in the upper part of hydrothermal discharge zones. Closely spaced drilling across active and inactive sulfide deposits will also delineate the extent of alteration and determine the geochemical reactions which control alteration. Specifically, these holes will establish the relative effects of high-temperature metalliferous fluid, vs. locally advecting seawater and heated pore water, on the mineral assemblages in sediments adjacent to vent sites. Hydrothermal alteration and transfer of heat into sediments in the upflow zone changes the physical properties of the sediment, inducing dewatering and fracturing. These changes influence the relative importance of movement of hydrothermal fluids along beds with high primary permeability (i.e., turbidites) vs. the movement of fluids along thermally or tectonically induced fractures. The local subsurface plumbing affects the cooling and mixing rates of subsurface hydrothermal fluids and therefore the mechanism and extent of sulfide deposition and alteration within the sediments.

Drilling at the Middle Valley sites will also provide important controls on fluid/rock ratios, fluid residence times, and reaction rates. The high-temperature alteration mineralogy in the deeper source region is distinct from the shallow alteration zones that form below sulfide deposits in hydrothermal upflow zones. The deeper alteration and metamorphism should record the chemical exchange between seawater and the upper oceanic crust. This drilling will address the differing responses of sediment and basalt to high-temperature hydrothermal interaction.

Downhole Measurements During Leg 139

To meet the highest priority objectives of Leg 139, a variety of downhole measurements are planned. Because of the high formation temperatures and corrosive fluids expected at most sites (Fig. 12), several special tools are scheduled for use during Leg 139. Important measurements include subbottom formation temperatures, pore pressures, and fluid fluxes, as well as formation chemistry, sonic velocity, porosity, and resistivity in sedimentary and igneous sections. In the upper part of the sedimentary section, temperatures will be measured as frequently as possible with the APC temperature coring shoe (APC tool), and the water sample, temperature, and pressure (WSTP) tool. Both of these tools have recently undergone redesign and upgrading and will appear in their final forms for the first time during this leg. A slim-hole, high-temperature Japex pressure, temperature, fluid-flow (PTF) logging tool is also expected to be on board; this tool should operate at temperatures to 375°C.

The PTF tool will be run first in all holes that are to be logged. Because it will not require hole cooling during operation, this tool can be run without installing the sidewall entry sub (SES) in the drill string. Because high borehole temperatures are anticipated, however, a section of special logging cable will have to be added for this leg. The results of

PTF logs will be used to determine the strategy for logging with other tool strings which are not designed to operate at temperatures above 165°C. If PTF logs indicate that temperatures in the hole will remain below 150°C for the following 36 hours, then standard procedures can be used for logging with the other tools, and the SES would be necessary only if the hole is expected to be unstable. If PTF temperature profiles indicate that the hole has recovered, or will soon recover, to temperatures in excess of 150°C, then the SES will be installed in the string to assist with hole cooling during logging. The hole will be cooled initially by rapid circulation. Then, with the end of the pipe held close to total depth in the hole, logging will proceed. The tool string will hang just below the end of the pipe and follow the drill pipe up the hole while circulation is maintained.

Standard logs

The standard logs consist of four combination tool strings. The seismic-stratigraphy string, the litho-porosity string, the geochemical string, and the formation microscanner. In some cases, several of the tools from the first two strings will be combined into a "quad-combo" string, which excludes either the neutron porosity or lithodensity tools. These tool strings are leased from and run by the Schlumberger logging subcontractor; the tools included in each string are listed below.

I. Seismic-stratigraphy string
- Natural (spectral) Gamma Tool (NGT)
- Long Spacing Sonic Tool/Digital Sonic Tool LSS/SDT
- (Phasor) Dual Induction Tool/Shallow Focus Resistivity Tool (DIT/SFL)
- Caliper (CALI)

II. Litho-porosity string
- Natural (spectral) Gamma Tool (NGT)
- Compensated Neutron Porosity Tool (CNT-G)
- High-temperature Lithodensity Tool with Caliper (HLDT/CALI)

III. Geochemical string
- Natural (spectral) Gamma Tool (NGT)
- Aluminum Activation Clay Tool (AACT)
- (Induced) Gamma Spectrometer Tool (GST)

IV. Formation-microscanner string
- Natural (spectral) Gamma Tool (NGT)
- Formation Microscanner (FMS)
- General Purpose Inclinometer Tool (GPIT)

Several specialty tools will require a separate lowering on the wireline. These tools include the digital and analog borehole televiewers (BHTV), the dual laterolog, the multichannel seismic tool, and the wireline seismic tool (WST), which is run for vertical seismic profiles (VSP). Generally these tools have a lower temperature rating than the standard tools. The WST is run by Schlumberger and the remaining tools are provided and run by the Borehole Research Group at Lamont-Doherty Geological Observatory.

Several other special tools are scheduled for deployment during Leg 139, including the drill string straddle packer, and high-temperature borehole fluid samplers from Los Alamos National Laboratory and/or the Lawrence Berkeley Laboratory. The packer will also be used in conjunction with a third-party spinner-flowmeter system to determine the detailed permeability structure in several boreholes. Finally, several holes will be instrumented with a thermistor string and pressure sensor. These holes will be plugged with a removable seal, through which fluids and data can be sampled later by either a remotely operated vehicle or a submersible.

Operational Plan

JOIDES Resolution will leave San Diego on 10 July 1991 and steam toward proposed site MV-7, with a transit of 4.5 days. We will come on site using GPS and/or an Oceano transponder net currently in place, and will drop additional beacons. MV-7 will be drilled and cored first, with an extensive series of shallow APC/XCB and RCB holes, and then with a deeper reentry hole.

Initial operations at this site will be done in a non-standard sequence. Three RCB holes will be drilled first to tag (A, B) and penetrate (C) basement. These holes will be closely spaced (50-100 m) along a line perpendicular to the normal fault scarp at this location, with the goal of intersecting basement at three different depths where the normal fault forms the contact between sediments in the hanging wall and basalts in the foot wall. After the third RCB hole is drilled, the bit will be dropped and logging will begin with the PTF tool. A full suite of logs will follow, including standard strings (litho-porosity, geochemistry, seismic stratigraphy, FMS) and the dual laterolog. One or more borehole fluid samples may be collected as well.

Results from the first three holes will help to constrain the geometry of the fault so that holes D, E, F, and G can be optimally sited. The APC/XCB holes D, E, and F will be drilled in a similar, possibly interspersed array with the goal of determining the thermal and geochemical variations within the sediment above the dipping fault surface.

Frequent WSTP deployments will be made in the sedimentary section while drilling all non-reentry holes. The new APC (temperature) tool will be used extensively at this and all sites where APC coring is scheduled. Finally, a 250-m reentry hole (G), with standard cone and casing, will be drilled and extended ~50 m into basement. The reentry hole will be sited at a position where the inferred fault plane is fully within basement. After coring in basement is completed, a full suite of downhole measurements, including fluid sampling, temperature logs, and packer/flowmeter tests are scheduled. Finally, the cone will be plugged with an instrumented borehole seal.

We will next move to proposed site MV-2 to core a series of shallow holes into a sulfide deposit. Five holes are currently scheduled, all cored by APC/XCB to a maximum depth of ~120 mbsf with frequent WSTP deployments. No logging is planned at this site.

Operations at proposed site MV-3 will include emplacement of a second reentry system and borehole seal. Coring at MV-3 will begin with an APC/XCB pilot hole and an RCB exploratory hole, both with frequent WSTP deployments. A full suite of temperature and standard logs will be collected in the RCB hole following termination in basement, after the bit is dropped. A complete reentry cone and casing system will be deployed, with casing extending to a depth of ~260 mbsf (well into expected indurated sediments). Additional drilling will extend this hole ~50 m into basement. A full suite of downhole measurements will then be run, beginning with a borehole water sampler and PTF log, followed by standard Schlumberger logs, digital BHTV, VSP, and packer/flowmeter tests. The cone will then be plugged with an instrumented borehole seal.

Proposed site MV-1 will be drilled and cored next, beginning with four shallow APC/XCB holes to a maximum depth of ~120 mbsf. These holes are being drilled in part to determine the location of the shallowest basement at which a complete reentry assembly can be set. The sediment thickness, and thus the depth of each hole, will vary as a function of location relative to basement structure and massive sulfide bodies, with a probable range of 50-120 m. The APC and WSTP tools will be used at this site while temperatures are sufficiently low, and one or more of the holes will be logged, if possible, with the high-temperature logging tool. A single-bit RCB exploratory hole will be drilled next, to complete sampling above basement and to determine the depth to basement for the reentry cone and casing. The position, and so the sediment thickness, at the reentry hole will be constrained by the minimum amount necessary to set a reentry cone, probably ~50 m. The cone and casing will be emplaced next, and the hole will be drilled out to ~110 mbsf. A complete series of downhole measurements (nearly identical to that at proposed site MV-3) is planned to follow coring.

It is planned that some of the operations at sites MV-1, MV-3 and MV-7 will be staggered to allow for partial thermal equilibration of cased sections of the reentry holes before the cemented casing shoe is drilled out so that reliable temperature logs can be run. These operations are described more fully in the next section of this prospectus (Special Operations).

Proposed site MV-6 will be drilled last during Leg 139. A single hole will be cored using a RCB bottom-hole assembly. This hole is intended to penetrate only the uppermost portion of basement, at a depth of about 420-450 mbsf. The bit will be dropped and the hole logged with the PTF tool, followed by the standard Schlumberger suite. Operations will be terminated at site MV-6 when the time for Leg 139 is exhausted, and the ship will steam for Victoria, B.C., arriving after a 0.9-day transit on the morning of 11 September 1991.

Special Operations

Because of the unknown properties of the indurated sediments and sulfide rocks that will occur at proposed sites MV-1 and MV-2, special care must be taken in the use of both the APC and XCB tools, both to avoid damage to the tools and to optimize core recovery. Variables to consider will include the peak force and velocity of the APC barrel, and the type, rotation rate, circulation rate, and minimum extension of the XCB bit. To measure temperatures and collect formation fluids during breaks in drilling operations in non-reentry holes, a means to pass the slim-line PTF tool and water samplers through APC/XCB and RCB bits, without the use of a lockable flapper valve, will also be required. For safety reasons, these tools will be run with the bit held in the holes near the seafloor, and only if there are no indications of there being up-pipe flow.

Temperatures at depth at sites MV-1 and MV-3 will probably be high. Standard logging under these conditions will require the use of the SES so that the temperatures in the vicinity of the logging tools can be kept low by continuous circulation. Runs of the high-temperature PTF tool will be done prior to any logging to ascertain that the hole can be kept cool in this manner (e.g., that vigorous up-hole flow has not been stimulated by the existence of the hole).

To allow time for partial thermal reequilibration of reentry holes, there may be a break between the setting and cementing of the casing strings, and later deepening. The plan for operations at each reentry site is as follows: the reentry cone and conductor casing will be installed in the standard way, and the hole below drilled out to the desired depth. Following installation and cementing of casing, the hole will be backfilled with a high-viscosity or thixotropic fluid and logged with the PTF tool; the ship will then move on to the next site and begin work. The mud left in the reentry hole will reduce the tendency of the fluids in the hole to convect but will not damage the geochemical environment around the hole because the hole will be lined with casing and cement. After some time has passed, the ship will return to the reentry site and operations will continue with a repeat PTF log before the hole is flushed and deepened. A final run with the PTF and fluid sampling tools will be completed after bit wear prevents further penetration, and then the remaining logs will be run. When all other operations are complete, an instrumented borehole seal will be emplaced in the reentry cone.

Cores collected during Leg 139 will be stored in an oxygen-free environment to prevent degradation. Both archive and working halves will be placed in air-tight bags inside standard D-tubes and flushed with nitrogen before sealing. These and other special procedures will be carefully integrated with additional safety procedures to assure efficient core flow in the labs.

Safety Considerations

As the drilling and coring operations of Leg 139 will penetrate into known sites of hydrothermal activity, extraordinary safety precautions will be necessary to protect against hazards of hydrogen sulfide (in the borehole and in the cores) and steam flash from superheated borehole fluid. Safety measures are set forth in the *Hydrogen Sulfide--High Temperature Drilling Contingency Plan* compiled by the Ocean Drilling Program and SEDCO-FOREX. The plan will be submitted and approved by the Canada Oil and Gas Lands Administration (COGLA) prior to the commencement of the leg.

Specific measures will include installation of equipment such as H_2S detectors and alarms, ventilation equipment, portable breathing apparatus, and drill-string safety valves; extensive training and drills for shipboard personnel in steam blowout and H_2S emergency procedures; and special handling and storage procedures for cores containing dangerously high levels of H_2S.

In addition to these personnel-safety considerations, special precautions will be taken to protect drilling and logging tools from the effects of high downhole temperatures, corrosive fluids, and H_2S embrittlement. Equipment precautions include the use of extra circulation of cold seawater and of H_2S scavengers; these are detailed in the *Leg 139 Engineering and Operations Planning Document.*

The occurrence of hydrocarbons in the cores also will be monitored closely. Though chances of encountering a significant accumulation of hydrocarbons are small, the environment is favorable for the generation of thermally matured petroleum. The standard operational guidelines of the JOIDES Pollution Prevention and Safety Panel will be employed to minimize the chances of encountering significant accumulations of hydrocarbons.

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Table 1. Summary Site Information, Leg 139

Site	Latitude (N) Longitude (W)	Water Depth	Penetration* Sed.	Bsmt.	Drilling	Logging (days)	Total
Leg 139 departs San Diego on 10 July 1991							
MV-7	48°26.62' 128°38.55'	2480	250	50	12.3	5.8[1]	18.1
MV-2	48°26.96' 128°40.86'	2430	120	---	4.4	0.0[2]	4.4
MV-3	48°26.62' 128°42.65'	2450	470	50	9.9	6.1[3]	16.0
MV-1	48°27.40' 128°42.50'	2440	50-120	60	9.7	3.4[1]	13.1
MV-6	48°27.00' 128°40.43'	2470	420	<50	5.8	1.5[4]	7.3
Leg 139 returns to Victoria on 11 September 1991							
Alternate Sites:							
MV-2 (reentry)	48°26.96' 128°40.86'	2430	120	50	5.9	3.4[1]	9.3
MV-4	48°27.45' 128°46.28'	2450	650	50	13.0	4.4[1]	17.4
MV-5	48°27.15' 128°41.58'	2450	400	50	6.4	2.1[4]	8.9
MV-8	48°30.00' 128°45.20'	2540	500	---	7.9	2.5[4]	10.4

*N.B. The penetrations given here do not imply that permission has been given to drill to these depths. Drilling in any hole will be curtailed if the Operations Superintendent believes that the temperature, H_2S, or other conditions encountered could unreasonably risk the safety of the operation.

[1] Downhole tools include standard logging suite, DLL, PTF tool, borehole fluid sampler, packer/flowmeter, WSTP and APC tools, and instrumented borehole seal.
[2] Downhole tools include WSTP and APC tools.
[3] Downhole tools include standard logging suite, DLL, PTF tool, borehole fluid sampler, VSP, packer/flowmeter, WSTP and APC tools, and instrumented borehole seal.
[4] Downhole tools include standard logging suite, PTF, WSTP, and APC tools.

Table 2. Leg 139 Drilling Schedule

Leg 139 begins with port call in San Diego on 5 July 1991,
departing San Diego on 10 July 1991.

			Time on Site (days)	Transit Time (days)	
Transit from San Diego to MV-7					4.5
Arrive	MV-7	14 July	18.1		
Leave	MV-7	23 July			
Transit from MV-6 to MV-2				0.1	
Arrive	MV-2	23 July	4.4		
Leave	MV-2	27 July			
Transit from MV-2 to MV-3				0.1	
Arrive	MV-3	28 July	16.0		
Leave	MV-3	12 August			
Transit from MV-3 to MV-1				0.1	
Arrive	MV-1	12 August	13.1		
Leave	MV-1	25 August			
Transit from MV-1 to MV-6				0.1	
Arrive	MV-6	25 August	5.9		
Leave	MV-6	11 September			
Transit from MV-6 to Victoria					0.9
Arrive	Victoria	11 September 1991			
			Total Time	63.0	

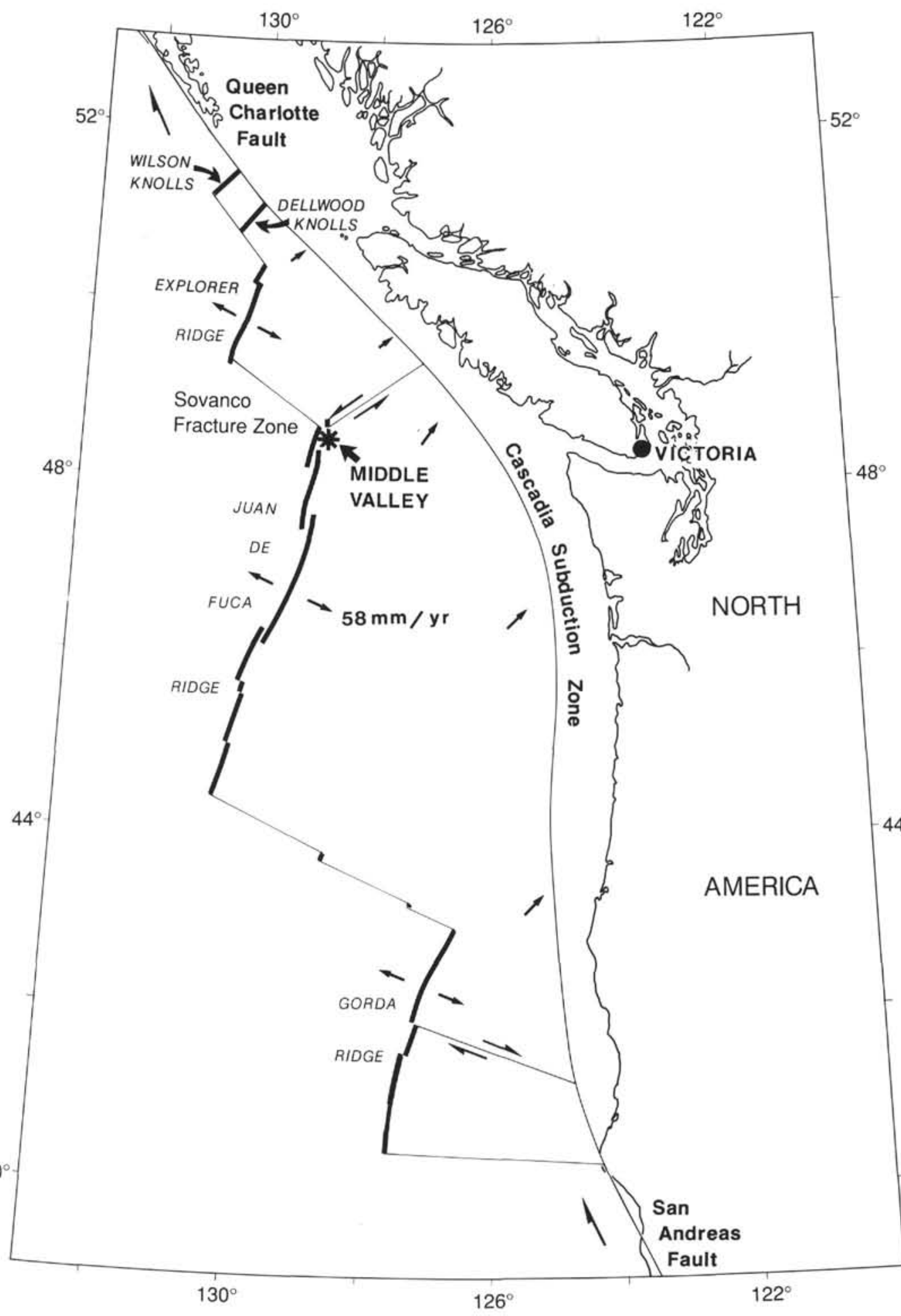


Figure 1. Location map for the Middle Valley drilling program.

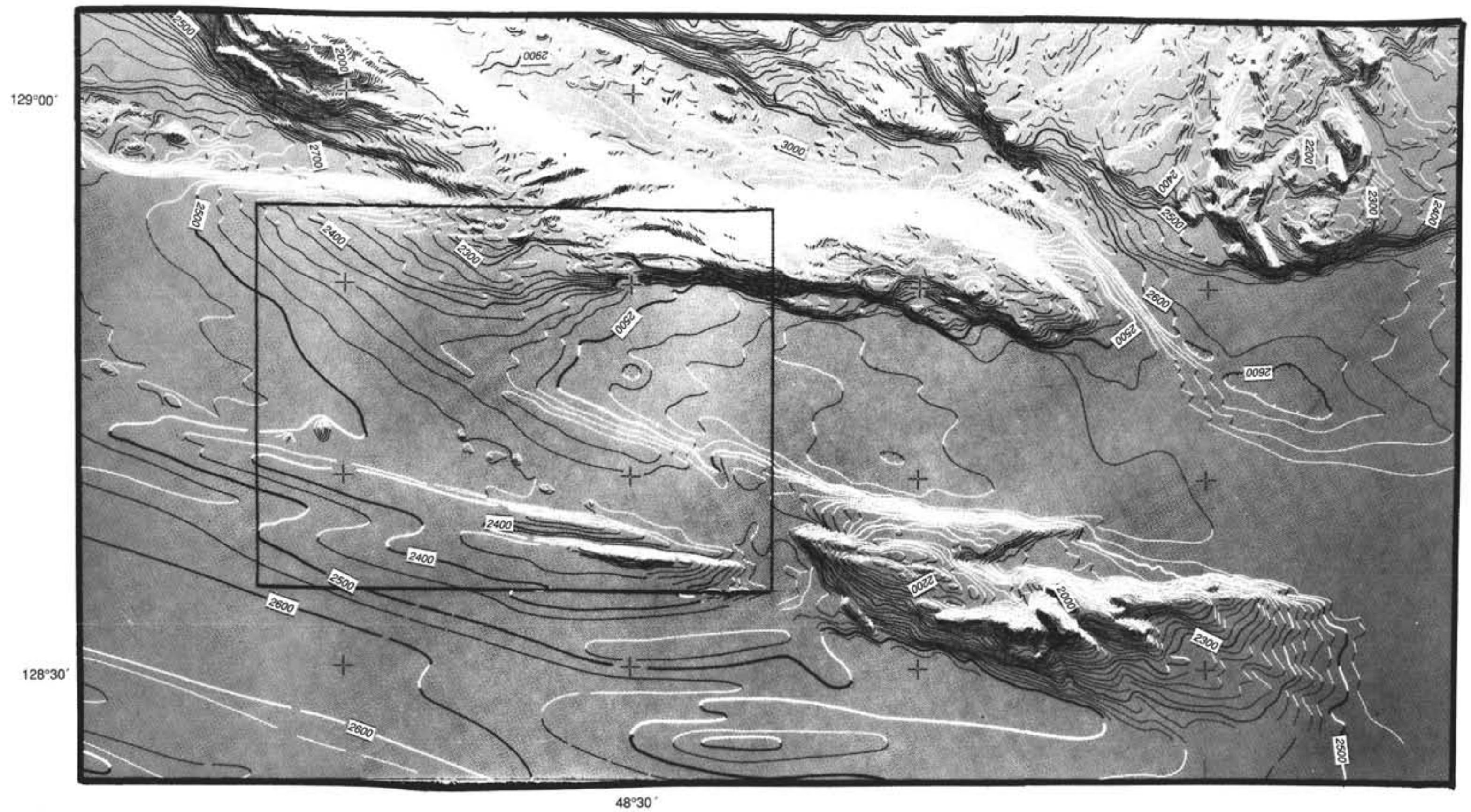
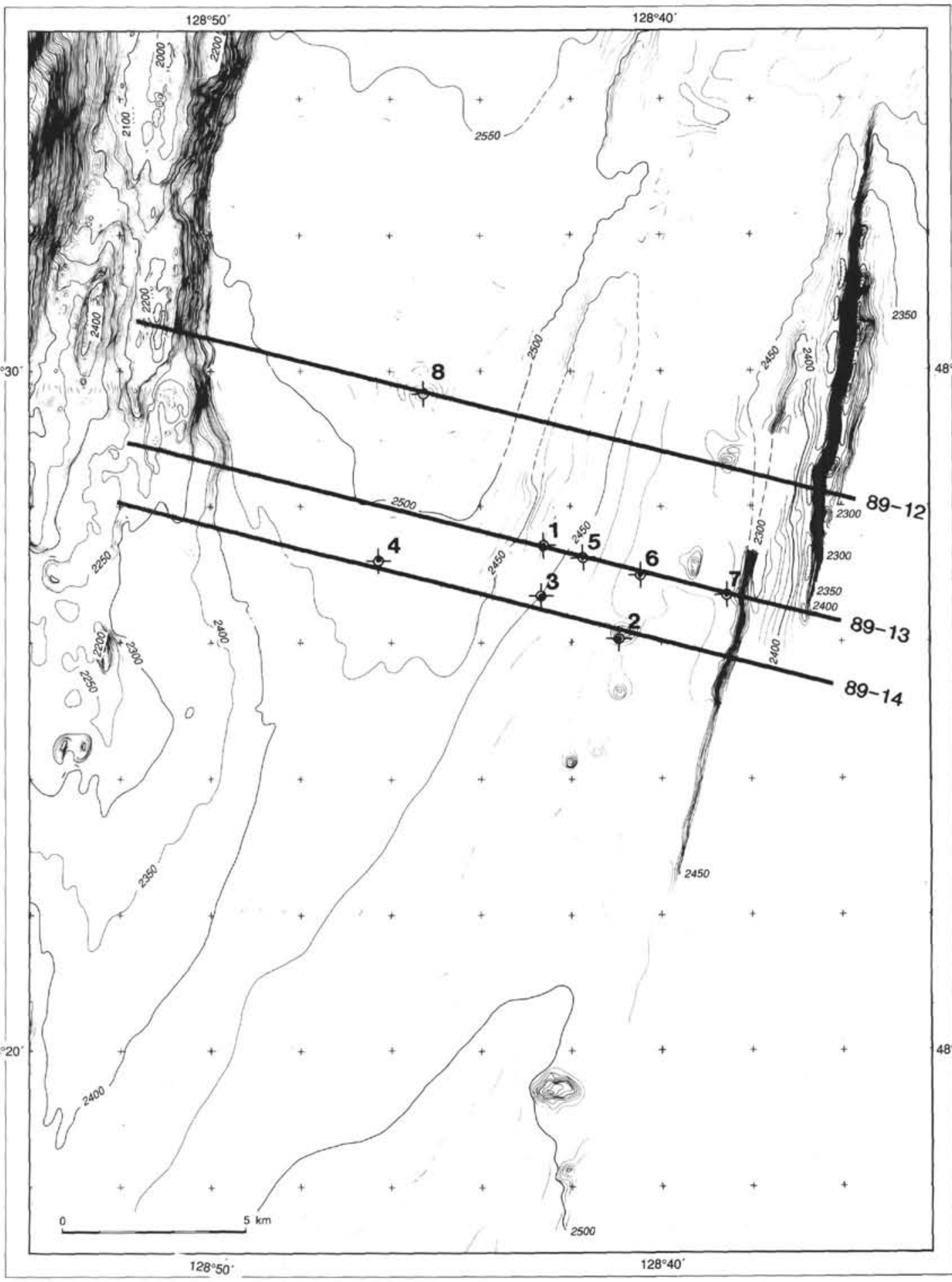


Figure 2. Seabeam-derived bathymetric map of Middle Valley, northern Juan de Fuca Ridge, with contours shown at 20 m intervals. The area shown in Figures 3-7 is outlined.



BATHYMETRY (UNCORRECTED METERS)

Figure 3. Seabeam-derived bathymetry of the area outlined in Figure 2, with contours shown at 10 m intervals. Locations of primary and alternate drilling sites MV-1 through MV-8 are shown, as are tracklines of the multi-channel seismic reflection profiles shown in Figures 9 and 10.

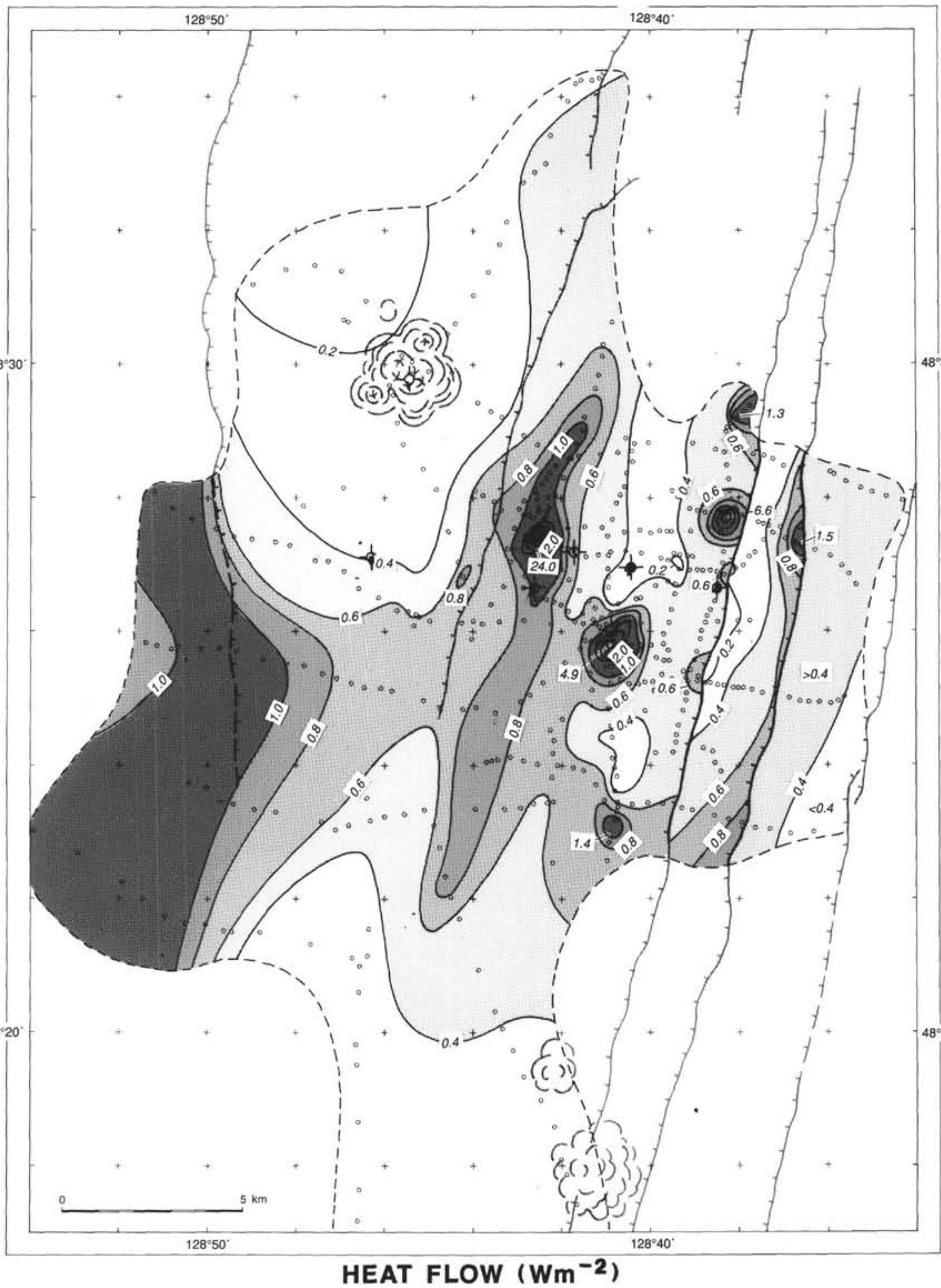
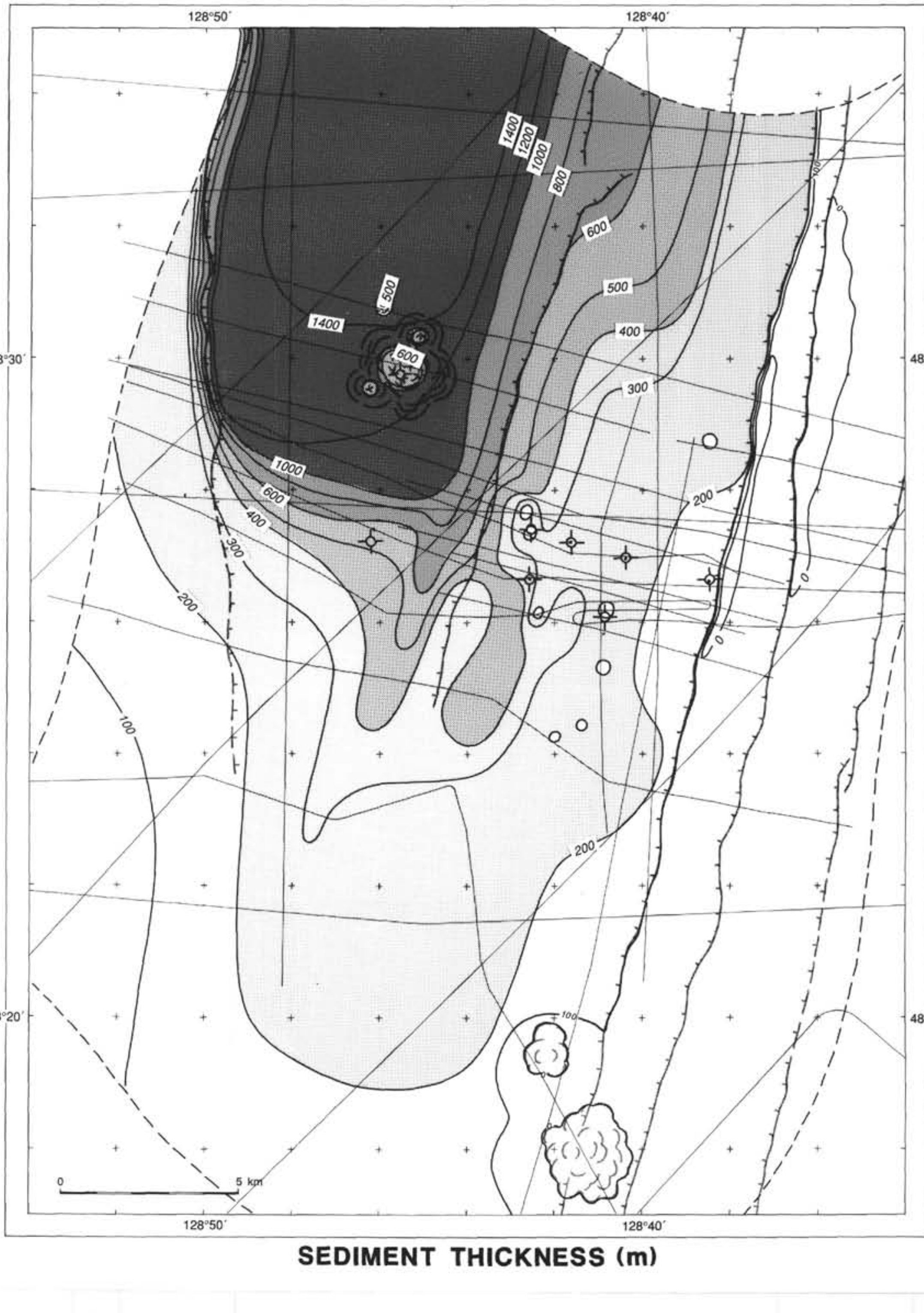
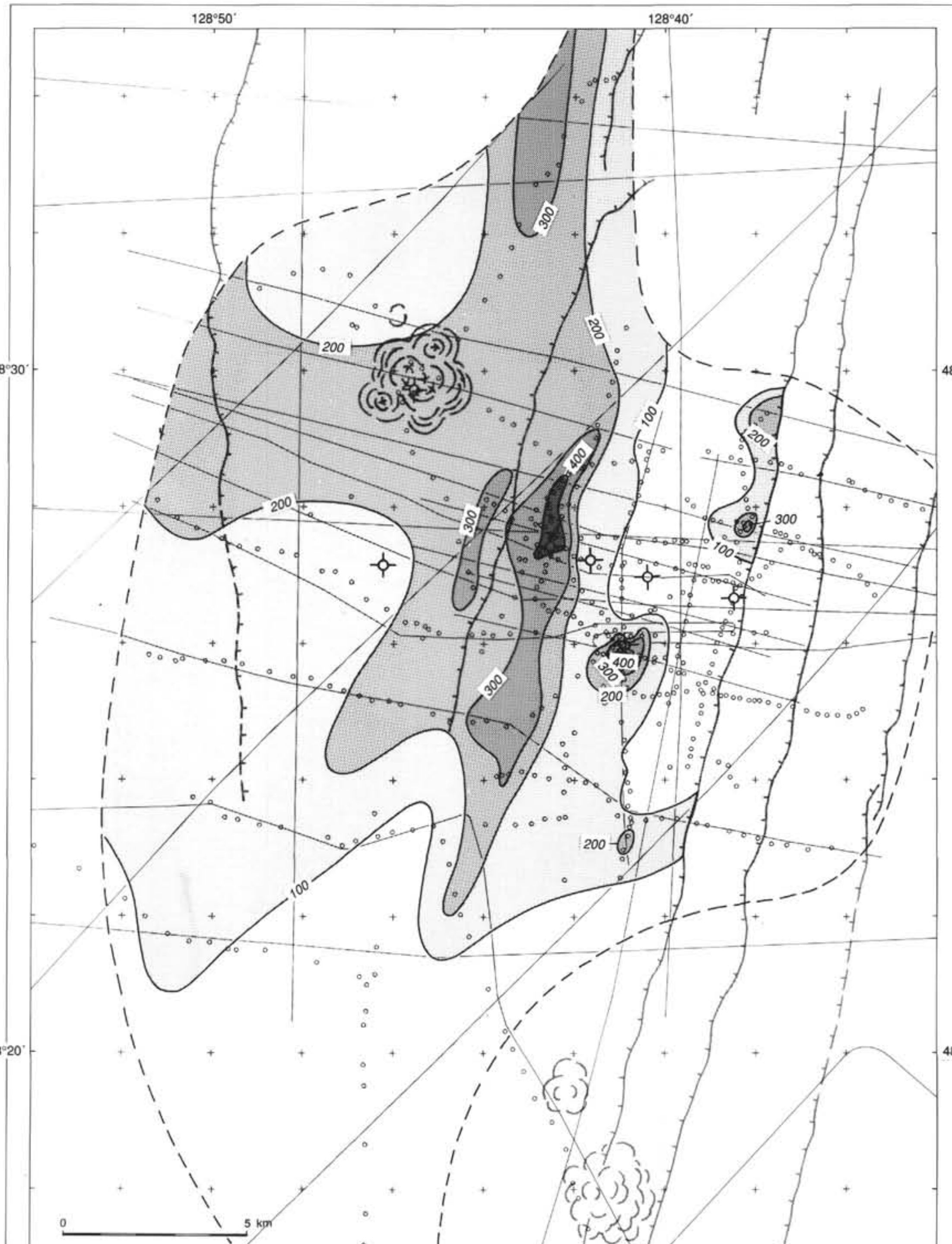


Figure 4. Contoured heat flow in the same area of Middle Valley as shown in Figure 3. Measurement locations from which the contours were derived are shown by open circles. Proposed drill sites are also shown.



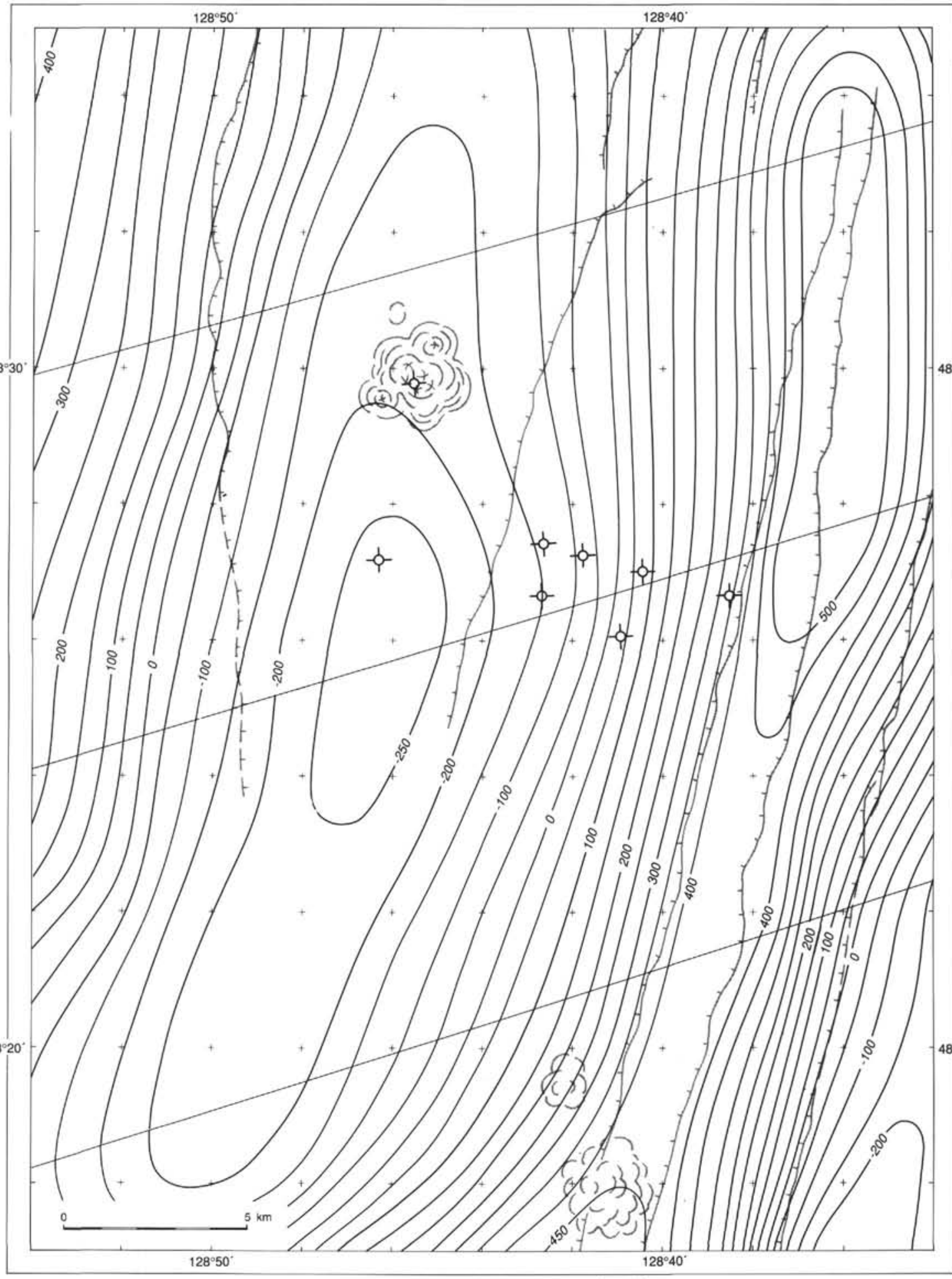
SEDIMENT THICKNESS (m)

Figure 5. Sediment thickness in Middle Valley estimated from single-channel seismic reflection profiles located along the tracklines shown. Because of the limited power and relatively high frequencies of the sound sources used, the isopachs shown provide only a lower limit for the depth to basement. Numerous sills can be seen interbedded with sediment deeper in the section in lower frequency multi-channel data (Figures 9 and 10). Depths to "true" basement cannot be well resolved.



BASEMENT TEMPERATURE (°C)

Figure 6. Temperatures estimated for the minimum-depth basement surface shown in Figure 5. Effects of thermal transients or advective heat transport have been ignored. Because of these effects, and the likelihood that the basement depths are significantly underestimated, the temperatures shown probably do not correctly represent the temperatures of hydrothermal fluids where convective heat transport dominates.



MAGNETIC FIELD (nT)

Figure 7. Magnetic field anomaly over Middle Valley, contoured in 50 nT intervals. The valley is centered in the Bruhnes normal-polarity chron, the eastern boundary of which is visible in the southeastern corner of the map. The localized negative anomaly over the valley itself is believed to be due to the persistent high temperatures and the high degree of alteration of the sediment-sealed crust.

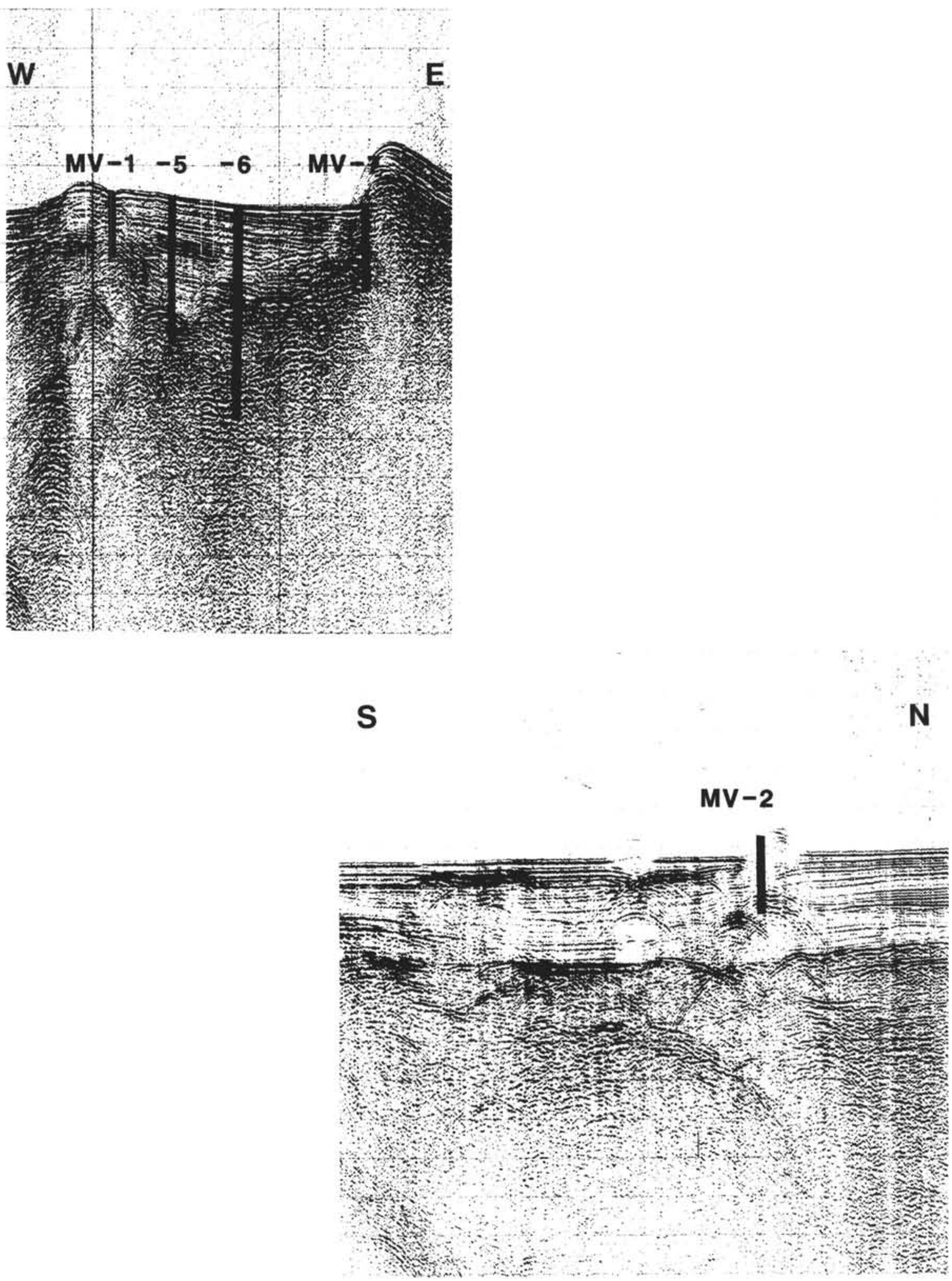


Figure 8a. Single-channel (650 cm^3 airgun source) seismic reflection profiles across Middle Valley drilling sites. Tracklines of the profiles are shown in Figure 5. Location and anticipated maximum penetration depths of drilling sites are superimposed on the seismic sections.

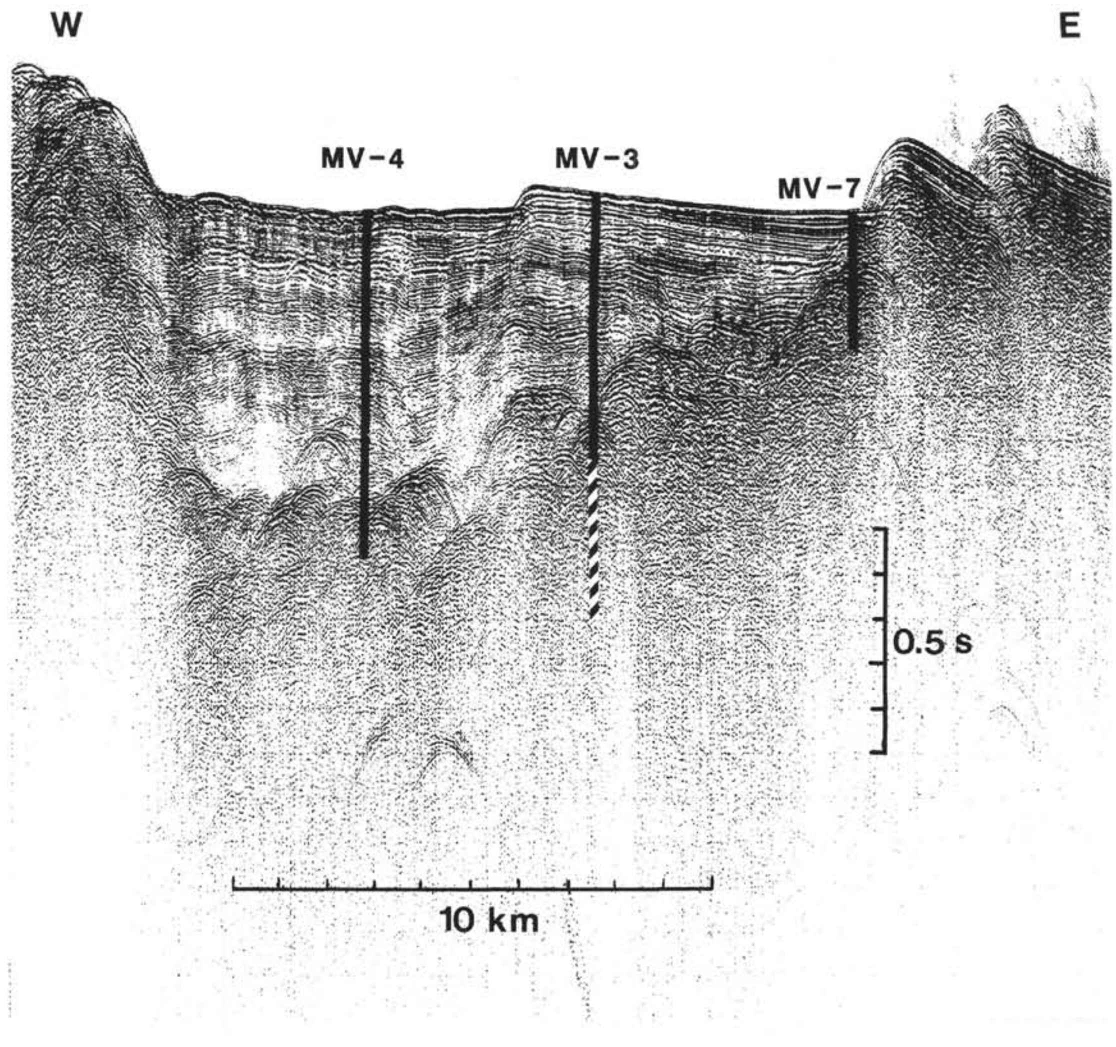


Figure 8b. Single-channel (650 cm^3 airgun source) seismic reflection profiles across Middle Valley drilling sites. Tracklines of the profiles are shown in Figure 5. Location and anticipated maximum penetration depths of drilling sites are superimposed on the seismic sections.

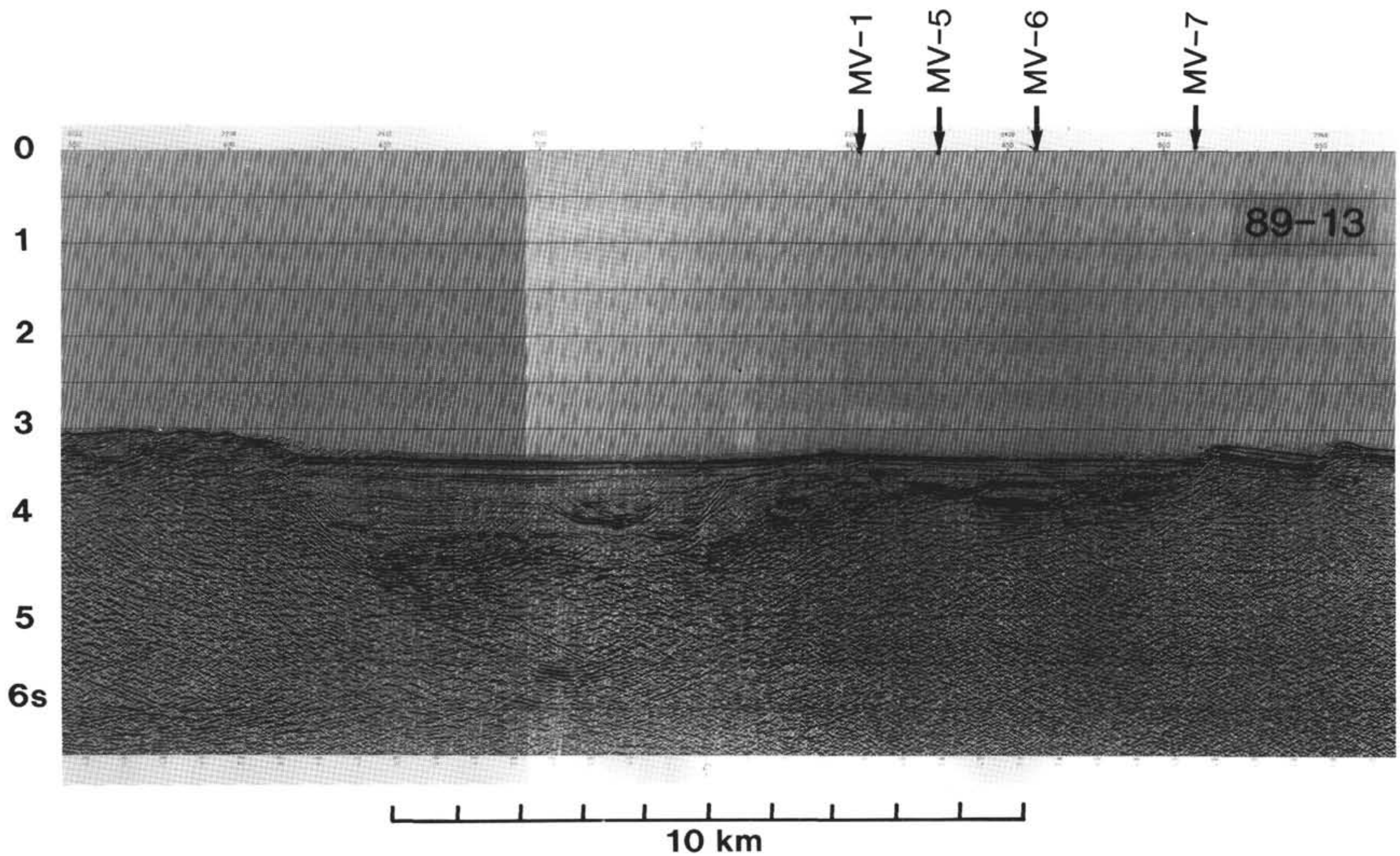


Figure 9a. Migrated multi-channel (~4 m^3, 60 airgun-array source) seismic reflection profiles crossing Middle Valley and the proposed drilling sites. Tracklines are shown in Figure 3.

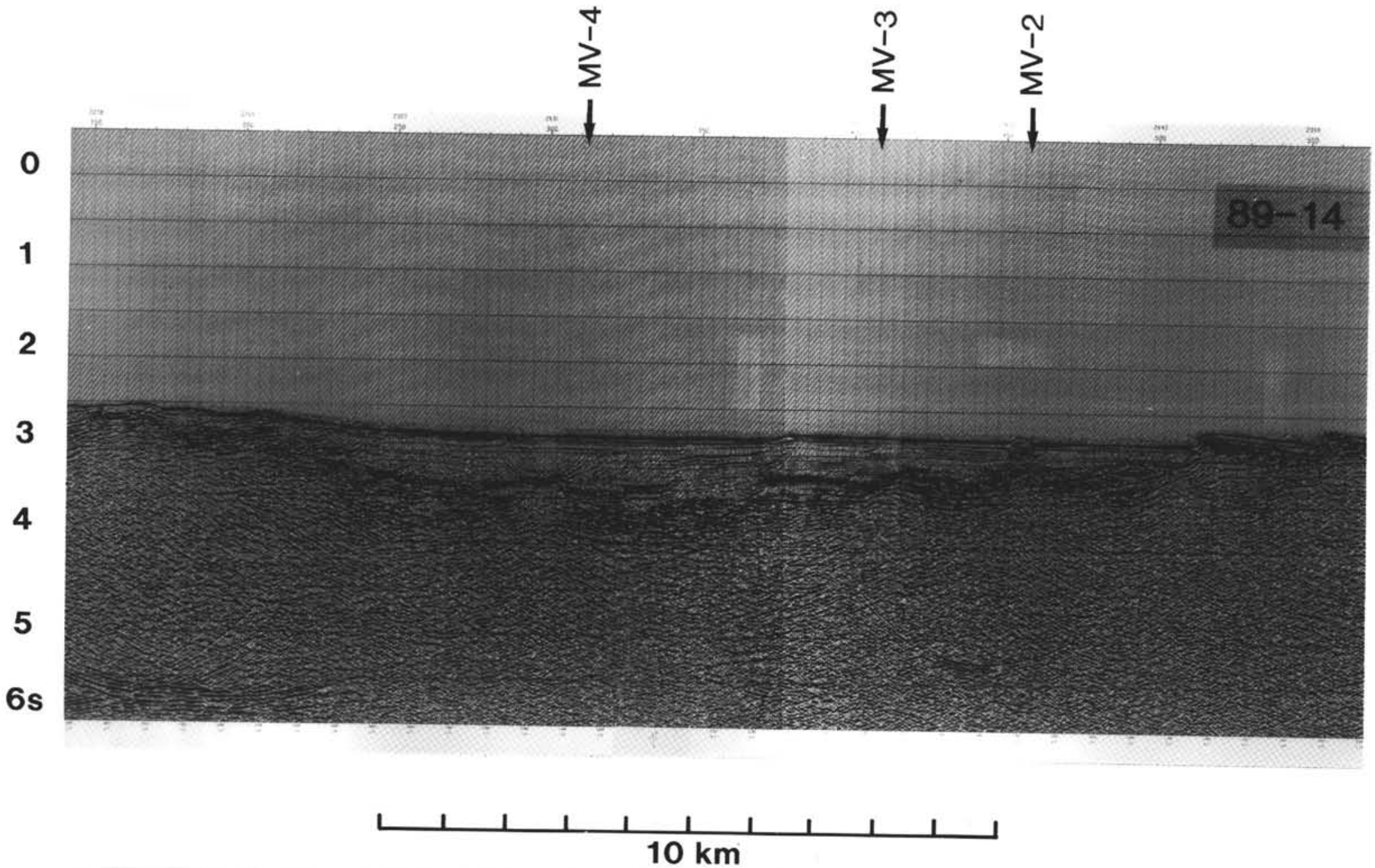


Figure 9b. Migrated multi-channel (~4 m^3, 60 airgun-array source) seismic reflection profiles crossing Middle Valley and the proposed drilling sites. Tracklines are shown in Figure 3.

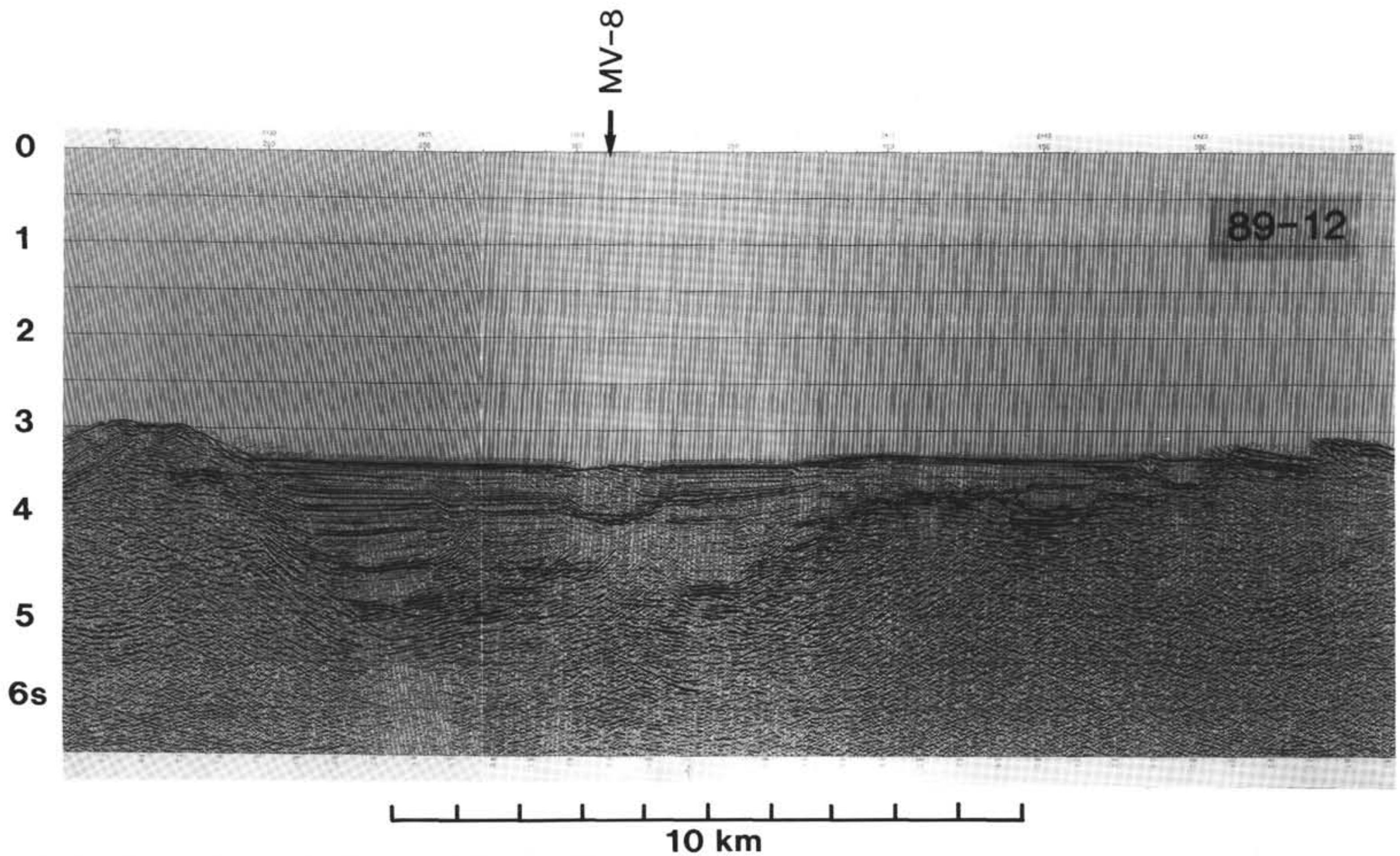


Figure 9c. Migrated multi-channel (~4 m^3, 60 airgun-array source) seismic reflection profiles crossing Middle Valley and the proposed drilling sites. Tracklines are shown in Figure 3.

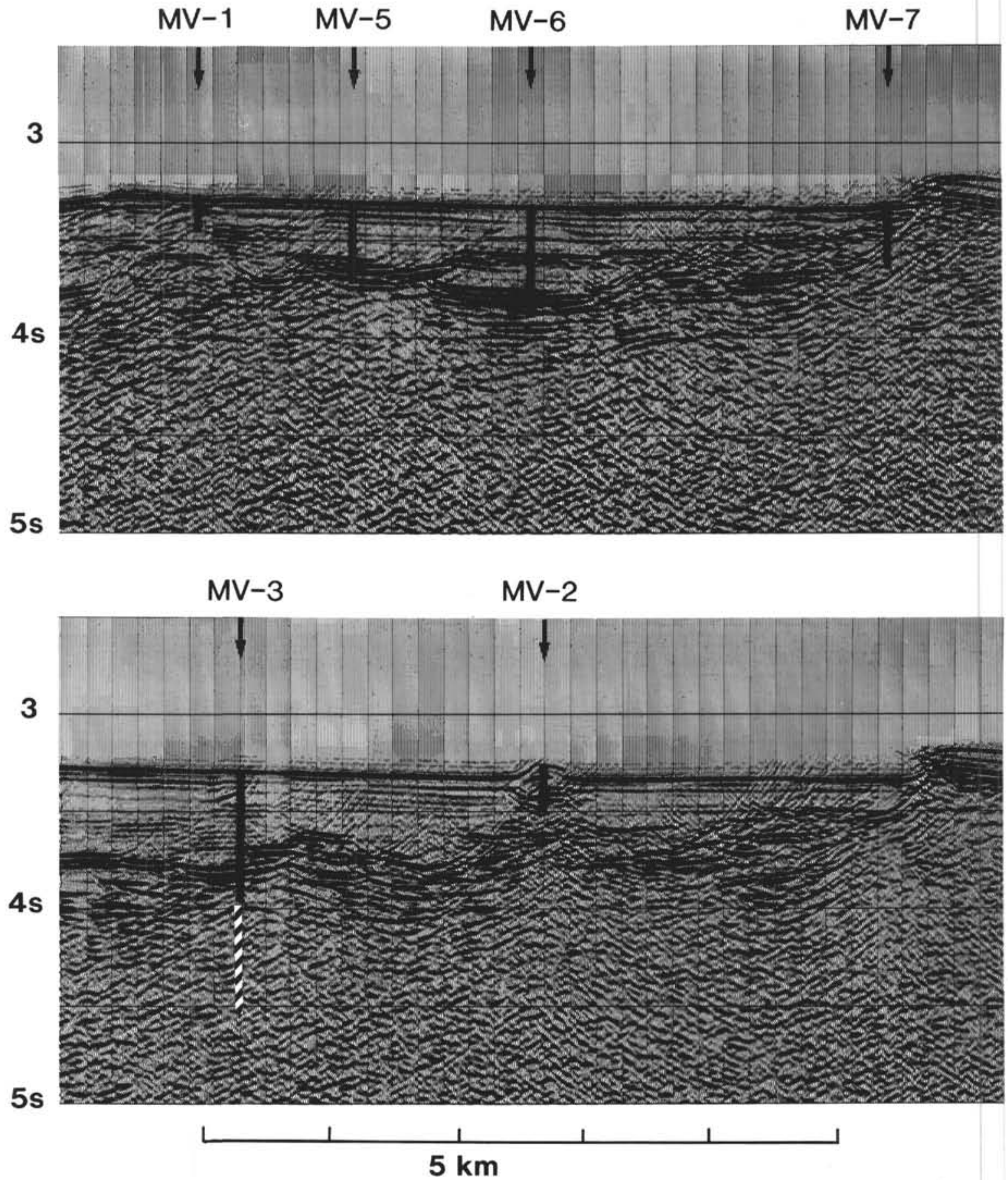


Figure 10a. Details of multi-channel seismic lines shown in Figure 9, with location and anticipated maximum penetration depths of drilling sites superimposed.

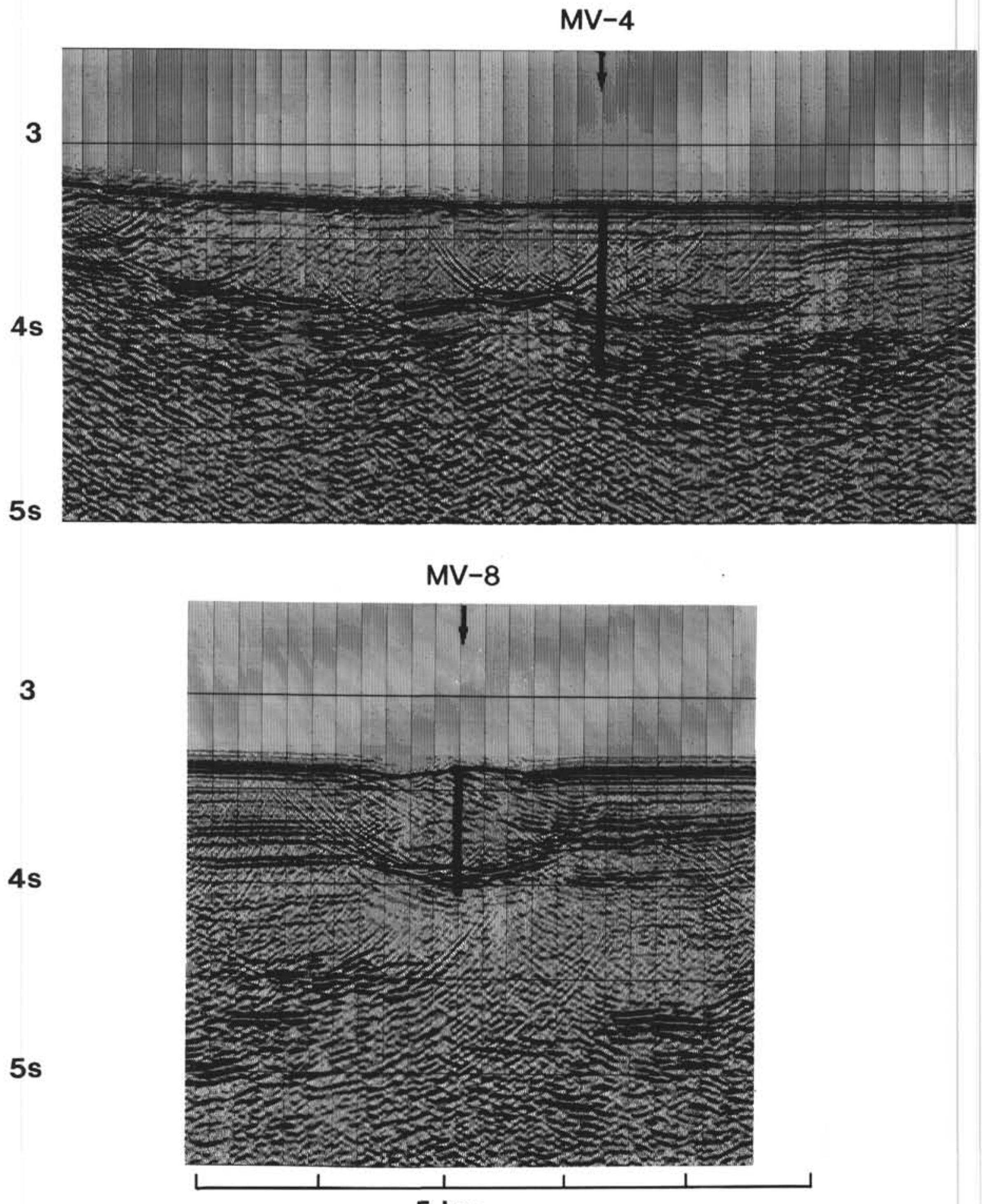


Figure 10b. Details of multi-channel seismic lines shown in Figure 9, with location and anticipated maximum penetration depths of drilling sites superimposed.

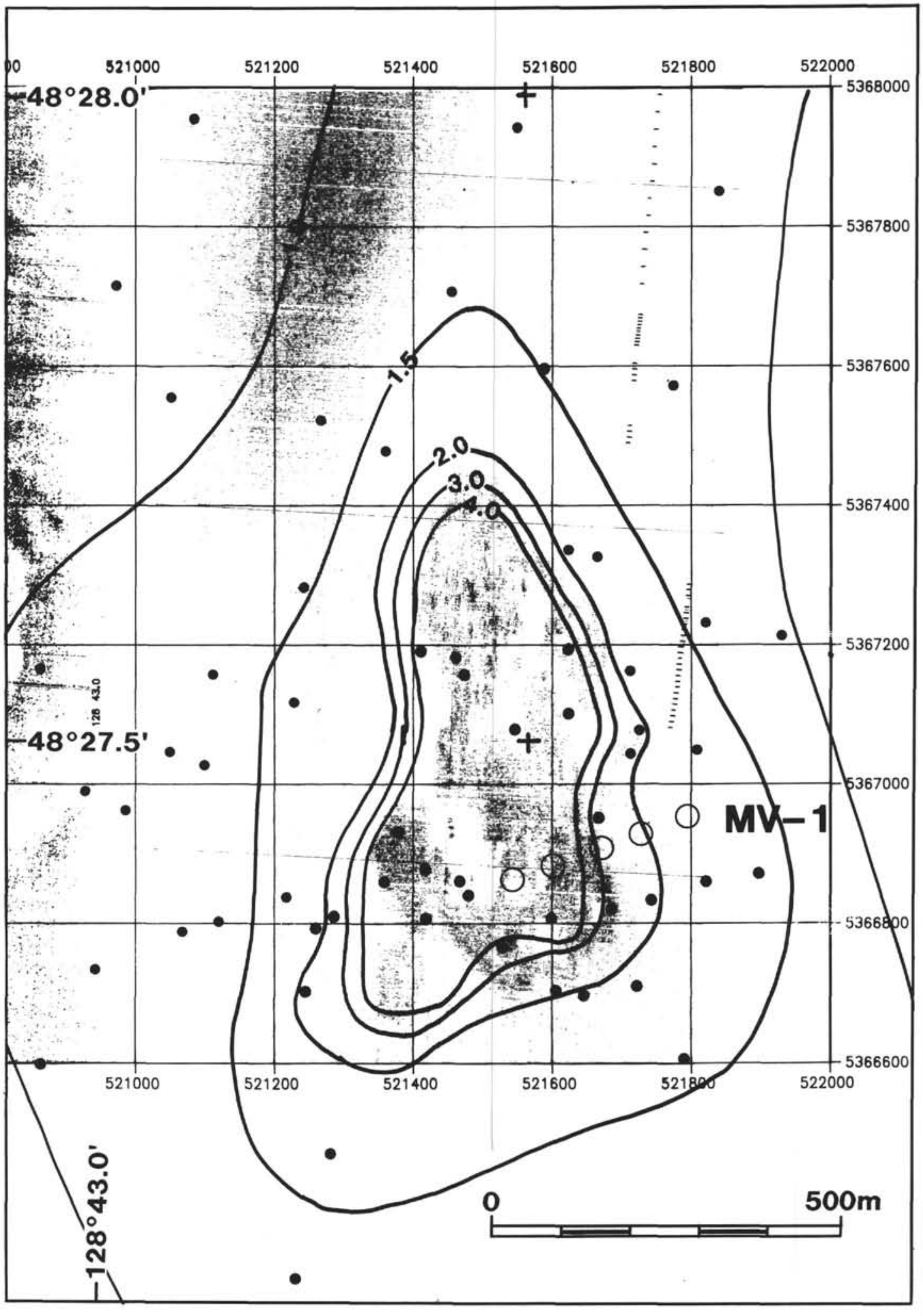


Figure 11a. Thirty kilohertz side-scan image (SeaMARC Ia), and heat flow (solid points, contoured in W/m2) over the zones of hydrothermal discharge and mineralization where site MV-I is located. Tentative locations of the multiple-hole arrays are shown as open circles.

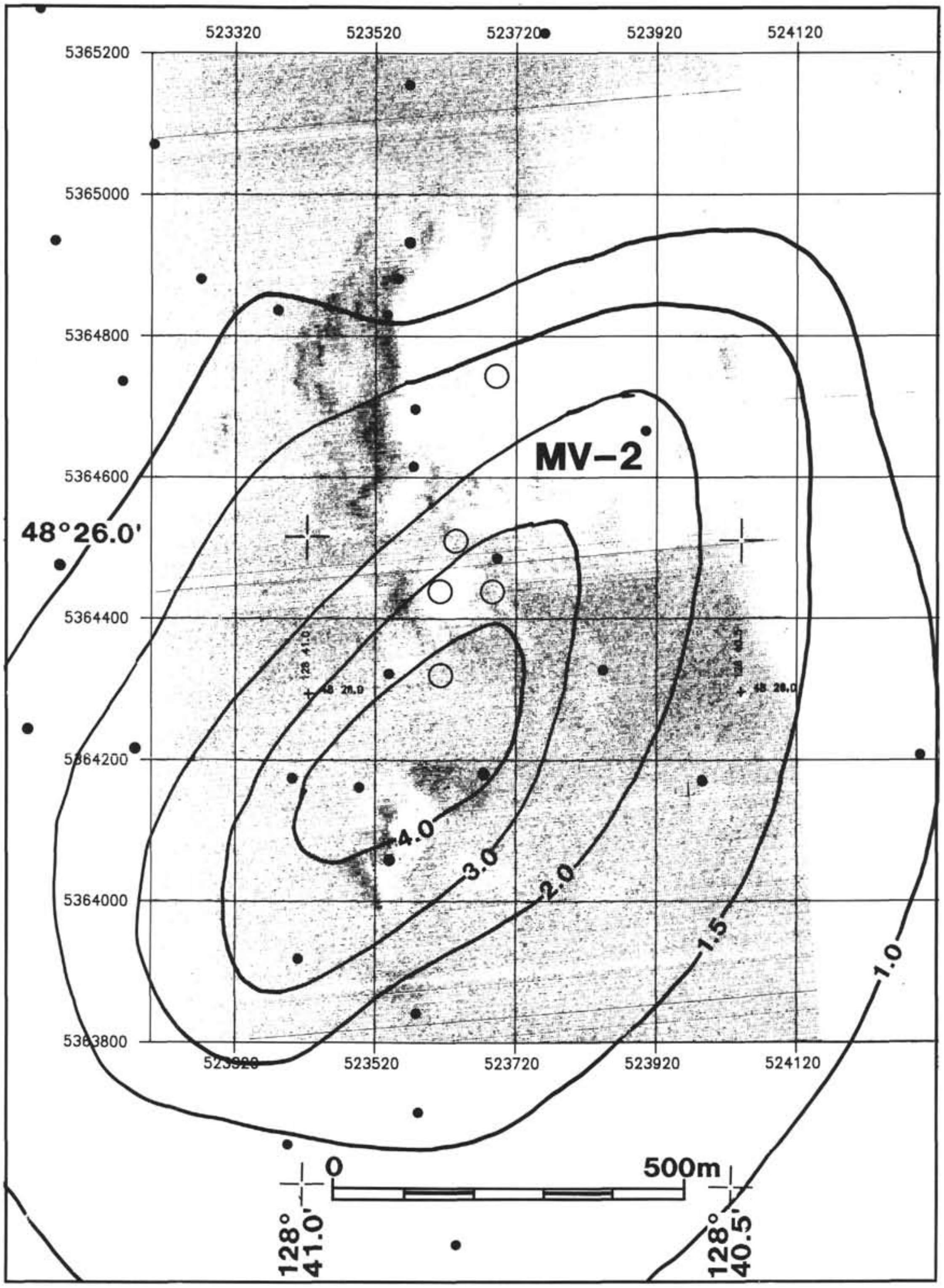


Figure 11b. Thirty kilohertz side-scan image (SeaMARC Ia), and heat flow (solid points, contoured in W/m^2) over the zones of hydrothermal discharge and mineralization where site MV-2 is located. Tentative locations of the multiple-hole arrays are shown as open circles.

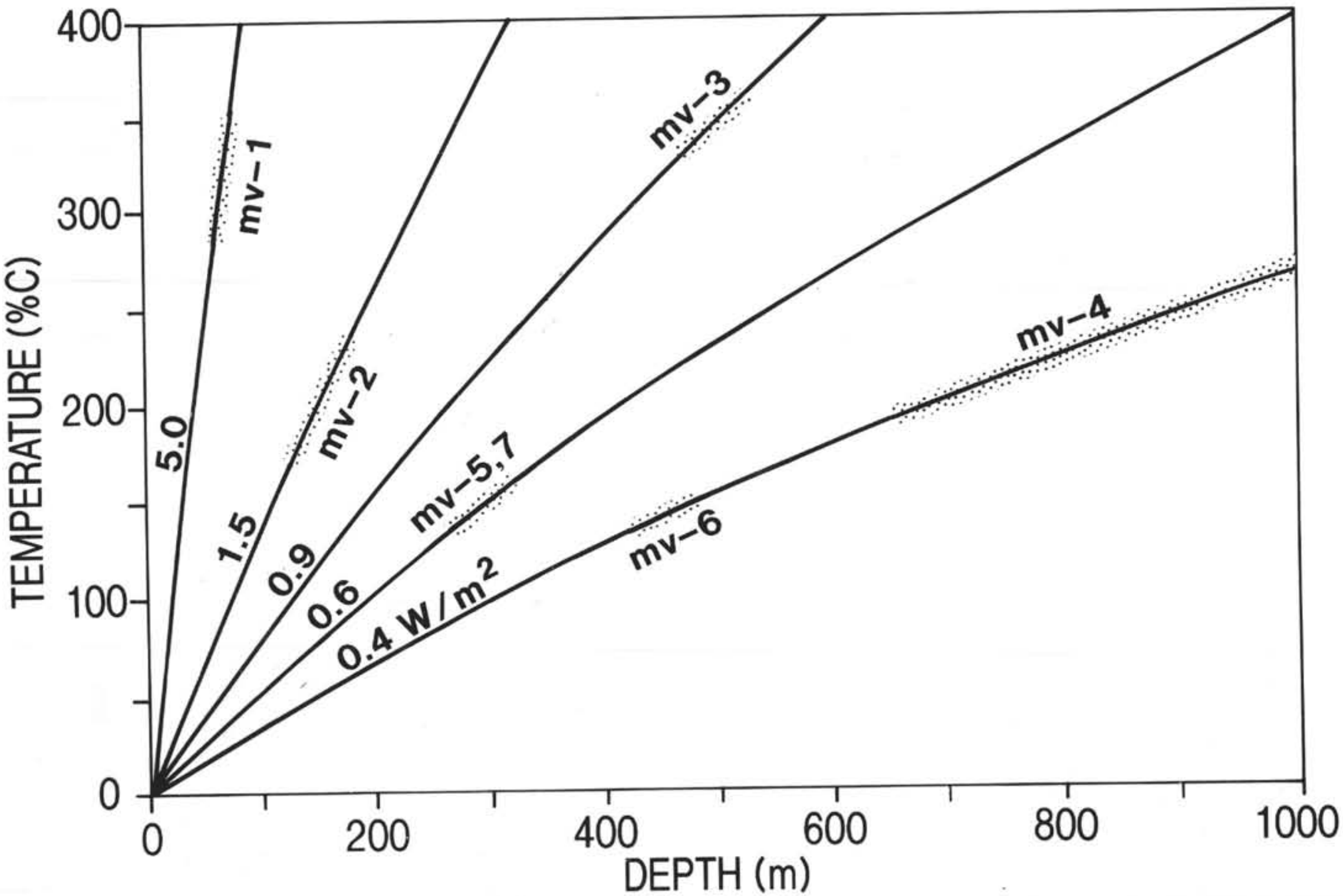


Figure 12. Estimated temperature-depth profiles at Middle Valley drilling sites. Stippled regions show the minimum depths to "basement" at each site. The conductivity-depth function used was estimated from MCS seismic velocities determined for the sediment section.

Site: MV-1 Priority: 1

Position: 48°27.40'N 128°42.50'W (MV-1A)
Near shot point 804, Line 89-13

Water Depth: 2440 m

Objectives:

To determine the extent and geometry of hydrothermal alteration and mineralization within the sediment section, to sample high-temperature hydrothermal fluids, to determine the nature of basalt alteration and deep mineralization, and to determine the fluid flow and thermal regime in an active upflow and discharge zone.

Tentative Drilling Program:

A,B,C,D: APC/XCB pilot holes drilled in an array radiating from the center of the vent field and heat flow anomaly at this site, with individual holes spaced 50-100 m apart.

E: RCB exploratory hole to find depth to set casing.

F: Reentry hole cased to depth of competent rock, and deepened to bit destruction. This hole will be situated as close to the center of the vent field and the underlying basement edifice as allowed by the constraints imposed by the setting of a reentry cone.

Sediment Thickness: Tens of meters to 120 m.

Nature of Rock Anticipated:
Indurated sediment at relatively shallow depths, minor massive or disseminated sulfide rocks, and altered basalt.

Formation Temperatures:
Locally high near the surface (up to 280°C) and at depth (possibly over 350°C).

Logging and Downhole Operations:
Numerous runs with WSTP and APC tools, PTF and sampler tools in several shallow holes plus the reentry hole, packer/flowmeter and borehole seal in reentry hole. Standard logs in RCB and reentry holes.

Site: MV-2 Priority: 1

Position: 48°26.96'N 128°40.86'W (MV-2A)
Near shot point 456, Line 89-14

Water Depth: 2430-2480 m (minimum at MV-2E)

Objectives:

To determine the extent and geometry of hydrothermal alteration and mineralization within the sediment section at a "mature" sediment-hosted sulfide deposit that occurs in a structure that is a characteristic host for large deposits in sedimented rift settings.

Tentative Drilling Program:

A,B,C,D,E: APC/XCB pilot holes. These holes will be completed by pogo-APC/XCB coring in an array radiating from the center of an uplifted sediment hill overlying a small volcanic intrusion. Individual holes will be spaced 50-100 m apart. Two holes will be drilled into the flank of this structure where massive sulfide rocks are exposed at the seafloor. This structural setting is felt to be very representative of many sediment-hosted sulfide occurrences. The final hole will be drilled as deep as possible toward the level of the buried basement reflector which lies roughly 120 m beneath the hill. No current discharge is known to occur within the area included in this array.

A reentry hole, probably situated close to hole MV-2 hole E, is considered as an alternate to the reentry hole at site MV-1.

Sediment Thickness: about 120 m.

Nature of Rocks Anticipated:

Indurated sediment at relatively shallow depths, local occurrences of massive or disseminated sulfide rocks, and altered basalts at depth.

Formation Temperatures:

Conductive conditions are likely to exist currently within the sediment section. Gradients up to 4°C/m may be present. The gradient at the deepest hole planned will probably be less than 1.5°C/m.

Logging and Downhole Operations:

Frequent runs with APC and WSTP tools will be made. No other logging or downhole measurements are planned.

Site: MV-3 Priority: 1

Position: 48°26.62'N 128°42.65'W
Near shot point 408, Line 89-14

Water Depth: 2450 m

Objectives:

To characterize the thermal, hydrologic, and chemical regime within a hydrothermal "reservoir" zone in the crust where regional-scale high-temperature fluid/rock interaction is believed to be taking place. To examine the influence that high temperatures have on sediment alteration in the absence of high rates of fluid flux.

Tentative Drilling Program:

A. APC/XCB pilot hole.
B. RCB exploratory hole (tag basement).
C. Reentry hole cased to depth of competent rock, deepened to bit destruction.

Sediment Thickness: 470 m

Nature of Rock Anticipated:

Glacial turbidite sediment, comprising interbedded muds, silts, and fine sands. Significantly indurated sediment at depth of a few hundred meters. Altered sills and sediments at level of acoustic basement. Highly altered basalts beneath.

Formation Temperatures:

Conductive conditions should exist within sediment section, with a near-surface gradient of ~1°C/m. Formation temperature at maximum penetration depth may exceed 350°C.

Logging and Downhole Operations:

Frequent runs with APC and WSTP tools within the upper part of the sedimentary section. Multiple runs with PTF and water sampler tools, and a full suite of standard logs, will be completed in the B and C holes. Specialty tools in the reentry hole include BHTV, dual laterolog, VSP, packer/flowmeter, and an instrumented borehole seal.

Site: MV-4 Priority: 2 (alternate to MV-3)

Position: 48°27.45'N 128°46.28'W
Near shot point 312, Line 89-14

Water Depth: 2470 m

Objectives:

To characterize the thermal, hydrologic, and chemical regime within a hydrothermal "reservoir" zone in the crust where regional-scale high-temperature fluid/rock interaction is believed to be taking place. To examine the influence that high temperatures have on sediment alteration in the absence of high rates of fluid flux. This site is located in the center of the rift valley.

Tentative Drilling Program:

A: APC/XCB pilot hole.
B: RCB exploratory hole (tag basement).
C: Reentry hole cased to depth of competent rock, deepened to bit destruction.

Sediment Thickness:

650-1230 m (range including depth to shallowest sill and deepest coherent reflector on MCS reflection profile).

Nature of Rock Anticipated:

Glacial turbidite sediment, comprising interbedded muds, silts, and fine sands. Significantly indurated sediment at a depth of a few hundred meters. Interbedded altered sills and sediments at the level of acoustic basement. Highly altered basalts beneath.

Formation Temperatures:

Conductive conditions should exist within the sediment section, with a near-surface gradient of ~0.4°C/m. Formation temperature at maximum penetration depth may exceed 350°C.

Logging and Downhole Operations:

Frequent runs with APC and WSTP tools within the upper part of the sedimentary section. Multiple runs with PTF and water sampler tools, and a full suite of standard logs, will be completed in the B and C holes. Specialty tools in the reentry hole include BHTV, dual laterolog, VSP, packer/flowmeter, and an instrumented borehole seal.

Site: MV-5 Priority: 2 (alternate to MV-6)

Position: 48°27.15'N 128°41.58'W
Near shot point 828, Line 89-13

Water Depth: 2455 m

Objectives:

To characterize the thermal, hydrologic, and chemical regime within the sediments and crust in that part of the axial rift where fluids are likely to pass from a regional recharge zone to discharge sites.

Tentative Drilling Program:

A: APC/XCB pilot hole.

B: RCB hole drilled to bit destruction.

Sediment Thickness: 260 m

Nature of Rock Anticipated:

Glacial turbidite sediment, comprising interbedded muds, silts, and fine sands. Significantly indurated sediment in the deeper part of the sediment section. Interbedded altered sills and sediments at the level of acoustic basement. Altered basalt beneath.

Formation Temperatures:

Conductive conditions should exist within the sediment section, with a near-surface gradient of ~0.7°C/m. Formation temperature at depth of acoustic basement should not exceed 200°C.

Logging and Downhole Operations:

Frequent runs with APC and WSTP tools will be made within the upper part of the sediment section. Multiple runs of the high-temperature PTF and water sampler tools, and a full suite of standard logs will be run in the B hole.

Site: MV-6 Priority: 1

Position: 48°27.00'N 128°40.43'W
Near shot point 858, Line 89-13

Water Depth: 2475 m

Objectives:

To characterize the thermal, hydrologic, and chemical regime within the sediments and crust in that part of the axial rift where fluids are likely to pass from a regional recharge zone to discharge sites.

Tentative Drilling Program:

A: APC/XCB pilot hole.
B: RCB hole drilled to bit destruction.

Sediment Thickness: 400 m.

Nature of Rock Anticipated:

Glacial turbidite sediment, comprising interbedded muds, silts, and fine sands. Significantly indurated sediment in the deeper part of the sediment section. Interbedded altered sills and sediments at the level of acoustic basement. Altered basalts beneath.

Formation Temperatures:

Conductive conditions within sediment section, with a near-surface gradient of ~0.4°C/m. Temperature at depth of acoustic basement should not exceed 150°C.

Logging and Downhole Operations:

Frequent runs with APC and WSTP tools will be made within the upper part of the sediment section. Multiple runs of the high-temperature PTF and water sampler tools, and a full suite of standard logs will be run in the B hole.

Site: MV-7 Priority: 1

Position: 48°26.62'N 128°38.55'W
Near shot point 910, Line 89-13

Water Depth: 2470 m

Objectives:

To characterize the thermal, hydrologic, and chemical regime within the sediments and crust in that part of the axial rift where fluids are likely to pass into the crust through thin sediments and along rift-bounding normal faults. To characterize the physical and compositional nature of a large-throw normal fault in basement, and to determine the influence that faults have on fluid flow.

Tentative Drilling Program:

A,B,C: RCB holes drilled to tag (A,B) and penetrate (C) basement.

D,E,F: APC/XCB holes drilled to tag basement.

G: Reentry hole cased to depth of competent rock, and deepened to bit destruction.

Sediment Thickness:

Will vary from hole to hole, with the minimum being a few tens of meters. The thickness of sediment overlying basement in the reentry hole is anticipated to be ~140 m.

Nature of Rock Anticipated:

Glacial turbidite sediment, comprising interbedded muds, silts, and fine sands. Minor induration of sediment at depth, with sediment interbedded with altered basalts at depth of acoustic basement. Fractured basalts may be encountered if a fault zone is penetrated.

Formation Temperatures:

A conductive thermal regime is probably present in the sediment section, with a near-surface gradient of ~0.6°C/m. Temperatures at the depth of acoustic basement should not exceed 100°-150°C.

Logging and Downhole Operations:

Frequent runs with APC and WSTP tools within the upper part of the sediment section in A-F holes, and a standard suite of logs in C and G holes. Special tool runs in the reentry hole include PTF, BHTV, dual laterolog, and packer/flowmeter. Reentry cone will be plugged with an instrumented seal.

Site: MV-8 Priority: 2

Position: 48°30.00'N 128°45.20'W
Near shot point 310, Line 89-12

Water Depth: 2540 m

Objectives:

To determine the nature of sediment deformation and alteration, and the thermal, hydrologic, and chemical regime in the vicinity of a recent major sill intrusion within the upper part of the sediment section at the center of the rift valley.

Tentative Drilling Program:

A: APC/XCB pilot hole.
B: RCB hole drilled to bit destruction.

Sediment Thickness: 500 m to sill or sill complex.

Nature of Rock Anticipated:

Glacial turbidite sediment, comprising interbedded muds, silts, and fine sands. Significantly indurated sediment near sill contact. Relatively young (less than a few thousand year-old) sill of unknown thickness at 490 m.

Formation Temperatures: Low near-surface gradient, ~0.2°C/m, probably increasing with depth to the level of the young sill.

Logging and Downhole Operations:

Frequent runs with APC and WSTP tools will be made within the upper part of the sediment section. Multiple runs of the high-temperature PTF and water sampler tools, and a full suite of standard logs will be run in the B hole.

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Electronics Technician:	Bill Stevens Ocean Drilling Program Texas A&M University 1000 Discovery Drive College Station, TX 77845-9547
Electronics Technician:	Mark Watson Ocean Drilling Program Texas A&M University 1000 Discovery Drive College Station, TX 77845-9547

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Marine Technician:	Don Sims Ocean Drilling Program Texas A&M University 1000 Discovery Drive College Station, TX 77845-9547
Marine Technician:	Gus Gustafson Ocean Drilling Program Texas A&M University 1000 Discovery Drive College Station, TX 77845-9547
Marine Technician:	TO BE NAMED
Marine Technician:	TO BE NAMED
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