OCEAN DRILLING PROGRAM

LEG 146 PRELIMINARY REPORT

CASCADIA MARGIN

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ABSTRACT

Leg 146 was directed toward investigation of tectonic dewatering in the accretionary wedge at the Cascadia continental margin. At five sites, two principal thematic objectives were pursued: (1) the mechanisms and geological consequences of diffuse flow and channelled flow within the wedge; and (2) the cause of bottom-simulating seismic reflectors (BSRs) and their relationship to the occurrence of gas hydrate and free gas.

Site 888, located in Cascadia Basin near the northern edge of Nitinat Fan, provides a reference section (with particular importance to porosity, temperature, and pore-water geochemistry) for the other sites located on the accretionary wedge. Diffuse fluid outflow from the wedge and the nature of a well-defined BSR were investigated at Sites 889 and 890 off Vancouver Island. Flow through fault zones was investigated at Sites 891 and 892 off Oregon. Site 891 examined the frontal thrust fault that connects to the master décollement. Site 892 exhibited a BSR displaced toward the surface along a hydologically active fault in the Pliocene section of the wedge.

A wide variety of downhole determinations were successfully completed on Leg 146 to characterize the fluid regime on the Cascadia margin and complement detailed laboratory analyses. In addition, the first long-term observatories — instrumented borehole seals (CORKs) — were deployed on a modern accretionary prism at Sites 889 and 892.

INTRODUCTION

Accretionary complexes evolve through a complex interplay of sedimentation, structural evolution, diagenesis, and fluid flow. These processes are particularly active near the toe of an accretionary wedge, where high porosity sediments overlying oceanic basement are initially deformed. Convergent motion in this region results in sediment compaction, over-pressuring and expulsion of pore fluids, and development of fault zones to structurally accommodate shortening and perhaps to function as aquifers. The movement of fluids to the surface perturbs normally diffusive geochemical systems and may result in localized cementation, formation of gas hydrates, and acceleration of geochemical fluxes to the water column.

Leg 146 was directed toward examining the role and behavior of fluids in these accretionary processes. By necessity, a single drilling leg can investigate only some aspects of the fluid regime; Leg 146 had as its primary foci:

1. The relative importance of dispersed and focused fluid flow and the associated geochemical fluxes from an active accretionary wedge;
2. The nature of gas-hydrate zones and the physical and chemical factors which support them in a convergent-margin setting.

Because the fluids are derived largely from the sedimentary section, investigation of fluid processes required that we measure the fluid chemistry, the temperature and pressure, the physical properties of the sediments involved, determine the nature and history of diagenetic events, and establish the structural evolution associated with accretion and fluid discharge.

The Cascadia margin represents the convergence zone between the Juan de Fuca and North American lithospheric plates (Fig. 1). Simple subduction has persisted here since the Eocene, resulting in westward growth of the continental slope by accretion of Cascadia Basin sediments. The modern convergence rate is approximately 42 km/m.y., directed N69°E (DeMets et al., 1990). Turbidites and hemipelagic deposits in the Cascadia Basin attain thicknesses of 3-4 km at the base of the slope. The décollement between the accretionary wedge and the subducting plate lies at various depths along the margin, so that half to nearly the entire sediment section is accreted at different locations. Compression of this section results in fluid expulsion at the seafloor, and may contribute to formation of well-defined bottom-simulating reflectors (BSRs) across much of the slope.

Drill sites were chosen on the basis of multichannel seismic reflection lines, submersible surveys and samples, sidescan sonar images, and heat-flow data. From these data it has been suggested that the margin off Vancouver Island is characterized by dispersed fluid discharge, while focused flow, evidenced by well-defined fluid vents, is prevalent off Oregon. Leg 146 was planned to investigate each of these areas to evaluate their respective modes of dewatering. Well-defined BSRs are present at one site off Vancouver Island and at one site off Oregon.

Drilling Objectives

Site 888 (Prospectus site VI-1) lies 7 km west of the base of the continental slope in Cascadia Basin, on the northern edge of the Nitinat Fan (Fig. 2). The site is little influenced by the tectonic stresses that deform and consolidate sediments within the accretionary wedge and in the proto-deformation zone seaward of the wedge toe, as it lies farther from the deformation front than the spacing of imbricate thrusts in the wedge. The basin sediments consist of turbidites and interbedded hemipelagic deposits. Nitinat Fan is the dominant depositional feature in the northern Cascadia Basin, and Site 888 has probably received much of its sediment from this depositional system. It may also have received turbidite sediments from smaller canyons east and north of its present position.

Drilling at this site provided a reference section for comparison with sites in the accretionary wedge of the continental margin and information on the types, age, and physical properties of sediment in the sedimentary section that is stripped from the oceanic crust to form the accretionary wedge. The state of compaction and thermal structure of the sedimentary section are of particular importance to understanding the mechanisms of growth of accretionary wedges and associated expulsion of pore water. The geochemistry of pore fluids provides indicators of fluid movement, and Site 888 allowed us to define the distribution of organic and inorganic species within the sedimentary section prior to subduction or accretion, providing the reference against which the movement of these species can be assessed.

The objectives for Site 888 were to define the chemical, thermal, physical, lithologic, chronostratigraphic, and hydrologic characteristics of the undeformed sedimentary section in the Cascadia Basin, near the toe of the accretionary wedge. Although the basic stratigraphy of Cascadia Basin was described at Deep Sea Drilling Project (DSDP) Site 174 , that section was located on a distal portion of Astoria Fan; it was not logged, and many of the geochemical (particularly isotopic) measurements necessary to understand the evolution of pore fluids were not made. Operations at Site 888 included a comprehensive program of in-situ measurements and core analyses of the inorganic and organic chemistry of fluids and solids, the resident bacterial mass and its activity, the thermal gradient, the lithologic composition, the bio- and magnetostratigraphy, and the physical properties of the sediment column.

Sites 889 (Prospectus site VI-5) and 890 (about 2 nmi from Site 889) lie at depths of 1322 and 1337 meters below sea level (mbsl), respectively (Fig. 3) on a 15- to 20-km-wide region of gently undulating seafloor in the mid-slope of the continental margin off Vancouver Island. A steep escarpment separates this region from the lower slope (2300-2500 mbsl) to the west. Beneath Sites 889 and 890, the seismic reflectors within the accretionary-wedge deposits characteristically are laterally incoherent (Fig. 4). This incoherence appears to be produced by faulting and by folding over wavelengths shorter than about 500 m. Stratified slope deposits cover the accretionary-wedge material at Sites 889 and 890. These sediments were interpreted from the seismic section to be hemipelagic deposits with some interbedded turbidites. As the accreted sediment was inferred to be of Pliocene age, the slope cover was thought to be Pleistocene sediment.

Within the incoherent, accretionary sediment section of the seismic profile, there occurs a strong, seismically continuous Bottom-Simulating Reflector (BSR) at about 276 ms two-way travel time (twt) below the seafloor (Fig. 4). The BSR is inferred to mark the base of a gas-hydrate stability field (R.D. Hyndman and G.D. Spence, pers. comm., 1992). It has been suggested (Hyndman and Davis, 1992) that the BSR on this margin is formed by the diffuse, upward advection of methane-bearing pore fluids that bring the methane into pressure and temperature conditions appropriate to the formation of methane hydrate. According to this model, the BSR is the boundary between overlying sediment containing hydrate and underlying sediment with no hydrate. Other models, such as that proposed by Miller et al. (1991), have suggested that the BSR results from the impedance contrast between sediment containing a small amount of free gas below the BSR and sediment containing only a few percent of hydrate above (as opposed to the few tens of percent suggested by Hyndman and Davis).

Drilling at Sites 889 and 890 was undertaken primarily to determine the geochemical, thermal, and hydrologic conditions that support formation of the BSR, and the physical properties of the sediments above and below the BSR. These sites were also drilled to define fluid flow and associated geochemical fluxes at a location believed to be devoid of a major, throughgoing fault zone, i.e., a location characterized by diffuse flow. Coordinated sampling, logging, and downhole experiments (in-situ temperature, LAST II tool, and CORK borehole seal) were conducted to sample and analyze fluids and the associated hydrates, and to determine the fluid-flow and thermal regimes.

Site 891 (Prospectus site OM-3) lies at the foot of the continental slope along the central Oregon coast, at 2674 mbsl (Fig. 5). The site is situated on the lowermost ridge of the continental slope. Cascadia Basin sediments lie immediately west of the ridge and Site 891. Sediments within the basin are 3.5-4.0 km thick (MacKay et al., 1992), and the upper part of the section is dominated by thick, upper Pleistocene sands associated with the southern reaches of Astoria Fan. These silty sands overlie silt turbidites characteristic of the lower, abyssal-plain deposits (von Huene and Kulm, 1973) above oceanic basement.

The marginal ridge is a seaward-vergent ramp anticline that overlies a landward-dipping, frontal thrust fault (Fig. 6) that is inferred to be an important flow path for fluids. The décollement, in which the frontal thrust is rooted, lies about 0.8 s twt (1.3 km) above oceanic basement. The ridge stands 700 m above the Cascadia Basin and extends approximately 10 km along strike. The eastern limb of the anticline lies unconformably beneath a cover of turbidites that fill the lower slope basin (Lewis and Cochrane, 1990). Biostratigraphic ages derived from the top of the anticline indicate that the ridge was elevated less than 300,000 years ago (Kulm et al., 1986).

The seaward flank of the ridge is cut by two submarine canyons: a large canyon at the northern end of the ridge, and the small canyon in which Site 891 was drilled. Detailed mapping and sampling in these canyons (Moore et al., 1990) indicate that the ridge is composed of thinly to thickly bedded silty sands and interbedded silty clays. The canyon where Site 891 is located is cut by a prominent 10-m scarp at a depth of 2770 mbsl, which is probably the surface trace of the frontal thrust. Evidence for fluid venting, which consists of numerous clam shells, bacterial mats, and carbonate crusts, is found at both the fault trace at 2770 mbsl and near the top of the canyon (2150-2250 mbsl). In the former occurrence the flow indicators are clearly fault-controlled; in the latter, fluid venting appears to be stratigraphically controlled, as it occurs at the apex of the anticlinal fold and probably reflects seaward flow along a landward-dipping, permeable zone (Moore et al., 1990).

The primary objectives at Site 891 were to sample the pore fluids within the frontal thrust fault, to ascertain their temperature, to measure the in-situ permeability of the fault zone, and to characterize the changes in physical properties associated with structural elements and diagenesis. We hoped to determine if fluids moving along the fault originate from source zones as deep as 3 km within the accretionary complex, or within the underlying, underthrust sedimentary sequence.

Site 892 (Prospectus site OM-7) is located at the top of the second ridge east of the foot of the continental slope off Oregon (Fig. 5). Sub-bottom reflectors beneath this ridge have poor lateral coherence but indicate that the beds dip eastward and crop out on the western slope. Sediments on this ridge are known to be Pliocene in age (Vern Kulm, pers. comm, 1990). The site is located about 350 m east of a prominent bioherm associated with the surface trace of an out-of-sequence thrust fault. The occurrence of clams, bacterial mats, methane bubbles, and massive diagenetic carbonate deposits at the bioherm indicates active fluid venting from the fault zone (J.C. Moore, P. Jeanbourquin, and J. Sample, pers. comm., 1992), and a flow rate of 1765 L/m^2/day was recorded within the bioherm (P. Linke and others, pers. comm., 1992). A well-defined BSR lies beneath Site 892. The BSR is deflected toward the surface along the fault zone, presumably by the movement of warm fluids from depth which perturb the position of the base of the hydrate stability field. Site 892 provided an opportunity to sample an active fluid pathway at shallow depths; the BSR occurs at about 65 mbsf and the fault zone at 125 mbsf.

Drilling at Site 892 was undertaken to determine the hydrogeology and fluid chemistry at a location within the Pliocene portion of the accretionary wedge, to assess the role of a thrust fault as an active aquifer, to determine the history of venting along this fault, and to delineate the effect of focused fluid advection on the development of gas hydrates. The sampling program incorporated coring, logging, and downhole experiments (in-situ temperature, LAST tool, and CORK borehole seal) to characterize the flow regime concentrated along the fault zone.

Site 893 (proposed site SB-1A) lies in the Santa Barbara Basin and contains sediments which are ideally suited for ultra-high resolution studies of marine records with regard to climate change and to the global carbon cycle. The sediments are deposited in a semi-enclosed basin behind a sill at a depth within the oxygen minimum zone. The high productivity in overlying waters, due to seasonal upwelling, leads to a high supply of organic matter and a corresponding depletion of oxygen in the bottom water. As a consequence, dysaerobic / anaerobic conditions develop near the seafloor, preventing benthic microfauna from disrupting the sediment. A bacterial mat develops which acts as sediment trap. The existence of both a terrigenous-clastic and marine-biogenic signal allows for detailed reconstruction of climatic fluctuations. Due to the high carbon content of the sediment, the carbon isotopic record of carbonate can be directly compared to the carbon isotopic composition of individual biological markers on a lamina basis. In addition, these sediments will enhance our knowledge about the history of coastal upwelling at interglacial-glacial time scales.

One day was allocated to operations in the Santa Barbara Basin. The estimated sedimentation rate (0.5 to 1m /1000 yr.) is such that double APC coring to 200 mbsf retrieved a substantial portion of the Quaternary record (last 0.5 m.y.). Two holes were cored. Hole 893A was cored to 196.5 mbsf and Hole 893B was cored to 68.8 mbsf. Cores recovered from this basin were cut into section lengths and received standard geochemical monitoring. The whole round cores were stored and shipped to College Station for further shore-based analysis.

RESULTS

Site 888

Drilling at Site 888 penetrated the top 600 m of the sedimentary section, which the seismic section from line 89-04 shows has a total thickness of 2.5 km. The lower 1.5 km of the section has the appearance of a sequence of distal turbidites. The character of the upper 1 km shows the proximity of a submarine fan with channels, lateral thickness changes, erosional surfaces, and localized progradation.

Lithostratigraphy

Unit I: (0-175.1 mbsf) Holocene to upper Pleistocene, interbedded gray to dark greenish gray clayey silts, and gray to dark gray, fine- to medium-grained sands, with some thin beds (30-50 cm) containing pebbles, volcaniclastic fragments, and pieces of wood. Between Units I and II is a transition zone, in which there is a gradual increase in the proportion of massive sand with depth.

Unit II: (175.1-457.0 mbsf) Upper Pleistocene, thick beds (>1 m) of massive dark gray, fine- to medium-grained sand with interbeds of clayey silt. The unit is predominantly sandy, and core recovery from it was low. The sands are poorly sorted.

Unit III: (457.0-566.9 mbsf) Upper Pleistocene, dark gray firm clayey silt and silt, finely laminated, with thin interbeds of fine to coarse sand and gravel. The unit may be divided into two subunits: IIIA (457.0-496.0 mbsf) predominantly silts, showing incipient lithification; IIIB (496.0-566.9 mbsf) clayey silts with sands, also containing isolated pebbles of granite, granodiorite, basalt, and quartzite which may be glacial dropstones.

Within the three lithostratigraphic units, three submarine-fan facies types were recognized, which are described as Facies B, C, and D, after the model of Mutti and Ricci Lucchi (1972). Facies C and D, interpreted as being deposited by normal- and low-density turbidity currents, are represented in Unit I, with Facies D predominant. All three facies types occur in Unit II, but the sands of Facies B are the principal type. The facies association of Unit II is the "middle fan sub-association." Lithostratigraphic Unit III comprises facies types C and D, which form an "outer fan sub-association." The turbidites in Unit III are of more distal character than those in Unit I.

The magnetic polarity of the cored interval is normal, except for an interval between 98 and 101 mbsf, that may correspond to the Blake event at about 110,000 yr. The section is therefore younger than 780,000 yr. Biostratigraphic control was poor. Radiolarians of the *Botryostrobus aquilonaris* Zone (less than 450,000 yr) were found to a depth of 170 mbsf.

The geothermal gradient has been established as 68°C/km, from 11 good measurements of temperature down to 315 mbsf. Thermal conductivities measured in the sediment cores increase in value downward through the uppermost 200 m to a mean value of 1.23 W/m°C for the section below that depth. The thermal gradient and conductivities yield a heat flow of about 73 mW/m^2 near the seafloor, which increases through Unit I to reach a value of 84 mW/m^2 through Units II and III. The upward decrease in heat flow is probably a consequence of the absorption of heat by the cool, rapidly deposited sediments.

Measurements of porosity and shear strength indicate that sediments in the cored intervals are under-consolidated. Wireline density and neutron logs show that the minimum porosity of the section lies at 300 mbsf. The downward increase in porosity shown by these logs beneath 300 mbsf, however, may be an artifact of poor hole conditions, especially in the case of the density log, which requires good contact with the wall of the hole. Porosity measured in core samples decreases with depth below 300 mbsf, as does porosity derived from the resistivity log. Sonic velocities also increase with depth below 300 mbsf, indicating decreasing porosity (Figure 7). The general state of undercompaction indicated by the logs and the measurements of physical properties may be attributed to rapid deposition, especially of the sandy section of Unit II. A good match between the seismic profile and the synthetic seismogram derived from downhole logging enables the profile to be accurately correlated with core and logging data from the site. The porosities derived from measurements at Site 888 match broadly, in the overall shape of their distribution with depth, porosity derived from seismic velocities obtained from the multichannel seismic data of line 89-04 (T. Yuan, G.D. Spence, and R.D. Hyndman, pers. comm. 1992) using the empirical porosity-velocity relation of Hyndman, Moore, and Moran (in press).

The geochemistry of the pore water in the section varies downward in response to bacterial sulfate reduction, carbonate diagenesis, and fluid flow within some intervals. The variations in several species are, however, quite moderate when compared with the other sites, such as Site 889, in the accretionary wedge. For example, chloride varies between 543 and 571 mM at Site 888, but at Site 889 chloride varies between 350 and 550 mM. Geochemical analysis of pore fluids and gases revealed several interesting aspects of fluid flow, gas migration, and diagenesis in the section. At 70 mbsf, chloride concentration sharply decreases by 12 mM from 571 mM, to which it had steadily increased from 545 mM at the seafloor. A pronounced minimum in chloride of 18 mM below surrounding values of about 563 mM occurs at 514 mbsf. Flow is required to sustain these anomalies, which would otherwise diminish by diffusion. The anomaly at 514 mbsf lies at a strong seismic reflector that is likely to represent a sand along which pore fluid may have flowed (low core-recovery prevents direct recognition of sand in this interval, and logging was not conducted to this sub-bottom depth).

Overall, organic carbon in the section is at a low concentration (0.2-0.4 wt%) and is refractory. Concentrations of methane above 200 mbsf are less than 5 ppmv. Ethane, propane, and butane are present only in trace amounts ($C_1/C_2 > 1000$), indicating that the methane is of bacterial origin. An anomaly of high methane gas content (68,000 ppmv) occurs in a high-porosity sand at 351 mbsf. It is not clear that the methane in this sand was formed in situ, yet fluid migration appears to be excluded as an explanation for its presence by the absence of anomalies in the fluid chemistry. In this instance the gas may have migrated into the sand independently of other fluids.

In summary, investigations at Site 888 revealed that the upper quarter of the sedimentary section on the ocean floor near Vancouver Island comprises a sequence of undercompacted sands and clayey silts that were rapidly deposited in a submarine fan, or in close proximity to it. The rate of sedimentation of the upper 100 m of section has been close to 100 cm/1000 yr, and sedimentation rates in the remainder of the cored interval have at least matched that rate, and were probably greater, judging from the character of sediments in Unit II (middle fan facies). In as many as four intervals of the cored section, there is evidence that fluid flow is occurring. It appears probable that much of this flow arises from differential compaction of heterogeneous sediments within the fan translating to horizontal flow, but the possibility that some of the flow has been transmitted horizontally from a region of compaction induced by the advancing accretionary wedge, 7 km distant, cannot be excluded.

Sites 889 and 890

Sites 889 and 890 are located in water depths of 1326 and 1337 mbsl, respectively. Coring began in bedded, slope-basin sediment, and at Site 889 extended into the underlying, deformed sediments of the accretionary wedge. Site 890 was cored to only 50 mbsf to sample the near-surface sediments. Major objectives at this site were the investigation of a well-developed BSR at 225 mbsf and characterization of diffuse fluid flow from the accretionary wedge. Holes 889A, 889B, and 889C penetrated the BSR. A borehole seal (CORK) was emplaced in Hole 889C to provide long-term observation of the thermal, chemical, and hydrogeological conditions associated with the gas-hydrate zone inferred to overlie the BSR, in a part of the wedge thought to be dewatering diffusely.

Sediments at Sites 889 and 890 range in age from late Quaternary to late Pliocene. There is a hiatus in the record at 87 mbsf, separating upper Quaternary from lower Pleistocene deposits. Hole 889A forms the most continuous record, and sub-bottom depths in the following discussion refer to this hole.

Lithostratigraphy - Site 889

Unit I: (0-128 mbsf) This unit includes clayey silts, fine sands, and diagenetic carbonates, and comprises slope and slope basin sediments which are hemipelagites, turbidites, and mass-flow deposits. Age is upper Quaternary.

Unit II: (128-301 mbsf) This unit is compositionally similar to the lower part of Unit I but is noticeably more consolidated than the overlying unit and is highly fractured. Diagenetic carbonates are observed throughout the section. Unit II is thought to consist of abyssal-plain silts and clays that have been fractured during accretion. Unit II extends to 300 mbsf, beneath which there is a sharp increase in glauconite content, at the top of Unit III. Age is lower Pleistocene to Pliocene.

Unit III: (301-345 mbsf) The sediments in Unit III appear to be abyssal-plain deposits like those in Unit II above, but the abundant authigenic glauconite suggests deposition under suboxic conditions. Age is late Pliocene.

Structural Domains

Domain I (0-104 mbsf) is dominated by subhorizontal bedding, with little apparent deformation of the slope basin sediments.

Domain II (104-127 mbsf) is characterized by less common sand/silt beds that dip 40°-70° to the west.

Domain III (below 127 mbsf) Small-scale fractures are evident and become more common downhole. Below 150 mbsf, fractures are pervasive and produce well-developed angular fragments that commonly exhibit an interlocked geometry. The fragment surfaces are sometimes polished and slickensided. The dominant fracture fabric dips 45° -60°. Because fractures are ubiquitous in Domain III, and no clear indicators of fault zones were recovered, we infer that tectonic stress in the accretionary-wedge sediments sampled at this site is accommodated largely by distributed strain.

The downhole variation in consolidation is clearly shown in the distribution of bulk density and porosity. Unit I is characterized by normally-consolidated deposits in which porosity declines regularly with increasing depth. Between 128 and 160 mbsf (upper Unit II) porosity decreases markedly; the sediments become overconsolidated, and remain so to the base of Unit II. There are distinct excursions from the general porosity decrease that correlate with variations in diagenetic carbonate cementation and organic geochemistry (organic carbon content, methane, N, and S concentrations). The BSR falls within one of these excursions, but it is not uniquely related to porosity, cementation, or organic geochemistry. Lithostratigraphic Unit III exhibits an apparently anomalous increase in porosity with increasing depth.

Inorganic chemistry of pore waters defines two zones, Zone 1 is from 0 to 130 mbsf and Zone 2 is from 130 to 386.5 mbsf. Within lithostratigraphic Unit I, sulfate declines to zero at 10 mbsf, accompanied by an increase in alkalinity. The loss of sulfate removes inhibition to carbonate deposition, and as a result Ca and Mg concentrations decrease markedly from 0 to 60 mbsf. Chloride concentration declines from 550 mM at the sediment-water interface to 363 mM at 130 mbsf. The linear change in Cl is diagnostic of a diffusion gradient.

From 130 to 386.5 mbsf, Cl concentration is nearly constant at 370 mM. The concentrations of Na, Mg, and phosphate are also nearly constant, indicating that the low Cl concentration is a dilution effect. Low-Cl fluids might be derived by lateral advection from land, by dehydration of hydrated mineral species at depths >1-2 km within the accretionary wedge, or perhaps by clay membrane filtration. However, the most probable source of low-Cl fluids is either dissociation of gas hydrate disseminated within this interval during core retrieval or dissociation of the hydrate in situ, following a change in temperature that is sufficiently recent (a few thousand years) for the low chlorinity not to have been dispersed by diffusion or by fluid advection. The degree of dilution suggests that less than 40% of the pore volume is filled with hydrate. Below 300 mbsf, increases in the concentration gradients of calcium and silica, and a decrease in the potassium gradient, indicate diffusion or mixing with a deeper seated fluid.

Lithostratigraphic Unit I yields elevated methane concentrations (60-80 x 10^3 ppmv) below the sulfate reduction zone. Methane declines to <30 x 10^3 ppmv at the base of Unit I. Over this same interval, ethane and propane are essentially absent and the C_1/C_2 ratio is >10^3, indicating that the methane is biogenic. A small spike (33 ppmv) in ethane concentration at 129 mbsf (associated with the Cl minimum) suggests a deeper source for fluids at this level.

Gas compositions change markedly in the interval from 130 to 247 mbsf. Headspace samples contained 30-77 x 10^3 ppmv methane, 5-35 ppmv ethane, and 0.5-3.4 ppmv propane. The concentrations of methane found in this interval may come from pore water that is saturated in methane, and some may have been released from dissociated hydrate in cores recovered from the hydrate stability zone. The degree of saturation of methane in the pore water of the cores, however, still remains to be calculated.

Below 250 mbsf, the methane concentrations become highly variable. Ethane increases markedly below 300 mbsf, and propane increases markedly below 360 mbsf. Within this interval, the C_1/C_2 ratio declines from values of about 2000 to <100, indicating a mixture of thermogenic and bacterially derived gas.

Holes 889A and 889B were both logged with the geophysical and formation microscanner (FMS) tool strings; a vertical seismic profile (VSP) was run in Hole 889B. Logs show the base of Unit I to have particularly high porosity. This high-porosity zone is associated with geochemical anomalies (Cl, Ca, Mg, S, N, methane, ethane), which implies that it collects fluids evolved from greater depths. Within Unit II, high velocity and resistivity values correlate with low neutron porosity, indicating the presence of carbonate cementation.

Six in-situ temperature determinations were made with the WSTP and ADARA tools. Temperature increases linearly with depth, with a gradient of 54°/km. The data imply conductive heat loss rather than advection, although upward movement of fluid at rates of around 1 mm/yr or less cannot be excluded and predict the base of the hydrate stability field for methane and pure water (17°C) at 260 mbsf.

The BSR at Sites 889 and 890 is situated 276 ms twt below the seafloor in the migrated seismic section. Time-depth curves derived from the sonic log and VSP indicate that the BSR is located at 225 mbsf in Hole 889B. There is no evidence in either the logs or cores for the accumulation of hydrate in massive form, but a temperature of -1.4°C measured on the core-receiving catwalk in a core recovered from 220 mbsf (about 10°C lower than temperatures measured in other cores from around this sub-bottom depth) could have been produced by the dissociation of hydrate filling 8% or more of the pore space.

Although the sonic log does not exhibit a substantial decrease in velocity across the BSR, the VSP data define a rise in velocity just above the BSR, with a distinct low-velocity zone beneath it (Fig. 8). Velocities are lower than in seawater and suggest the presence of small amounts of free gas. The disparity between the sonic log and VSP results may be attributed to drilling disturbance, which could deplete the gas phase in the immediate vicinity of the borehole; in addition, the sonic log will not record velocities lower than that of the seawater filling the hole.

At present, the geophysical and geochemical data, taken together, are best explained by the presence of hydrate in the sediment above the BSR at 225 mbsf, and by the presence of a small amount of free gas (no more than 5%) in the 25-m interval beneath the BSR. If this interpretation of the data is correct, then the experimentally derived stability field for hydrate formed from a solution of pure water and pure methane is not appropriate for the natural system investigated at Site 889. The estimated stability field for methane and seawater (Hyndman et al., 1992) gives a closer prediction of the depth of the BSR. The low chlorinity in the interval beneath the BSR might have its origin, at least in part, in dissociation of hydrate accompanying the upward migration of the base of the hydrate stability field, as the upper few hundred meters of the section warmed after the last glacial period.

The pattern of variation at Sites 889 and 890 in the organic and inorganic geochemistry of the pore fluids and in physical properties does not show some of the large discontinuities that are seen at Sites 891 and 892 in association with major faults. With the exception of a narrow interval around 130 mbsf, there is little evidence of significant fluid flow that is confined to conduits or fluid pathways provided by permeable beds or faults. Lithostratigraphic Units II and III are pervasively fractured, and it seems probable that flow through the section will be quite dispersed through this fractured rock. In-situ fluid pressure measured with the LAST II tool at a depth of 140 mbsf was indistinguishable from hydrostatic pressure, although more processing is needed to remove the effect of drill-string heave from the data. No direct evidence for large-scale fluid flow through the section was discovered at Site 889, and the linearity of the increase of temperature with depth implies that any flow that is occurring must have a velocity of less than a few millimeters per year.

The borehole seal (CORK) deployed at Hole 889C should provide data on temperature, pressure, and pore-water composition after the effects of drilling have been equilibrated. From these data, it should be possible to determine the temperature profile through the hydrate stability zone in more detail, and post-cruise hydrogeologic tests in this sealed hole should define rates of fluid advection in the accretionary wedge through the region of the BSR.

Site 891

Site 891 lies on the westernmost ridge of the Oregon continental margin at 2663 mbsl (Fig. 5). The ridge is an anticlinal thrust sheet formed by movement along the frontal, landward-dipping fault. The fault roots in the décollement beneath the accretionary wedge which forms the outer continental margin. The frontal thrust fault is imaged on seismic reflection profile OR-5 at a depth of about 375 mbsf at Site 891 (Fig. 9). The negative polarity of that reflector suggested that the region beneath it might contain overpressured fluids. Site 891 was drilled to determine whether fluid advection occurred at this site and, if it did, whether it was focused along the fault zone or through stratigraphic aquifers elsewhere in the section.

Three holes were drilled at Site 891. Only three APC cores were collected in Hole 891A (total depth, 9.9 mbsf). Hole 891B provided cores to 472 mbsf, although core recovery was very low (<11%). Hole 891C was drilled to 491 mbsf and logged with the quad-combo and geochemical tools and the FMS. Both a VSP and a two-ship oblique seismic experiment were also conducted in this hole.

Because of the low core recovery and the compositional and textural similarity of all sediments recovered at Site 891, only one lithostratigraphic unit was designated; this was subdivided into three subunits.

Subunit IA: (0-198.2 mbsf) Displays convolute- and cross-lamination, tilted beds, and convolute deformation. Age is upper Quaternary.

Subunit IB: (198.2-383.9 mbsf) Marked by an increase in induration and fracturing, and a decrease in the degree of sorting. Age is upper Quaternary.

Subunit IC: (383.9 mbsf-472.3 mbsf) Marks a return to less consolidated, less fractured, and better sorted sediments. Age is upper Quaternary.

The lithologies sampled consist dominantly of clayey silts and fine to medium sand. Allochthonous pebbles and diagenetic carbonate concretions are distributed randomly throughout the section. Several cores below 200 mbsf contain wood fragments. Biostratigraphic and paleomagnetic results are consistent with a post-middle Pleistocene age for the entire column. The structural position, age, and composition of the sediments suggest that Site 891 accumulated as proximal deposits on Astoria Fan prior to uplift.

Turbidite beds are steeply inclined (about 60°) above 84 mbsf, overlying variably dipping beds (0°-50°) to 198 mbsf. Shear bands appear sparsely in the interval between 100 and 198 mbsf, but there are no other strain indicators above 198 mbsf. In contrast, numerous discrete fractures are observed from 198 to 278 mbsf and from 321 to 375 mbsf. Two fault zones (263 and 375 mbsf) are recognized within these intervals by the development of shear fabrics and polished and slickensided surfaces. Between the two fractured zones (278-321 mbsf) no shear fractures occur, but development of a bedding-plane fissility suggests a compaction fabric. Below 375 mbsf, few fractures are observed and bedding dips 14°-20°.

Pore-water chemistry and physical properties define three distinct zones in Hole 891B which are not coincident with the lithostratigraphic subunits:

Zone 1: (0- 200 mbsf) This interval is characterized by (1) porosity which declines regularly from about 50% at the seafloor to about 38% at depth; (2) low concentrations of methane, carbon dioxide, and a virtual absence of higher hydrocarbons; (3) low Cl concentration, the presence of sulfate, low alkalinity, and a stable Mg/Ca ratio. This zone appears to be a region of normal gravitational compaction which is dominated by sulfate reduction.

Zone 2: (200-440 mbsf) This zone differs significantly from Zone 1 and suggests little hydraulic communication between the two. Methane concentration increases markedly in Zone 2, and its sympathetic variation with organic carbon content indicates bacterial methanogenesis. Ethane, higher hydrocarbons, and carbon dioxide appear below 240 mbsf and define maxima at 314, 340, 367, and 410 mbsf. These maxima represent thermogenic (hydrothermal) hydrocarbon incursions that indicate at least localized fluid advection. The presence of the olefin ethene (C_2H_4), which is unstable, suggests that the fluid dispersal system is active. The total nitrogen/organic carbon ratio indicates that organic components have a mixed terrestrial/marine origin. Cl concentrations in Zone 2 are high and relatively constant, SO_4 is absent, and Mg is low. These concentrations indicate that Zone 2 waters belong to a separate hydrologic system from those in Zone 1, and the interface between the two shows little evidence of diffusion between them. Carbonate cementation at 191 mbsf, which is suggested by high velocities (2.2 km/s) and resistivities (2.6 ohm-m) in the logs, may form a barrier to fluid exchange. Fault zones or intervals of anomalous compaction define several discontinuities (at 260, 308, 375, and 440 mbsf) in the porosity distribution in Zone 2. The two upper zones are apparent in the pore-water (Li, Mg/Ca ratio, and silica) and gas (ΣC_2-C_6) chemistry; the anomalies probably reflect flow along permeable faults or sand beds. The lack of a significant geochemical anomaly at 375 mbsf suggests that the thrust imaged on the seismic reflection profile may be a horizon of little or no active fluid flow.

Zone 3: (440 mbsf- total depth) This zonal boundary is defined primarily on the basis of a pronounced increase in porosity (from 40% to 60%) at 440 mbsf. Fluids beneath this depth exhibit consistently high values of methane and low concentrations of higher hydrocarbons and carbon dioxide. The pore waters are also characteristically low in Cl and high in Ca, suggesting that they have been affected by clay dehydration reactions. The porosity inversion and geochemical signature suggest that the active portion of the frontal thrust may have stepped down to near the top of this interval. Zone 3 appears to represent the footwall section beneath the frontal thrust fault.

The pore-water chemistry in Hole 891A (0-9.9 mbsf) is substantially different from that characteristic of seawater or of Zone 1 in Hole 891B. The concentrations of Cl, Si, phosphate, Mg, Na, and Ca are similar to those observed in Zone 2, suggesting a minimum depth of origin of 200 mbsf. The disparity in pore-water composition between Holes 891A and 891B, which were separated horizontally by only 30 m, emphasizes the spatial heterogeneity of fluid flow in this accretionary setting.

Site 892

Site 892 lies on the western flank of the second ridge on the accretionary wedge that underlies the Oregon continental slope (670 mbsl; Fig. 5). The site was positioned to intersect both the BSR (68 mbsf) and a hydrologically active, landward-dipping fault (105 mbsf). Site 892 was drilled to delineate the hydrogeology and fluid chemistry of a Pliocene portion of the accretionary wedge, to assess the importance of a fault zone as an active aquifer, to determine the history of flow along this fault and its effect on the temperature regime, to analyze the structures developed around active and relict fault zones, and to investigate the effect of focused fluid advection on the occurrence of gas hydrates and the BSR.

Coring extended to a depth of 176.5 mbsf in Hole 892A. Hole 892B was drilled to the same depth; a packer test was conducted in the hole, and a borehole seal (CORK) was deployed to provide long-term observation of the thermal, chemical, and hydrogeological conditions at the fault zone. Hole 892C was logged to a depth of 125 mbsf with the seismic stratigraphy log, the lithodensity log, and the FMS, and a VSP was run. Holes 892D (0-166.5 mbsf) and 892E (0-62 mbsf) provided cores and temperature determinations additional to those collected at Hole 892A, in selected intervals.

The section cored at Site 892 is divided on the basis of structural characteristics into three domains. Domain I (0-52 mbsf) consists of moderately dipping (<35°) beds of silt and fine sand, with fractured intervals in some of the silts. A fault zone is inferred at 52 mbsf (Domain I/II boundary) from an abrupt reduction in bedding dip to 10°-20°, and by fractures in the FMS log. The presence of shear bands and stratal disruption in the interval 62.5-67 mbsf suggests a fault zone. Fractured intervals, scaly fabric, and veins increase downhole in Domain II (52-106 mbsf) to culminate in a strongly developed fault-zone fabric in Domain III (106-175 mbsf). The interval between 116 and 147 mbsf exhibits a pervasively sheared, consolidated mélange fabric.

Radiolarian-based biostratigraphy of the Pliocene section confirms the positions of the fault zones. Two stratigraphic inversions are apparent in Hole 892A, between 45 and 50 mbsf and between 107 and 117 mbsf. In Hole 892D the lower inversion occurs between 76 and 110 mbsf, and the upper inversion is not recognized. In addition, the biostratigraphy defines a hiatus at 23-30 mbsf in Hole 892A and at 32-43 mbsf in Hole 892B.

The sediments at Site 892 consist dominantly of terrigenous silty clay and clayey silts with scattered sand layers. The sediments at Site 892 appear to be Pliocene abyssal-plain deposits, similar to the lowermost sediments recovered at DSDP Site 174 in Cascadia Basin.A single Lithostratigraphic Unit was defined. This unit was divided into two subunits.

> Subunit IA (0-67.8 mbsf) is richer in sand than the deeper section of the hole. Most of the sand layers consist of authigenic glaucony pellets. Grain size decreases downward through the subunit, while the proportion of biogenic silica increases near its base. Age is lower to upper Pliocene.

> Subunit IB (67.8-176 mbsf) contains fewer sand layers, less glaucony and biogenic silica, and an irregular distribution of grain sizes. Most distinctively, however, Subunit IB exhibits the fracturing and stratal disruption which define structural Domains II and III. Age is upper Pliocene.

Marked downhole discontinuities occur in physical properties at Site 892. Abrupt dislocations in bulk density and porosity occur at 17, 67.8, 116, 144, and 164 mbsf. The discontinuity at 17 mbsf is clearly a function of the gas hydrates observed between 2 and 17 mbsf, the sublimation of which disrupted the near-surface sediment, resulting in a very high porosity (>67%). Beneath the visible hydrates, porosity declines normally to about 55% at 67.8 mbsf (top of lithostratigraphic Subunit IB), and then becomes variable (42%-62%), with little evidence for further general consolidation.

Compaction appears to be localized about the faulted intervals where strain hardening has occurred. These same intervals are adjacent to porous, fractured zones which, at 67.8 and 116 mbsf, apparently serve as active fluid-flow zones.

Active flow at Site 892 is indicated by geochemical anomalies in the pore waters, by a packer test that measured superhydrostatic fluid pressures, and by local higher-temperature excursions from an otherwise linear increase in temperature with depth. Furthermore, the presence of gas hydrates and elevated levels of hydrogen sulfide at 2-17 mbsf may be an indirect consequence of the underlying flow regime.

Bacterial methanogenesis occurs at very shallow depths (possibly within the upper 2 mbsf) at Site 892. Although biogenic methane probably persists to the base of the hole, it is mixed with higher hydrocarbon gases below 67.8 mbsf. Thermogenic hydrocarbons (C_2-C_6) were sampled and must be derived from deeper within the prism (1-4 km), as the maturity of the local kerogen is insufficient to produce them. The gases also include ethene, an unstable olefin, the presence of which implies advection of petroliferous pore waters, although gas migration might occur independently. The distribution of higher hydrocarbons suggests movement of fluids through the section at 67.8, 107, and 125 mbsf.

Gas hydrates occur as macroscopic crystals, pellets, and aggregations distributed in the upper 17 m of sediment, and probably as disseminated deposits to 68 mbsf. The disseminated hydrates have a patchy distribution as indicated by the variable dilution of Cl. Temperature measurements and analysis of the heat budget in the cores with observable hydrate (<17 mbsf) indicate that less than 10% of the pore space is filled with hydrate.

The occurrence of high concentrations of H_2S in near-surface sediments and its presence to 60 mbsf indicate either that H_2S is formed bacterially but its usual removal as monosulfides and/or pyrite is inhibited, or that H_2S is allochthonous to these near-surface sediments and has a hydrothermal source. The close association of H_2S with the gas-hydrate zone suggests that free sulfide may be stored as clathrate in situ.

The geophysical logs in Hole 892C (located 20 m north of 892A) are sensitive, though somewhat inconsistent, indicators of fault zones inferred from the cores. Between 61 and 68 mbsf and between 83 and 90 mbsf, measurements of high density, high velocity, and high resistivity from the logs define fault zones that are apparently strain-hardened. The same intervals show temperature and ethane anomalies, and the upper interval exhibits a pronounced discontinuity in density/porosity. By contrast, a fault zone inferred to occur at 106 mbsf (ethane anomaly, fracturing in core) is represented by low resistivity and bulk density and high neutron porosity.

Logging unequivocally indicates that the BSR is caused by the presence of free gas below 71 mbsf. Below this level sonic velocity drops to a uniform value of 1.5 km/s, indicative of borehole fluid, which implies that velocity in sediment surrounding the borehole is even lower. The low sonic velocities are attributed to free gas in the formation below the BSR and are confirmed by the VSP (≤1.4 km/s, 68-91.5 mbsf).

Temperature is a sensitive indicator of advective flow . In-situ temperature measurements at Site 892 define a linear temperature gradient of 51°C/km, which suggests conductive heat transfer. Superimposed on this gradient, however, are two anomalous points at 67.5 and 87.5 mbsf, which have temperatures 1.6°C and 2.5°C higher than predicted by the linear gradient, respectively. These points are attributed to local advection of warm fluids along fault zones delineated by the logs. The limited vertical extent of the anomalies, however, indicates small spatial diffusion of the temperature signal, and requires very recent fluid flow (within the last 10 years).

The temperature distribution also constrains the hydrate stability field at Site 892. The temperature gradient predicts the base for the stability field of hydrate formed from pure-methane/pure-water at 120 ± 4 mbsf. The BSR, which is commonly interpreted to indicate the base of the hydrate zone, is situated at 68 mbsf. The disparity between the measured temperature and predicted temperature at the BSR (2.1°C) suggests that the experimentally derived phase boundary for pure-methane/pure-water is not directly applicable to the gas-hydrate system on this margin. Application of the theoretical stability zone for pure-methane/pure-water hydrate to the temperature anomalies noted in Hole 892A would imply two or more layers of hydrate stability. Resolution of the apparent disparity between the theoretical gas-hydrate stability field and the position of the base of that field observed at Site 892 must await determination of the gas composition of the hydrates and may require experimental determination of an appropriate gas/seawater hydrate stability field.

The drillstring packer experiment determined that the pressure of the fluid in the formation at Site 892B is about 0.2 MPa above hydrostatic. However, because the hole was open for at least 36 hours prior to the test, the apparent formation pressure does not represent an equilibrium condition. A post-cruise record of pressure (and temperature) recovery at Site 892B will come from the borehole seal (CORK) deployed in this hole.

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FIGURES

Figure 1. Location map showing position of Cascadia continental margin, convergence of the Juan de Fuca plate relative to the North American plate, and the positions of sites drilled on Leg 146.

Figure 2. Location of Site 888 relative to the base of the continental slope (approximately 2300 mbsl) and the northern margin of Nitinat Fan. Contour interval, 100 m. Mottled areas are closed depressions.

Figure 3. Location of Sites 889 and 890. The Cascadia Basin continental slope boundary is defined by the 2500 m contour line. Contour interval, 100 m. Mottled areas are closed depressions.

Figure 4. Line drawing of seismic reflection line 89-08, showing position of Site 889 on seismically incoherent accretionary deposits and overlying bedded sediments of the mid-slope, the thrust sheets of the lower slope, and undeformed Cascadia Basin deposits to the west.

Figure 5. Position of Sites 891 and 892, seismic reflection lines OR-5 and OR-9, adjacent bathymetry (in meters), and position of thrust faults on the Oregon continental margin.

Figure 6. Line drawing of MCS line OR-9 (after MacKay et al., 1992). Site 892 is located at shotpoint 440. Heavy lines indicate positions of inferred faults. Vertical exaggeration is approximately 2:1 at the seafloor.

Figure 7. Comparison of porosity as a function of depth, derived from shipboard measurements of physical properties, from geophysical logs down Hole 888B, and from seismic interval velocities obtained from multichannel seismic reflection line 89-04. Measurements of porosity made on samples with a pycnometer are represented by vertical crosses. Porosity estimated from the GRAPE-determined bulk density, using a grain density of 2.8 Mg/m^3, is shown by individual points that plot on vertical lines spaced by the measurement increment. A thick dashed line is the best-fitting logarithmic curve through the GRAPE data. The curves for the porosities derived from the density log, neutron log, resistivity log, sonic log, and seismic reflection data are indicated by labels on the plot. Porosity was derived from the density log, using a grain density of 2.8

Mg/m^3. Porosity was derived from the sonic log and seismic reflection data using the empirically derived relation: porosity = -1.18 + 8.607/velocity - 17.89/velocity^2 + 13.94/velocity^3, from Hyndman et al. (1992). Also shown are empirically derived reference curves for normally compacted sand, clayey silt, and silty clay, from Brückmann (1989).

Figure 8. Plot of first arrival times of seismic waves (converted to two-way travel time below seafloor) against depth of the downhole geophone in the VSP at Site 889. From these data, the reflection time of the BSR below seafloor (276 ms) is found to correspond to a depth of 225 mbsf. By fitting a smooth curve through the time-distance points and differentiating it, the broad variation in velocity in the region of the BSR has been derived. Velocity gently increases to a maximum at about 210 mbsf, beneath which it decreases with an increasing steepness to a value of about 1.1 km/s at 238 mbsf. The velocities lower than 1.5 km/s could be caused by the presence of a small quantity of free gas (<5%) in the sediment. The increased velocity above the BSR could be produced by the presence of hydrate.

Figure 9. Line drawing of seismic section OR-5, showing position of Site 891, which penetrates the frontal thrust fault (after R. von Huene, pers. comm).

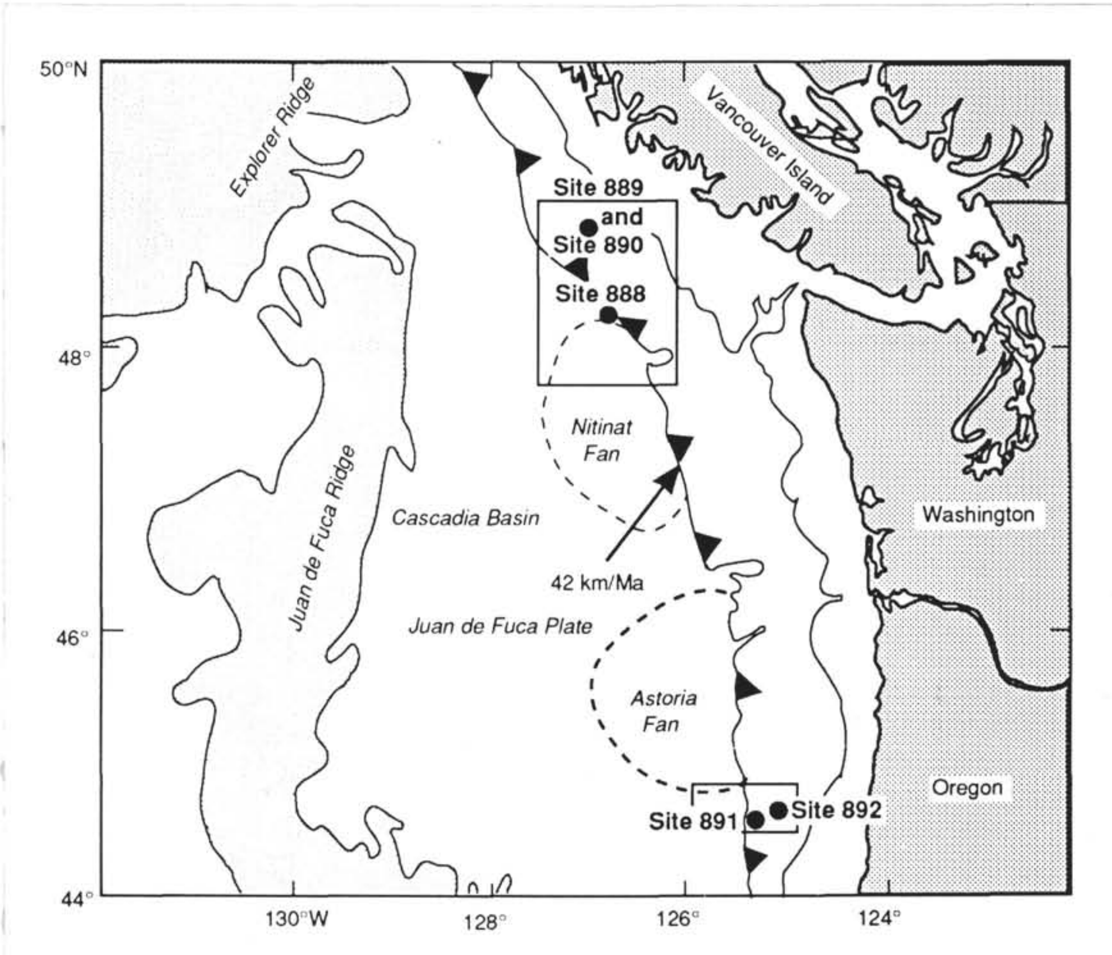

50°N
48°
46°
44°
130°W
128°
126°
124°
Explorer Ridge
Vancouver Island
Site 889
and
Site 890
Site 888
Nitinat
Fan
Juan de Fuca Ridge
Cascadia Basin
42 km/Ma
Juan de Fuca Plate
Washington
Astoria
Fan
Site 891
Site 892
Oregon

Figure 1

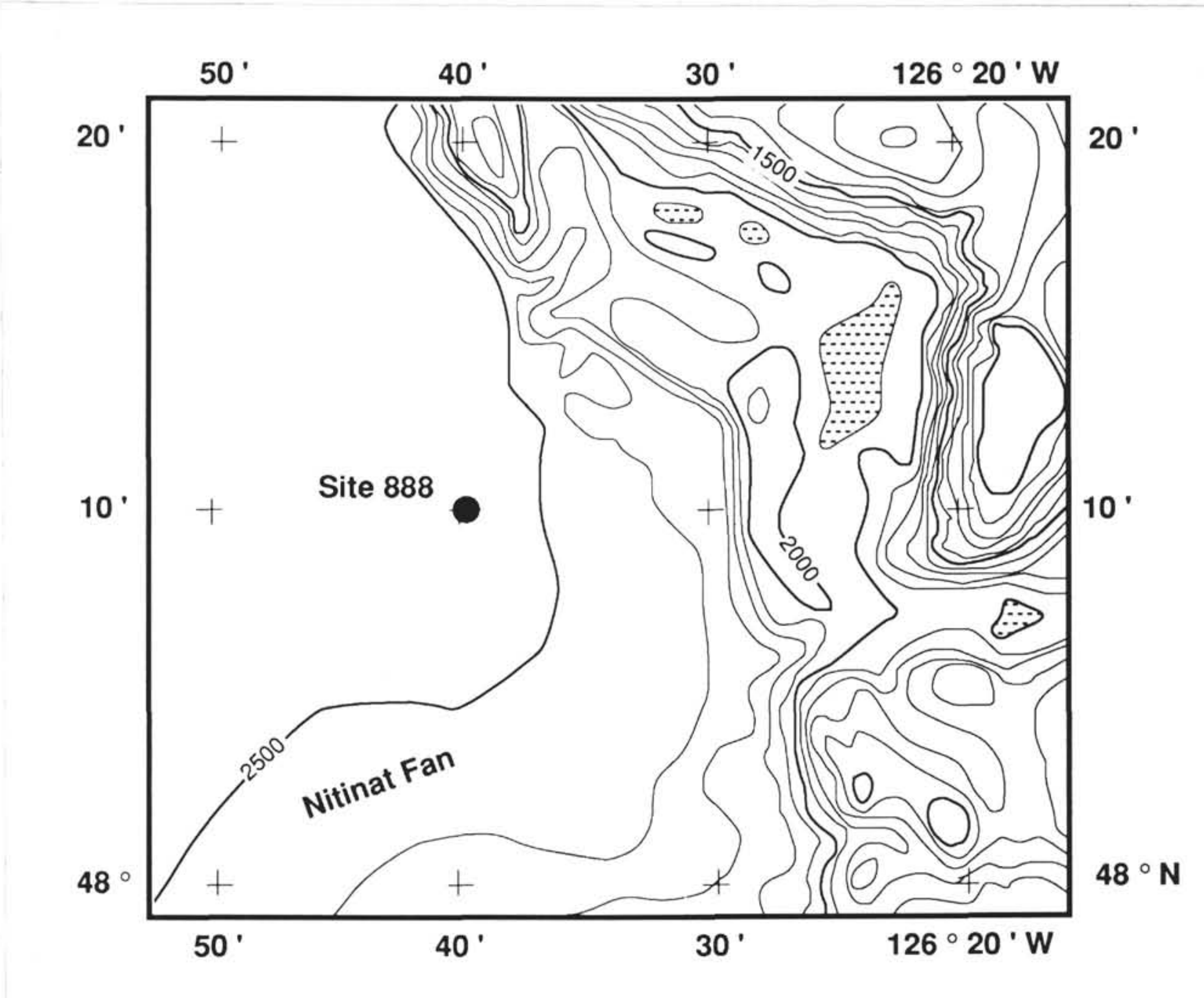

50'
40'
30'
126° 20' W
20'
20'
1500
Site 888
10'
10'
2000
2500
Nitinat Fan
48°
48° N
50'
40'
30'
126° 20' W

Figure 2

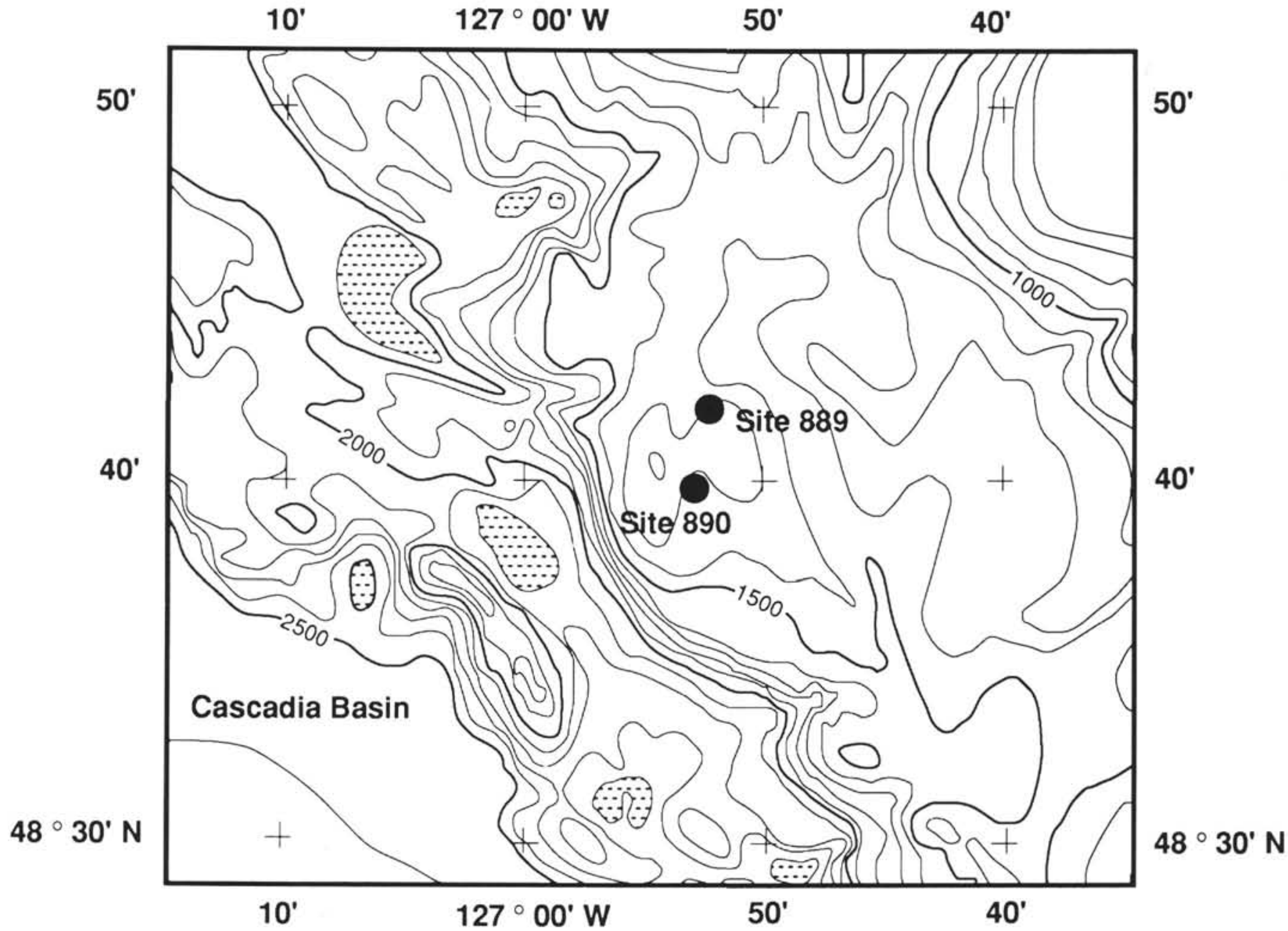

10'
127 ° 00' W
50'
40'
50'
50'
1000
Site 889
2000
40'
40'
Site 890
1500
2500
Cascadia Basin
48 ° 30' N
48 ° 30' N
10'
127 ° 00' W
50'
40'

Figure 3

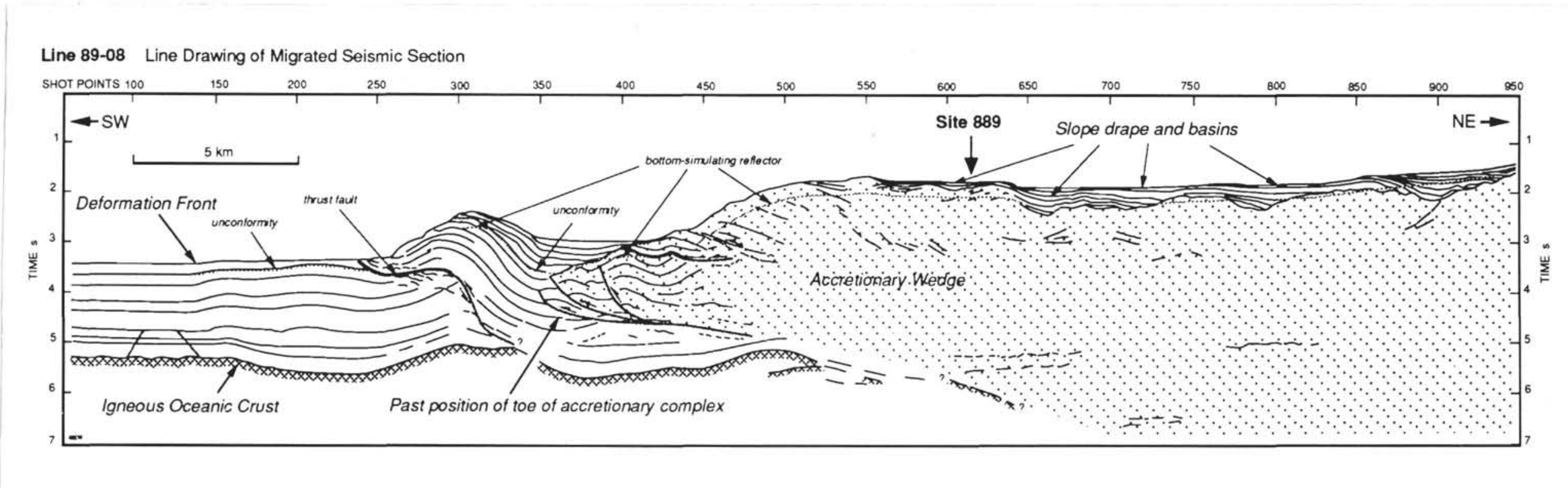

Line 89-08 Line Drawing of Migrated Seismic Section
SHOT POINTS 100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
SW
NE
Site 889
Slope drape and basins
5 km
bottom-simulating reflector
Deformation Front
thrust fault
unconformity
unconformity
Accretionary Wedge
Igneous Oceanic Crust
Past position of toe of accretionary complex
TIME s
1
2
3
4
5
6
7

Figure 4

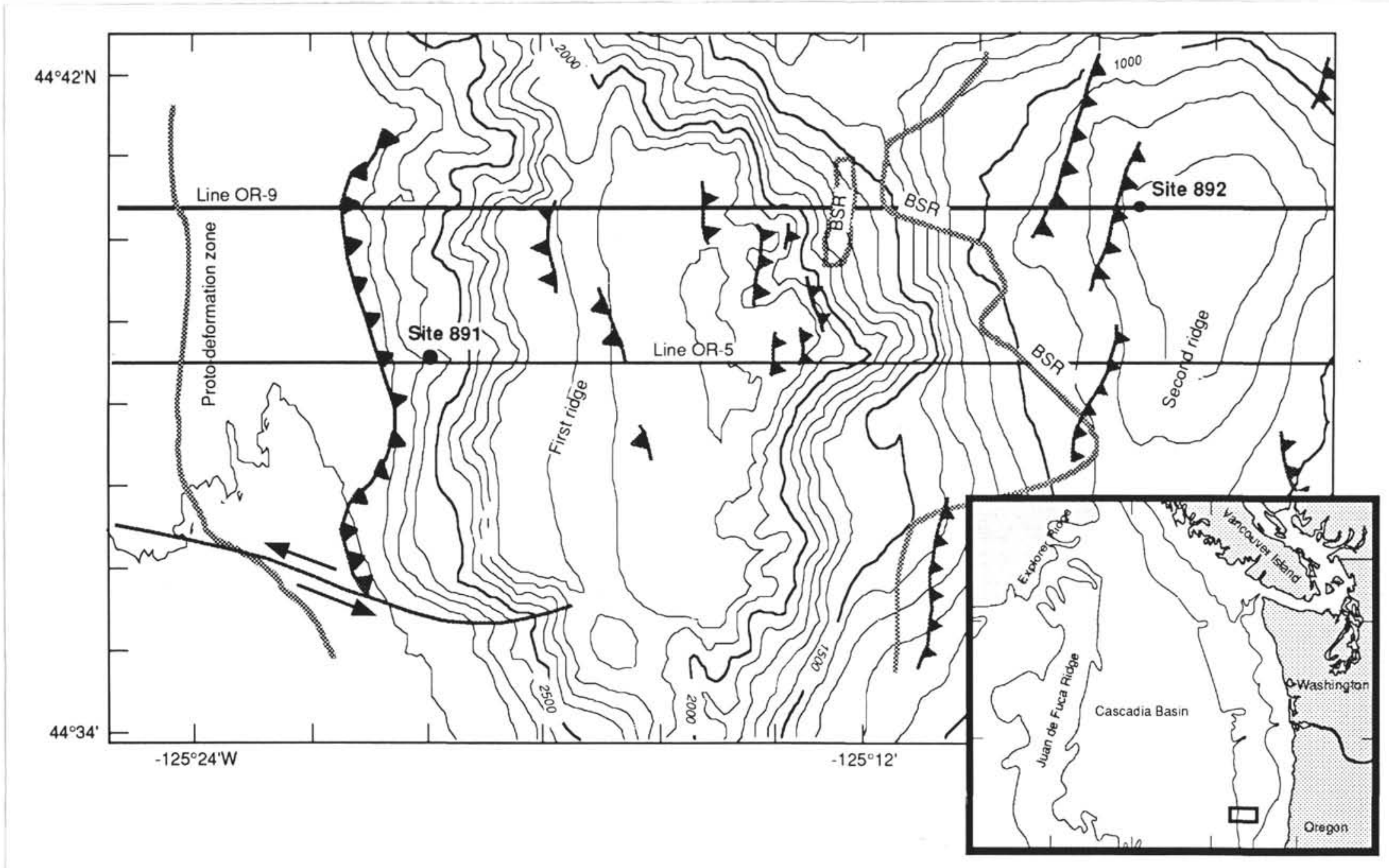

44°42'N
44°34'
-125°24'W
-125°12'
Line OR-9
Line OR-5
Proto deformation zone
Site 891
Site 892
First ridge
Second ridge
BSR
BSR
BSR
1000
1500
2000
2000
2500
Explorer Ridge
Vancouver Island
Juan de Fuca Ridge
Cascadia Basin
Washington
Oregon

Figure 5

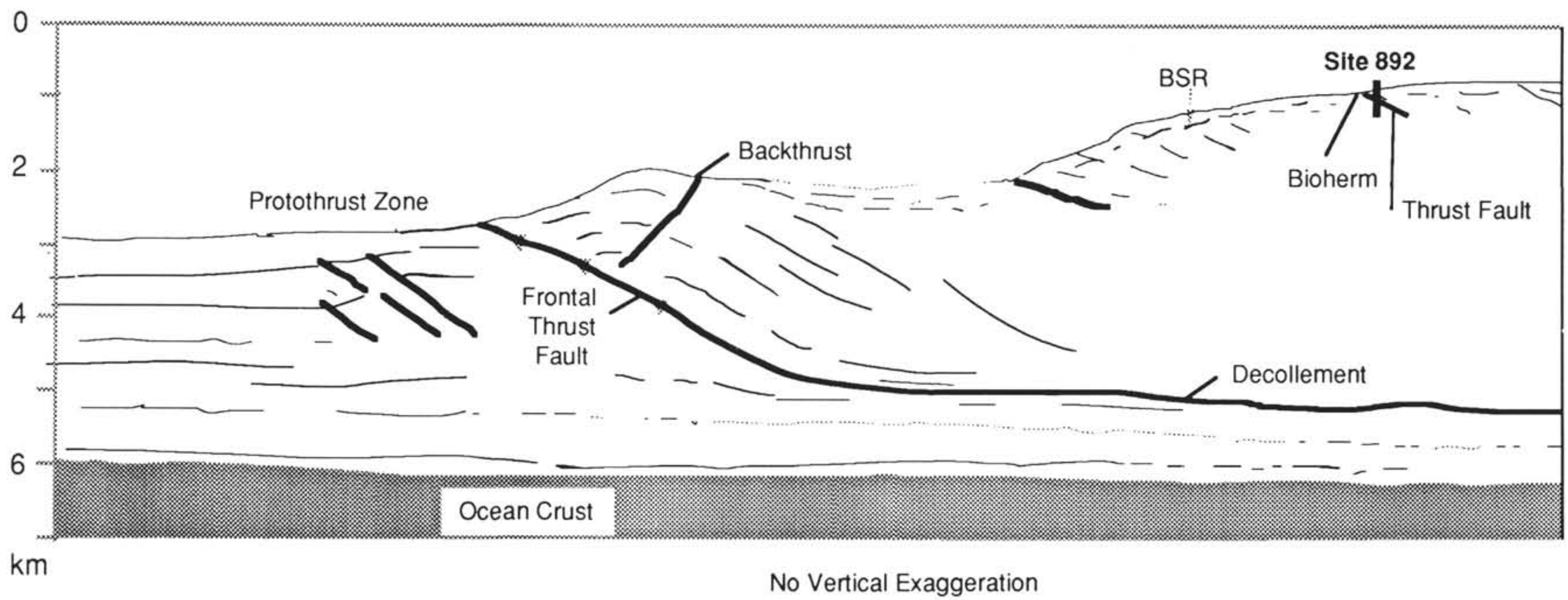

0
2
4
6
km
Site 892
BSR
Backthrust
Bioherm
Thrust Fault
Protothrust Zone
Frontal
Thrust
Fault
Decollement
Ocean Crust
No Vertical Exaggeration

Figure 6

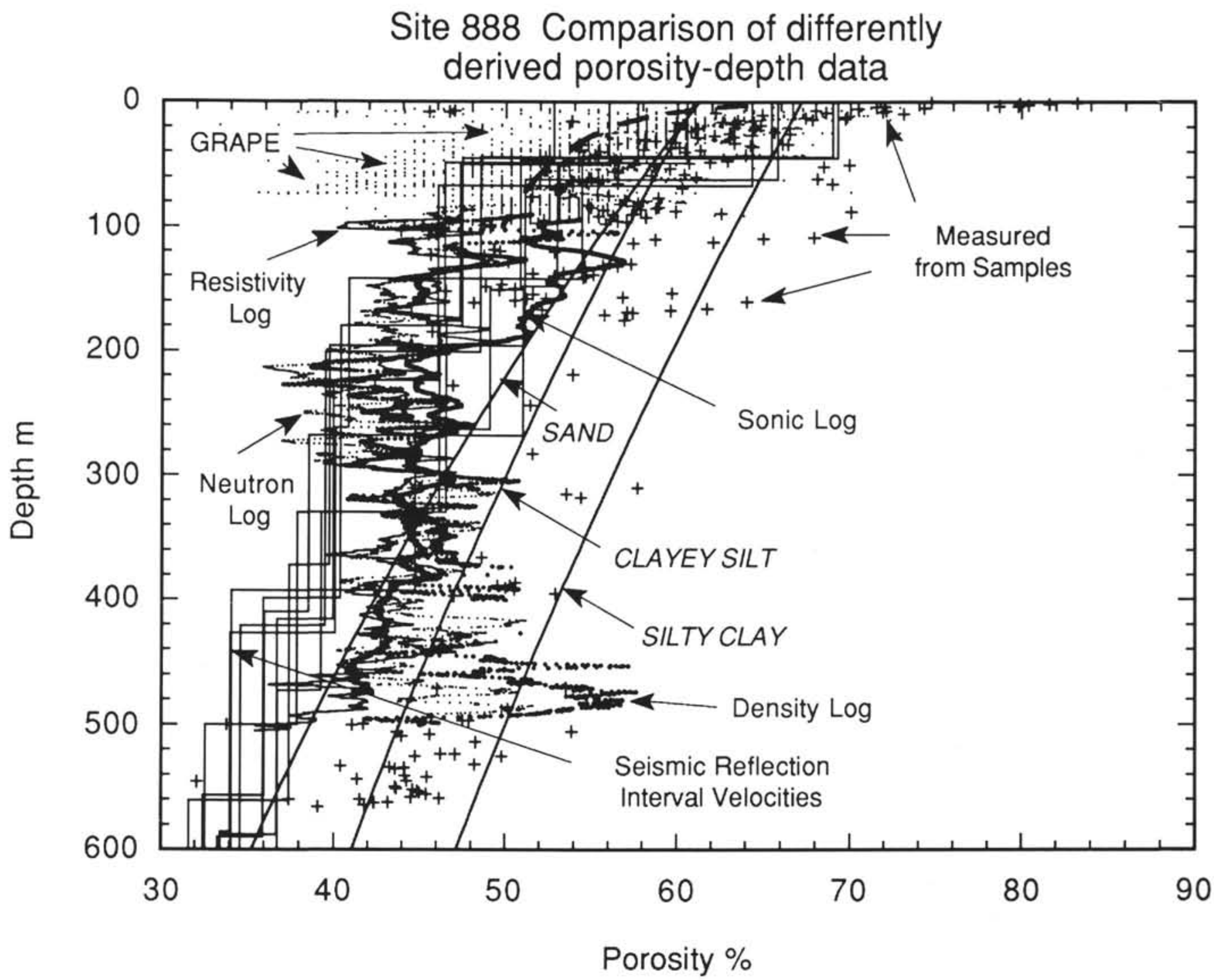

Site 888 Comparison of differently
derived porosity-depth data
GRAPE
Resistivity
Log
Neutron
Log
Measured
from Samples
Sonic Log
SAND
CLAYEY SILT
SILTY CLAY
Density Log
Seismic Reflection
Interval Velocities
Depth m
0
100
200
300
400
500
600
30
40
50
60
70
80
90
Porosity %

Figure 7

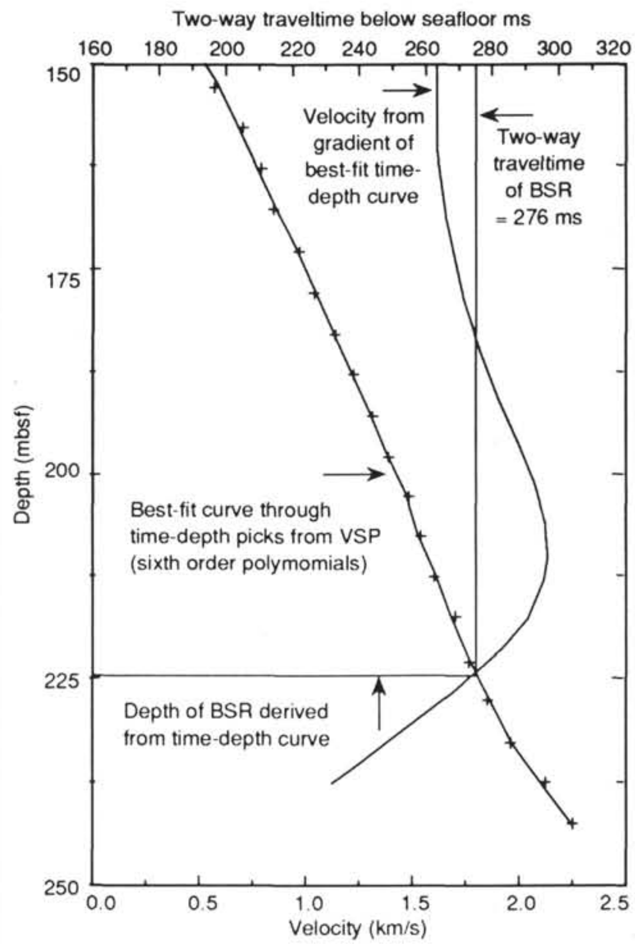

Two-way traveltime below seafloor ms
160 180 200 220 240 260 280 300 320
Depth (mbsf)
150
175
200
225
250
Velocity from gradient of best-fit time-depth curve
Two-way traveltime of BSR = 276 ms
Best-fit curve through time-depth picks from VSP (sixth order polymomials)
Depth of BSR derived from time-depth curve
0.0 0.5 1.0 1.5 2.0 2.5
Velocity (km/s)

Figure 8

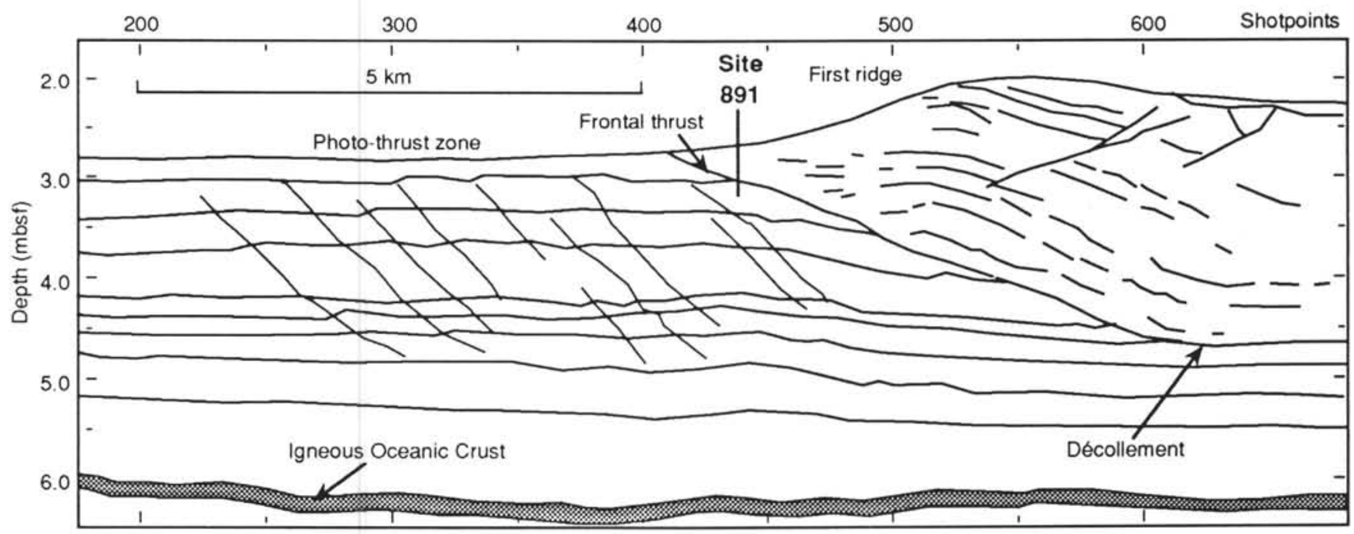

200
300
400
500
600
Shotpoints
5 km
Site
891
First ridge
Frontal thrust
Photo-thrust zone
Depth (mbsf)
2.0
3.0
4.0
5.0
6.0
Igneous Oceanic Crust
Décollement

Figure 9

OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 146 were:

Operations Superintendent:	Glen Foss
Development Engineer:	Tom Pettigrew
Schlumberger Engineer:	Steven Kittredge
LDGO Logging Technician:	Katherine Rodway

OVERVIEW

Leg 146 of the Ocean Drilling Program was dedicated to the study of the Cascadia convergent continental margin. Drilling was concentrated in two primary areas of the margin, the Vancouver Island and central Oregon Coast regions. Principal topics of investigation included the effects of subduction and accretion on the fluids and sediments at the continental margin, as well as the occurrence of gas hydrates and their relationship to bottom-simulating reflectors present in the area. A final site in California's Santa Barbara Channel was devoted to shallow holes for paleoclimatic studies.

The drillship *JOIDES Resolution* departed Victoria, B.C., on 25 September 1992 and reached port in San Diego, CA, on 22 November 1992. Coring and downhole measurements were carried out at three sites (nine holes) on the Vancouver Island Margin, two sites (eight holes) on the Oregon Coast, and one site (two holes) in the Santa Barbara Channel. In addition, a previously drilled hole on the Juan de Fuca Ridge was visited for the purpose of servicing a borehole seal.

Drilling and downhole-measurement activities were intense for the entire expedition, and a wide variety of systems and instrumentation was utilized. Much of the operationally ambitious leg was conducted under hostile downhole and environmental conditions. An unusual 7-hr weather shutdown occurred, as well as the loss of three drilling assemblies to unstable hole conditions.

Accomplishments of particular note were the installation of instrumented borehole seals in cased reentry holes at the Vancouver Island and Oregon areas and the first successful permeability measurements using an inflatable packer in an accretionary margin.

VICTORIA PORT CALL

Leg 146 of the Ocean Drilling Program began at 1030 hr (all times are local) 20 September 1992 with the first mooring line at Ogden Point Docks, Victoria, B.C. The arrival was nearly a full day ahead of schedule due to unforeseen operational circumstances at the final drilling site of Leg 145.

The unscheduled first day in port was put to good use as much of the 5-in. drill pipe in the racker was broken down for shipment.

Port-call activities began in earnest on 21 September as ODP and ODL crew changes took place and offloading of the drill pipe began. Important work items accomplished during the port call in addition to crew changes, routine resupply, and public relations functions included:

- augmentation of the reentry coaxial cable winch drum capacity by extension of the flanges;
- loading 270 joints new and 153 joints recoated 5-in. drill pipe and assembling it into stands;
- repair and augmentation of the DCS data acquisition system;
- replacement of a deteriorated main seawater cooling line in the engine room;
- weld repairs by divers to a rudder stock packing ring;
- replacement of thruster #9 pinion shaft;
- loading 74 m.t. bentonite and 83 m.t. barite;
- loading three CORK assemblies with related tubulars, ROV platforms, instrumentation, running tools, perforated liner, etc.; and
- receiving over 548,000 gallons of marine diesel fuel.

With scheduled port-call tasks complete, the vessel departed Victoria at 0900 hr 25 September.

VICTORIA TO SITE 888

Despite opposing winds, which held the ship's speed to about 10.5 kt, only 13 hr was required to transit the Strait of Juan de Fuca and reach the Vancouver Island Margin operating area. No seismic profiling was done; the vessel was navigated to the geographic coordinates of the first site before thrusters and hydrophones were lowered and final positioning was achieved in dynamic positioning (DP) mode. A positioning beacon was launched at proposed site VI-1 at 0100 hr 26 September.

SITE 888 (VI-1), CASCADIA BASIN

Site 888 was the seawardmost of the proposed Vancouver Island sites and was situated seaward of the deformation front of the accretionary prism. Its primary purpose was to provide a reference section for study of chemical, thermal, physical, and hydrologic characteristics of the undisturbed upper sediment column. The location was about 67 nmi southwest of Cape Beale on Vancouver Island and about 76 nmi west-southwest of Cape Flattery, Washington.

HOLE 888A

The initial pipe trip was slowed by measuring and drifting operations normally performed on the drill string during the first pipe trip of a leg and also by the requirement to "double-break" the connections on 26 stands of new drill pipe. After eight hours of tripping, the advanced piston corer (APC) had been lowered to the bit, and Hole 888A was spudded exactly 24 hr after the last mooring line had been cast off in Victoria.

Because of high sampling demand, the operating plan called for dual APC "mud-line" cores at Site 888. The first core was "shot" from 2527 m, 6 m above the corrected precision depth recorder (PDR) depth, in an attempt to determine water depth and to provide a short core for supplementary sampling. A full core barrel was recovered, however, raising doubts as to whether the sediment/water interface had been recovered.

HOLE 888B

The bit was raised 4 m above the previous core depth, and the second APC core was attempted. The recovered core was almost exactly 4 m shorter than Core 888A-1H, indicating that the bit had been placed just at the seafloor for the first core and that seafloor depth was 2527 m below driller's datum.

APC coring then continued, with magnetic orientation and temperature shoe measurements beginning with Core 3H. The sediments were clay and silt with interbedded sand. Water sampling temperature probe (WSTP) probe runs were made following Cores 5H, 8H, 11H, 12H, and 17H. Core 12H, in sand, gave incomplete stroke indication. Full-stroke indication returned for Cores 13H-17H; temperature shoes were discontinued after Core 11H due to overpull in excess of 60,000 lb. Overpull exceeded 110,000 lb on Core 17H (to 151 mbsf), and APC refusal was indicated as nearly the entire core barrel had to be drilled over to achieve withdrawal.

Three extended core barrel (XCB) cores then were taken with fairly good recovery as clay gave way to sand with depth. As the sinker bars were being removed from the drill string to provide better coring hydraulics, they became stuck in the upper part of the top drive/swivel assembly and 1-1/2 hr was required to free them. Three additional XCB cores were attempted, with only a few cm of recovery; a WSTP run also was unsuccessful in the soft sand.

The coring mode was changed back to APC in an attempt to recover the loose sand. APC coring continued in the advance-by-recovery mode with consistent incomplete-stroke indications. The core barrels recovered a considerable amount of sand, but much of it was flow-in material resulting from the "hypodermic" action of APC withdrawal. Two WSTP attempts were unsuccessful in obtaining water samples or valid temperature data, but an APC shoe recorded good temperature data on Core 33H at 292 mbsf. The rebound of the APC being fired into the relatively incompressible sand resulted in APC Core 37H becoming stuck at the outer core barrel as the coring line became fouled with the GS retrieving neck. Attempts to jar and pull the APC free caused the coring line to part just above the rope socket. Lost time, including fishing the sinker bars and APC assembly, was about 7 hr. Two XCB cores then produced 90 cm of total core, so the APC again was deployed. On the first attempt (at 348 mbsf), the APC and coring line again became stuck. This time the sinker bars and APC were successfully recovered on separate wireline trips without the line breaking, but an additional 2 hr was lost.

XCB coring then continued in alternating clay and sand units, with fairly good coring results in clay but little or no recovery in sand. One additional WSTP probe run was attempted at 405 mbsf, but it was unsuccessful in sand. The clays and silts became increasingly indurated with depth and induced various mechanical failures of the XCB system. The most serious was the loss of the lowermost inch of a cutting shoe for the entire circumference of the shoe. The junk from that failure was augmented by tungsten carbide cutter inserts from other shoes. A flow sleeve was collapsed when a high circulation rate (440 gpm) was used in an attempt to prevent core jamming. High torque resulted in "belling" connections between cutter shoes and their adjacent subs.

Vessel heave to 10 ft and rolls to 10° on 29 and 30 September reached the operational limits of the rig, and a shutdown was narrowly avoided. Large swells from two directions, winds to 30 kt, and variable currents combined to force the vessel onto a high-roll heading. It was necessary to put the ship's stern into the wind, thereby putting the wind sensors in the lee and depriving the ASK system of that automatic input.

Low core recovery in unconsolidated sand prompted a trial run of the vibra-percussive corer (VPC) at 452 mbsf. The attempt was unsuccessful because circulation could not be established through the corer to actuate the hydraulic hammer.

At 514 mbsf, the pressure core sampler (PCS) was deployed. A 1-m core was attempted with normal parameters. The PCS was found to be stuck at the bit when the pulling tool was engaged to recover it. In jarring the PCS loose, the shearpin of the GS pulling tool failed, and it was necessary to make a second wireline trip to recover the sampler. Upon recovery to the rig floor, the PCS ball valve was found to be open and the closing mechanism only partially stroked. Sand in the mechanism was blamed for the impaired function and for difficulty experienced in dismantling the sampler for redressing.

Coring operations were terminated at 567 mbsf with Core 65X. Most scientific objectives had been realized and no more time was to be spent in reaching the original 600-m penetration objective.

A wiper trip then was made to 73 mbsf in preparation for logging operations. No resistance was encountered except for drag up to 50,000 lb in the uppermost 31 m of the section. The tight hole was cleaned out easily, and no drag was experienced on the trip back toward total depth. The top drive was picked up for the final cleaning of anticipated fill at the bottom of the hole. When the drill string had been lowered to within 22 m of total depth, it began "taking weight." The string was raised immediately, and the pump was started. At that point, the pipe was found to be firmly stuck, though circulation could be maintained at somewhat elevated pressures. A tendency for 300-500 psi standpipe pressure to persist after cessation of pumping suggested that cuttings or sand had collapsed into the hole and bridged around the drill string, forcing circulation out into the permeable sand formation.

After 4 hr of attempting to free the pipe, the back-off string shot was prepared, and the logging sheaves were rigged. The back-off approach was elected to preserve the logging option in case only a small amount of drill string was left in the hole. In an attempt to save valuable lower bottom-hole assembly (BHA) components, the first shot was attempted at the outer core barrel (OCB) in the hope that the bit was stuck. The shot rod was inadvertently lowered to the bit during a depth check with the casing collar locator (CCL), and the rod became fouled with the flapper of the lockable float valve (LFV) assembly. To avoid damaging the charge or cable, the first charge was fired at the bit sub; it was ineffective in freeing the pipe.

A second back-off charge was detonated at the top of the uppermost drill collar on the chance that the string was stuck at the BHA diameter increase. The string remained stuck. As the sticking obviously was higher in the hole, the approach was switched to the more positive severing charge. Severing charges were detonated at 367 mbsf (above a likely bridging zone) and 187 mbsf (near the top of the sand section). Neither freed the pipe, but reductions in circulating pressure indicated that the pipe had been ruptured. The pipe was "worked" after each attempt and showed some sign of movement after the latter shot. In addition, a lack of residual standpipe pressure indicated that circulation up the annulus had been regained. Some vertical movement, and eventually rotation, was regained after overpulls of up to 350,000 lb. The string finally came free after two stands of pipe had been pulled, indicating that the top of the sticking zone had been at about 130 mbsf.

Upon review of the events, it appears that the original sticking occurred when a mass of sand or cuttings was dislodged by the wiper trip and flowed down the hole, bridging around the drill string at some point above the BHA. During the protracted efforts to free the string low in the hole, swelling clays stuck the upper part.

When the pipe had been freed, the upper part of the hole was filled with weighted drilling mud before the trip out with the abbreviated drill string.

HOLE 888C

Because downhole science was a major objective of the site, a dedicated hole for logging was considered to be warranted. The drillship was offset about 73 m southwest of Hole 888B during the pipe trip.

A tri-cone drill bit was selected to maximize penetration rate, and a mechanical bet release (MBR) disconnect modified for use with a drill bit was used. A new BHA was assembled and run to the seafloor.

Hole 888C was spudded at 0515 hr 3 October and was drilled to 600 mbsf with interruptions only for mud sweeps at 200 and 400 mbsf. Each drilled interval was double-reamed before the connection was made, and there was no excess torque or fill on connections. Because of better hydraulics and the more efficient design of the drilling bit, rotating time was reduced from 17-1/2 hr in 888B to 7-1/2 hr. Total drilling time was 18-1/4 hr. After a 50-bbl mud sweep at total depth, two wireline runs were made to release the bit and to downshift the MBR sleeve. The end of the pipe then was pulled to 102 mbsf for logging.

To minimize mechanical disruption of the borehole and/or degradation of the hole wall with time, logging commenced immediately without a wiper trip or rigging of the side-entry sub (SES). Tests had shown only minimal clay instability in seawater, so the hole was not filled with inhibited logging fluid.

The first logging run was with the heavy "quad-combo" tool string. The tool encountered some resistance or "drag" in the upper part of the hole but reached 513 mbsf before coming to rest on a bridge (or fill) in the hole. The log was recorded up to 73 mbsf, as the drill string was raised ahead of the logging tool by one stand as it ascended. As expected, the caliper log showed the hole wall to be irregular, with sand zones washed out and some clay intervals actually less than bit diameter. Very little of the hole was enlarged beyond the range of the caliper, however, and log quality was good.

The next scheduled run was to be a check-shot vertical seismic profile (VSP) using the Schlumberger well seismic tool (WST). A final tool check before lowering revealed a malfunction of the closing mechanism on the clamping arm. After an hour of troubleshooting, the tool was replaced by a backup WST. The tool met an obstruction at the end of the drill string, which was cleared by rigging a circulating head on the drill pipe and pumping with the rig pump. After the WST had cleared the pipe, it stopped repeatedly and had to be "worked" down the hole--probably partly because of progressive hole deterioration and partly because of light tool weight (one-sixth of the quad-combo's). An operational check of the tool was made about 100 m beyond the pipe. Lack of response to clamping commands and test shots from the water gun indicated that power was not reaching the WST. The tool was recovered, and the electronics were found to be flooded.

Because of the difficulty in lowering the WST, the drill string was run back into the hole to clean it out while a third WST was readied. "Drag" on the drill string increased with depth, and the circulating head was rigged at 315 mbsf when it had increased to 25-30K lb. The open-ended pipe was circulated to 358 mbsf, where it met a solid obstruction. Without a bit, there was little hope of opening the hole deeper--even with the top drive. As the open-hole interval was too short to satisfy the VSP objectives, and because the operation was falling behind schedule, logging operations were terminated.

Before recovery of the drill string began, the hole was filled from 358 to 182 mbsf with heavy drilling mud. The end of the pipe then was pulled to 182 mbsf, and a cement plug calculated to extend up to 159 mbsf was emplaced.

The two positioning beacons were recalled during the pipe trip. Beacon s.n. 764 responded to the release command by changing its pulse repetition rate (PRR), but the unit did not surface. The other beacon was recovered successfully. The BHA had been recovered at 0445 hr 5 October.

SITE 889 (VI-5), VANCOUVER ISLAND ACCRETIONARY MARGIN

The Vancouver Island Margin site targeted for the most extensive investigation was located about 33 nmi north-northwest of Site 888 and about 43 nmi south-southwest of Point Estevan on Vancouver Island. Only 3-3/4 hr was required for the short transit. An additional 3/4 hr was spent in lowering thrusters and hydrophones, and a positioning beacon was dropped at the desired prime location at 0930 hr 5 October.

The operating plan included multiple holes and a reentry hole to be retrofitted with a CORK installation and long-term pressure and temperature monitor. The original beacon drop was near the planned reentry hole. Supplementary holes were to be located at a distance of 200 m or greater from the reentry hole to minimize chances of hydrologic influence on the borehole.

Because the drill site was less than 10 nmi from the center of an old munitions dumping ground, certain safety precautions were imposed by the Canadian government. They included the requirement to conduct a video survey of the seafloor in the drilling area to ascertain that the seafloor was clear of hazardous objects and also a prohibition on coring the uppermost 20 m of the sediment section.

After a two-hour test of the vibra-precussive core (VPC) system at the rig floor, an APC/XCB BHA was made up and run to the seafloor. The vibration-isolated TV (VIT) frame was lowered along with the string, and a brief video/sonar survey was made of the beacon location and the proposed reentry drill site 20 m away. To measure water depth accurately, the seafloor was tagged with the bit while being observed by TV. The measured depth was 1325 m from driller's datum.

A jetting test then was performed to determine the depth to which 16-in conductor casing could be set for the planned reentry-cone installation. The bit was jetted, without rotation, to 55 mbsf with a maximum circulation rate of 275 gpm and a maximum weight of 14,000 lb applied to the bit. Though further jetting would have been possible with those parameters, 55 m was considered more than an adequate length of 16-in casing to support the reentry cone and anticipated short 11-3/4-in casing string. The bit was pulled clear of the seafloor for the move to the location of the exploratory hole.

The VIT frame had remained just above the seafloor during the jetting operation, so the video survey commenced as offsetting began. The move and survey began smoothly except that sediment scraped from the BHA by the VIT obscured the seafloor at times. As the distance between holes was to be about 200 m, and the maximum dependable beacon positioning range was about 130 m (10% of water depth), the move was halted momentarily for the launch of a positioning beacon. The new beacon would extend the offsetting range and act as a backup reference for both the reentry hole location (Hole 889B) and the planned supplementary holes (Hole 889A and Hole 889C). The move had resumed before the beacon reached the seafloor, and the signal was noted to be of suspect quality. A backup beacon was launched immediately. Two minutes later it was seen to be floating near the ship. The crane was manned and the ship was diverted from its offset track to recover the beacon. More "chasing" was required than expected, and about an hour was required to bring the beacon aboard and return the ship to the planned Hole 889C location, where a third beacon was launched. The diversion resulted in a more extensive video survey than had been anticipated; however, no man-made objects were identified.

The latest beacon produced a totally unusable signal, but the ship was able to position on the original beacon (200 m away) and the second "flaky" signal (100 m away) to begin operations at Hole 889A. An additional beacon was launched during coring operations the following day.

HOLE 889A

Before the VIT was recovered, it was used for viewing contact of the bit with the seafloor at 1322 m below driller's datum. The obligatory 20 m from seafloor to core point then was drilled, beginning at 0005 hr 6 October, and the APC was lowered into position.

Oriented coring began with Core 2H, with temperature shoes run on Cores 1H, 3H, 5H, 7H, 9H, and 13H. A WSTP run was made at 104 mbsf after Core 9H. Considerable hydrocarbon gas content caused disruption and expansion of cores from the beginning. Plastic core liners failed on three cores. Incomplete stroke of the APC began with Core 6H, and coring proceeded by the advance-by-recovery method through Core 16H at 129 mbsf, where penetration had decreased to nil. A PCS core was tried at 128 mbsf, with sediment and gas recovered under hydrostatic pressure.

Continuous XCB coring then proceeded, with additional WSTP attempts at 140 and 168 mbsf. The APC refusal point marked the approximate boundary between undisturbed slope sediments and the underlying sheared and fractured accretionary sediments of the continental margin. As coring progressed, circulating pressures were elevated, apparently due to plugged jet nozzles. Pressure was so high on Core 21X that the XCB flow tube collapsed and prevented any core from entering. One or more jets cleared on the following core, but high circulating pressure persisted. Five additional PCS runs were made, with the final one at 266 mbsf. Two of them recovered water under pressure, but no sediment was captured.

Hole conditions were good until the bit passed 300 mbsf, but they deteriorated quickly beyond that depth. After recovery of Core 44X, hole fill had increased to 14 m, and serious hole trouble was imminent. Coring was terminated at 345.8 mbsf because of poor hole conditions and a low rate of progress (ROP) of 5-6 m/hr.

The hole was swept with 25 bbl of extra-high-viscosity mud, and a wiper trip was made to 73 mbsf. No resistance was felt as the bit was raised and lowered--until it came to rest on fill 50 m above total depth. Cleaning the fill from the hole and circulating an additional high-viscosity mud flush consumed 3-1/4 hr. A second wiper trip was made to check hole stability. The result was a reduction in hole fill from 50 to 49.5 m. It was apparent that removal of the material from the hole was not possible with the available techniques, probably because an interval of excessive hole diameter reduced annular velocity and impeded cuttings transport.

A go-devil was pumped through the lockable float valve (LFV) to open it for logging, the bit was pulled to logging depth at 73 mbsf, and the logging sheaves were rigged. The logging program consisted of "quad combo" and FMS runs from 260 and 255 mbsf, respectively. Log quality was adversely affected by washed-out and irregular borehole walls.

Upon completion of logging operations, the hole was displaced with 11 lb/gal drilling mud from fill at 273 mbsf to about 145 mbsf. The bit then was pulled to 145 mbsf, where a plug of cement was spotted to fill the hole to about 125 mbsf. After the plug was set, the drill string was pulled clear of the seafloor and flushed to clean out any remaining cement slurry.

SITE 890 (VI-5)

Because of the proximity of Site 889 to the munitions dumping ground, it was necessary to move farther south to core the uppermost 20 m of the sediment section. As that core was of high scientific interest, the addition of a site for shallow coring was warranted.

The drillship was moved in DP mode with the drill string suspended (with knobby joints past the keel) and navigation by GPS. A beacon was launched at the new position at 1100 hr 9 October. The string of beacon misfortunes continued, as the signal was found to be of poor quality when the beacon landed. A second unit was dropped a half hour later as spud preparations began.

HOLE 890A

During the move, the PDR profile had displayed a "side echo" as the vessel had approached a bathymetric feature about 20 m higher than the surrounding seafloor. As the ship took station at the drilling location, the shallower reflector had become dominant. Because there was doubt as to which reflection represented the seafloor directly beneath the rig, the spudding plan included lowering the bit until it actually tagged the seafloor as sensed by the driller's instrumentation before actuating the APC. All observers agreed that the weight indicator "steadied up" and the motion compensator began to close when the bit reached about 1308 m. An APC core then was "shot" from 1305 m in an attempt to core the seafloor interface. Nothing but water was recovered. More pipe was added to the string and another apparent weight indication was seen at about 1337 m. The next attempt was from 1333 m, and sediment was recovered by the corer, but the core liner and the piston pin had both failed. The core (890A-1H) was in poor condition, with some apparently lost and other parts disturbed in the process of removal from the core barrel. A second, less disturbed, core of the interval was requested, so the bit was repositioned to 1335 m for a respud.

HOLE 890B

On the second attempt, an undisturbed seafloor core was recovered, and the seafloor depth was established at 1337.2 m. Four consecutive APC cores then were taken, with temperature-recording shoes on Cores 2H and 4H. No core was recovered in 4H due to a liner failure, which apparently also affected the temperature measurement adversely. Following the retrieval of Core 4H, the first deployment of the lateral stress tool (LAST-2) was made. The tool appeared to function as designed. Because of the failure of Core 4H, an additional core was requested to complete the overlap in section with Site 889. The APC was fitted with a temperature-recording shoe, the 2.5 m of hole disturbed by the LAST probe was drilled out, and Core 5H was taken from 38.3 to 47.8 mbsf.

The drill string then was recovered, ending Site 890, and the two positioning beacons were recalled.

RETURN TO SITE 889

HOLE 889B

During the pipe trip for an RCB BHA, the vessel was offset in DP mode to the proposed location of the second exploratory hole, and a new positioning beacon was placed. The VIT was deployed and run down with the pipe for a seafloor survey. The beacon was videotaped, and the seafloor was searched as the offsets were entered to move the pipe to the drilling location. No hazardous or man-made objects were sighted. After seafloor depth was determined to be 1327 m by observing bit contact with the TV, the VIT was recovered in preparation for spudding.

The hole was drilled without difficulty to 197 mbsf, where a mud sweep was circulated and the "wash barrel" was retrieved. The WSTP probe was run to record sediment temperature prior to commencement of coring. Core 1R had no recovery, which was initially attributed to an excessive circulation rate during the coring operation. The next core barrel contained only a small carbonate concretion in the core catcher. As the presence of additional concretions could block the core throat of the bit, the bit deplugger was pumped to the bit and recovered before coring continued. Core 3R recovered 2.3 m of sediment core--but four meters of hole fill had accumulated when the pipe connection was made.

Inadequate hole cleaning persisted, with 1-6 m of fill despite mud sweeps of various volumes on every core. A badly needed WSTP run was made after Core 5H but was unsuccessful because the fill could not be cleaned completely from the hole. Carbonate concretions interfered with core recovery on two or three occasions. Below about 330 mbsf, core recovery decreased, and hole conditions began to deteriorate progressively. Torque and circulating pressure began to build during Cores 20R and 21R and did not respond to mud sweeps. When 14 m of fill accumulated during the retrieval of Core 21R, coring operations were terminated at 386.5 mbsf.

To prepare the hole for logging, a 30-bbl sweep of extra-high-viscosity pre-hydrated bentonite mud was circulated, and a wiper trip was made to 71 mbsf (with slight overpull up to 238 mbsf). When the bit was run back, fill was found at 305 mbsf. After 3-1/2 hr and three mud sweeps, the hole had been cleaned only to 338.5 mbsf, and opening any additional hole for logs appeared futile. The "wash" barrel was recovered, and the MBR was actuated by wireline to release the bit at 331 mbsf. The pipe was then pulled to 89 mbsf, and the logging sheaves were rigged.

The first logging attempt with the seismic stratigraphy tool string could not pass an obstruction at 238 mbsf. A log was recorded up to 61 mbsf by raising the drill string one stand in the derrick. An attempt was made to clean the hole deeper with the drill string in case the obstruction was only a bridge, but the open-ended BHA was stopped by "tight hole" at 297 mbsf. Because logging the bottom-simulating reflector (BSR) was an important site objective, the situation warranted deployment of the side-entry sub (SES) to emplace the logging tools deeper in the hole. The SES was rigged in deteriorating weather and was used to obtain a seismic stratigraphy log from 259 mbsf. With the hole opened by the recent passage of the pipe, a formation microscanner (FMS) log was recorded from 251 mbsf without assistance from the drill string.

The second phase of the logging program was a "check shot" VSP using the Schlumberger (WST). The SES was used to place the WST at 243 mbsf, and the pipe was pulled up the hole to 107 mbsf (to minimize noise). The VSP was conducted with an array consisting of an air gun, a water gun, and a hydrophone on a 200-m cable--all suspended from #3 crane. Winds of up to 40 kt had produced 16-ft seas, a highly unfavorable environment for a seismic survey. The operation was interrupted twice and was complicated by handling problems when the array had to be recovered in the bad weather conditions for repairs to hose and gun leaks.

Upon completion of the VSP, the logging tools were rigged down and the pipe was run back as far as possible. The hole was filled with 12 lb/gal mud from 258 to 155 mbsf and then plugged with cement from 155 to 125 mbsf. The drill string then was tripped for emplacement of the reentry-cone installation.

HOLE 889C

The preassembled reentry cone was moved into position in the moonpool as soon as the BHA had been recovered. Final fit-testing of the casing hanger and running tool was done. Four joints of 16-in. conductor casing were made up, lowered into the reentry cone, and latched into the lower cone by means of the double-jay running tool. A specially-spaced BHA then was assembled, incorporating the running tool above sufficient drill collars to put the 14-3/4-in. jetting/drilling bit at approximately the level of the bit with the running tool jayed into the transition (casing hanger) joint. With the running tool engaged and the cone/casing/BHA a unit, the upper BHA stand was attached, and the entire assembly was lowered on the drill string.

The VIT was deployed for TV observation of the jetting and releasing operations just before the top drive was picked up and the drill string was spaced out for spudding. Hole 889C was spudded at midnight 14/15 October. The jetting operation encountered resistance from about 3-1/2 mbsf, and real difficulty was experienced from 7 mbsf. It was necessary to lift up the drill string repeatedly to break the casing loose from sticky upper clays, which seemed to reconstitute immediately around the casing. After three hours of jetting and moving the casing, the skirt of the reentry cone was landed at the seafloor with the casing shoe at 51 mbsf. The drill string was unjayed easily from the casing hanger, and release was verified by jetting a few meters beyond the casing shoe. The VIT was then recovered, and a ball was dropped to block some of the bit jets and provide better hydraulics for drilling ahead.

A 14-3/4-in. hole then was drilled to 300 mbsf with mud sweeps at 150, 200, 250, and 300 mbsf. No drilling problems occurred, and the hole seemed absolutely clean at total depth. The bit was pulled up to the casing shoe and held there for 2-3/4 hr while the upper stand of the cementing "stinger" for the surface casing string was assembled and stood back in the derrick. A quick trip back to total depth was then made for a check on hole conditions. Light reaming was required from 268 mbsf in hole that seemed only slightly under-gauge, and only 2 m of solid fill was found. The hole was swept with 50 bbl of pre-hydrated bentonite mud before the pipe was tripped for the surface casing string.

The 11-3/4-in. casing string consisted of 19 joints of range-3 casing and one telescoping "expansion" joint. When the casing had been assembled, it was landed on the moonpool doors while the cementing stinger was made up inside the casing with connections at the rig floor. The stinger was lowered until the running tool could be made up to the hanger in the moonpool. About 2-1/2 hr was lost when the hex-kelly running tool would not make up to the casing hanger and the running tool had to be replaced by the backup tool (which required some modification). The casing string then was lowered on drill pipe to reentry depth, and the VIT was positioned for reentry.

Reentry was routine, after which the VIT was recovered and the ball was pumped to the shoe to activate the float. The casing string encountered an obstruction at 117 mbsf, and the top drive was rigged to enable circulation. The resistance turned out to be a minor bridge. Two or three more bridges were knocked out, and up to 20K lb drag was noted on the final few meters before the casing landed in the reentry cone. The drill string was raised to verify that the snap ring of the casing hanger had engaged. Right-hand rotation was then used to release the casing string, and preparations were made for cementing.

The surface string was cemented into place with 100 bbl of 16 lb/gal slurry, which was followed by a latch-down top plug, 4 bbl of additional cement slurry, and 20 bbl of fresh water. The plug was displaced to the shoe with seawater until the plug "bumped" at the shoe. After the stinger was unseated, it was recovered with the drill string.

HOLE 889D

About 36 hr was required for the cement to cure before the shoe could be drilled out. The time was to be utilized to drill a dedicated hole for downhole measurements, including the APC temperature shoe and the LAST-2 and Geoprops instruments.

During the pipe trip, the ship was offset to the approximate coordinates of Hole 889A. Hole 889D was spudded at 1330 hr 17 October and was drilled to 80 mbsf for the first planned APC core. When the APC landed, the drill string could not be pressured up to actuate the corer. A high circulating rate was used to apply pressure to achieve some penetration, and the standard routine for temperature measurement was followed. Upon recovery, the shearpins were found to have failed prematurely before the APC was landed. No temperature data were collected due to an instrument failure. After a second drilled interval to 105 mbsf, another APC attempt was made. The same failure to build pressure was experienced, so the same procedure was followed in an attempt to acquire temperature data. When the APC was recovered, it was found that the pins had not sheared--apparently because of a failure of the seals to seat at the landing/saver sub. The temperature instrument functioned normally, but no data of value were collected because no sediment penetration occurred.

After an additional interval (to 140 mbsf) had been drilled, the "wash" XCB barrel was stuck at the bit. Two wireline runs were required before the barrel was jarred loose and recovered, apparently the latch dogs were stuck. The lateral stress tool (LAST-2) then was deployed, and pressure data were recovered (though the probe was slightly bent). After an XCB core to 149.5 mbsf and two mud sweeps, the motor-driven core barrel (MDCB) was used to cut a core and provide a 4.5-m "rathole" for the Geoprops probe. Unfortunately the probe only entered the hole by about 1 m--apparently due to hole fill--and the packer elements were not inflated. Temperature and other functions of the tool were tested, but no science was done.

During the latter tests in Hole 889D, weather and vessel-motion conditions had deteriorated. A wind gust of 68 knots was recorded while the hole was being filled with 12 lb/gal mud. The weather improved through the morning as the pipe trip was made, and the vessel was offset back to Hole 889C.

HOLE 889C (return)

After a routine reentry with a drilling BHA and tri-cone bit, cement was tagged just 10 m above the casing shoe. The cement drilled easily, but the plug and shoe required about 2-1/2 hr to drill out. The bit broke through the cement into open hole about 1-1/2 m below the shoe. Only three or four minor bridges and about 10 m of fill were encountered as the 14-3/4-in. rathole was cleaned out to the previous total depth of 1686 m, 42 m below the casing shoe. The hole was swept with mud before drilling resumed with the 9-7/8-in. bit. The planned total depth of 359.5 mbsf was reached without incident. After an additional mud sweep, the bit was pulled into the casing (25K lb overpull), and an hour was spent on the installation of special rig instrumentation. The bit was then run back to total depth for a final check on hole conditions and fill. Two bridges or ledges were contacted, and 28 m of fill was found in the hole. Another mud sweep of 50 bbl was pumped, and the short trip was repeated. Only one ledge was hit on the down trip, but again there was 28 m of fill in the hole. After another 50-bbl sweep, the hole was drilled an additional 25 m to provide extra rathole for the 5-in. perforated liner. A final sweep of 50 bbl was circulated, and the bit was tripped to the surface. There was no overpull.

Only 4 hr was required to assemble the liner of four joints of perforated and two joints of unperforated 5-in. line pipe, attach it to the drill string, and run it to 1145 m, despite deteriorating weather conditions. Operating limits were reached briefly both for vessel roll and for positioning (2%) in wind gusts to 50 kt with heavy seas at right angles to an 18-foot swell. The VIT was deployed, and the reentry was made under extremely adverse conditions. Waves actually broke over the DP control house during the reentry operation.

The 5-in. liner was run into the hole and landed with vessel heaves of up to 5 m. Solid weight was taken about 2 m above the calculated landing depth, and the coring line was used to shift the RST actuating sleeve. It was impossible, under the operating conditions, to determine whether the 2 m depth discrepancy was the result of differences in measurement, tidal fluctuation, the liner hanger landing on cement adhering to the casing wall, the liner landing on fill in the hole, or some combination of those factors. Because there was no positive indication of release, the VIT was run back for observation of the MBR clearing the reentry cone; successful release was confirmed.

During the liner deployment, the ASK system had been taxed to its limit, and there had been several alarms as positioning excursions reached 2% of water depth. Vessel roll was considerable but acceptable for handling drill pipe with the mechanized racking system. The motion was found to be too great for safe handling of the heavy, vertically racked drill collars, however, and it was necessary to halt operations for 7 hr before assembling the packer BHA for scheduled permeability tests.

Under improved weather conditions, the TAM straddle packer (TSP), with two elements installed, was made up into the BHA and run to reentry depth. The packer was run into cased hole about 180 m before the top drive was picked up. A pressure test then was conducted on the surface equipment by installing the rig-floor safety valve below the top drive and pressuring up with a mud pump. A steady pressure bleed-off was improved (but not eliminated) by switching to the other (recently rebuilt) pump. Isolating the pump in the pump room reduced the pressure decline to a negligible amount.

The setting go-devil for the TSP was pumped into place after the packer had been positioned at 203 mbsf, midway between two casing-collar connections. When the go-devil landed, the pump was stopped at about 300 psi internal pipe pressure. The pressure was noted to bleed off fairly rapidly.

After a wait of several minutes for downhole pressure gauges to stabilize, the pump was started to inflate the packer elements. The pressure buildup appeared normal, but pressure again bled off when the pump was stopped. Several attempts were made to set the packer by "rolling" the pump slowly to maintain setting pressure. Each time, the packer would appear to set and hold drill-collar weight for a few seconds when the control sleeve was shifted down. The packer would always break loose, indicating a loss of inflation pressure. The task of setting the packer was made more difficult by vessel heave of up to 3 m. A possible explanation for the pressure instability was leaking go-devil seals, so the go-devil was retrieved, and a second go-devil was pumped into place. Renewed attempts to set the packer required an even higher flow rate, with up to 150 gpm needed to maintain pressure. Efforts then were abandoned, and the drill string was recovered.

When the drill pipe had been recovered, the crossover sub to the uppermost drill collar was found to have a major sub longitudinal crack extending from the shoulder of the box connection, across the threaded length, and several cm down the wall of the sub. The crack was open as much as 1/8-in. and appeared to be the source of the drill-string leak. Loss of the entire BHA in the reentry hole had been narrowly averted. The packer was pressure-tested after recovery and was found to be in good condition.

The BHA then was reconfigured for deployment of the instrumented borehole seal (CORK). Three 7-in. drill collars were used as a "stinger" below the CORK. Above the CORK were a 3-ft drill collar pup joint (for handling) and two stands of drill collars. The drill string and VIT were deployed, and, again, reentry was routine. The string was held with the stinger stabbed into the cone and the CORK suspended above it for deployment of the thermistor sensor string.

Three hours then was required to lower the thermistor string into the pipe with special rigging while teflon sampling tubing was attached to the length of the sensor string. The data logger instrument at the top of the sensor string was landed in the drill pipe and attached to the coring line by means of an overshot retrieving tool. Upon lowering, the sensor string began to "hang up" as the data logger passed through the BHA. As the entire weight of the sensor string, including the sinker bar at the bottom and the data logger at the top, seemed to be lost at once, it was assumed that the data logger was stopping on an obstruction in the BHA. The data logger eventually was "worked" to the approximate depth of its seat in the CORK, but automatic latch-down did not occur as per design. When latching could not be achieved, the sensor string was retrieved to the rig floor. The teflon sampling tube was found to be broken off at its connection to the data logger and wadded in the pipe below it. The kevlar coating of the thermistor string was severely abraded. An electrical check showed that continuity had been lost to 2 of the 10 thermistors. The conclusion was that the coring line had been lowered too rapidly, with the lightweight sensor string overrunning itself. The damaged upper 15 m of the sampling tube was cut out, and a new section was spliced in.

A second attempt to land the sensor string then was made at an even slower core-winch running speed. The data logger again came to a stop inside the BHA. Upon reassessment of the problem, obstruction of the 5-in. liner was suspected. Thus, the entire sensor string was recovered, and the sampling tube was cut off and discarded. The lowermost meter of the tube was filled with sediment. The standard 3-3/8-in. sinker bar was lowered to check the depth of unobstructed cased hole. The sinker bar would not pass the 3.5-in. i.d. of the CORK, however, and the coring line had to be reterminated with 2-1/8-in. sinker bars. The second sounding attempt met resistance at 253 mbsf--10 m into the 5-in. liner and 6 m above the 11-3/4-in. casing shoe. Traces of sediment were found on the sinker bars.

Apparently the liner had become filled with sediment that flowed in through the perforations, or it had failed near the casing shoe during the rough-weather setting operation. Evidence supporting the former possibility was the observation of cloudy water in the reentry cone during reentries with the liner and with the packer BHA, but clear water before the casing shoe had been drilled out and for the CORK reentry.

In deteriorating weather, the sensor string was run back into the pipe without the fluid-sampling tube and concurrently was shortened to 240 m. On the third attempt, it was landed successfully, latched down, and released by shearing the overshot pin. The coring line was retrieved as wind gusts peaked at 46 kt.

Setting the CORK then was finalized by landing it in the 11-3/4-in. casing hanger, pumping down a setting ball, and testing the latch-in with 35K lb overpull. No setting indication was seen with the first ball, but, after a second ball was dropped, it was found that the mud pump had not been properly set up, and the proper pressure indication was then observed.

Before the running tool was unjayed from the CORK, the remotely-operated vehicle (ROV) landing platform was assembled around the drill pipe and dropped to the top of the reentry cone. The VIT was then run to verify proper landing of the platform and to observe release of the CORK. With Hole 889C isolated from the ocean, the drill string, VIT, and two beacons were recovered.

JOIDES Resolution departed Site 889 at 1015 hr 22 October in moderating weather.

HOLE 857D, MIDDLE VALLEY, JUAN DE FUCA RIDGE

Because of its proximity to the operating areas of Leg 146, a return to Hole 857D had been scheduled for the purpose of replacing the data logger and thermistor string. The hole had been drilled and CORKed on Leg 139 for the investigation of high-temperature fluid circulation on a sedimented spreading center. The drilling objectives had been deeper than expected, so the prefabricated sensor string was too short to provide optimum results. Because valuable data already had been collected from the upper part of the hole, there was strong scientific interest in data from greater depth in the open hole.

The vessel averaged only 9.4 kt in rough seas for the 75-nmi transit to the southwest of Site 889. GPS was used to navigate the ship onto the known geographic coordinates of Hole 857D, and a beacon was launched at 1915 hr 22 October.

Unfortunately the beacon auto-released as soon as it entered the water. An hour was spent in recovering the floating beacon, repositioning the ship, and dropping a replacement beacon. The pipe trip proceeded in increasing winds and was slowed by the requirement to measure and "rabbit" pipe that had not been used at shallower Sites 888-890.

Though initial sonar contact showed that the beacon had landed only about 50 m from the Hole 857D reentry cone, positioning for engagement of the CORK was difficult. To minimize roll and heave, it was necessary to position with winds to 30 kt on the beam--putting heavy demands on available power for the thrusters. Heavy cavitation of the thrusters also caused frequent loss of acoustics to the hydrophones, making it necessary to drop a backup beacon with greater signal strength. The first backup failed upon launch, so still another beacon had to replace it.

To access the CORK, it was necessary to lower an inverted funnel, 42-in. in diameter, over the upper end of the CORK, which extended through the central opening of the ROV platform above the reentry cone. Precise maneuvering was hampered by the environmental conditions and by sediment clouds kicked up by the surge of the skirted tool heaving near the seafloor. After several attempts had been aborted due to poor visibility, the modified running tool was stabbed successfully onto the CORK. The tool was designed so that it would engage automatically by "jaying" onto lugs on the CORK as soon as the running tool was lifted. A series of heaves, while the heave compensator was being adjusted for tension, applied excessive weight to the CORK (drill collar flexing was observed on TV). The running tool then became disengaged from the CORK, skidded across the landing platform, and dropped over the lip of the cone. Upon repositioning of the ship for another attempt at engagement, it was noted that the CORK had sustained severe damage. The upper section of the outer CORK housing was missing (stuck in the running tool but out of sight under the skirt). The CORK mandrel and data logger were seen to be lying against the side of the ROV platform opening, suggesting that the mandrel had failed and the seal to the borehole was broken.

As scheduled operating time was running out, and no special tools were on board to repair the damage, the drill string was recovered. Both operating beacons were recalled, and the ship departed Site 857 at 1300 hr 23 October.

SITE 857 TO SITE 891

The Central Oregon Margin operating area lay about 270 nmi to the southeast of Site 857. The transit was made in 25 hr at an average speed of 10.9 kt. Weather conditions were moderating but remained rough for most of the move. Assistance from the California Current accounted for the good transit speed.

Arrival at proposed site OM-3 was just in time for a scheduled rendezvous with *M/V Navigator* out of Newport, OR. The smaller vessel was waiting in the area and stood by while *JOIDES Resolution* took station on the site coordinates and launched a positioning beacon. It became apparent that the scheduled exchange between vessels, which involved a personnel transfer, would be unacceptably hazardous under the existing conditions of wind and swell (wind gusts to 34 kt, 9-ft seas, and 10-ft swells from divergent directions). The exchange was tentatively postponed until the following day, and *Navigator* departed for Newport.

SITE 891 (OM-3), OUTER RIDGE, OREGON ACCRETIONARY MARGIN

Bathymetry at the proposed drill site was sloping and rugged. Because a full reentry cone installation was planned, and because the reentry hole and the cored exploratory hole were to be separated by at least 200 m, it was necessary to conduct seafloor reconnaissance with the VIT. The ship was positioned so that the beacon would fall midway between the two planned holes, but GPS fixes revealed that it came to rest only about 20 m west of the designated location for the reentry hole. PDR readings were rendered untrustworthy by the irregular bathymetry, and the VIT was deployed well before the bit reached the depth of the uppermost PDR reflector. When the sonar indicated channel walls and a steep slope beneath the drill string, the vessel was offset to the west toward a more "open" area. The beacon was viewed (and videotaped) as the BHA passed it, and offsetting continued to a gently sloping spot about 23 m west of the beacon.

An APC/XCB BHA was made up, and the bit was lowered until it contacted the seafloor and the tag was observed at 2624 m from driller's datum. A jetting test then was conducted to determine maximum setting depth for 16-in. conductor casing in the reentry hole. Jetting refusal came at 40 mbsf for a circulation rate of 250 gpm and an applied bit weight of 16K lb. The bit was pulled clear of the seafloor for the move to the site of the exploratory hole.

The seafloor was viewed and videotaped for about half the distance until a steep escarpment was crossed and the seafloor dropped out of sight as the drill string was lowered to its limit. When the vessel had been moved 200 m to the north, more pipe was added to again tag the seafloor with the bit. A new depth of 2674 m was recorded but, after a minor adjustment of offsets to attain the exact geographic coordinates, another tag showed 2671 m.

HOLE 891A

A rare opportunity existed for observing and videotaping an APC spud, and the VIT was left in place while the APC was landed and pressure was applied to the drill string. The bit was positioned at 2669.5 m, and the "shot" was observed on TV. It also was noted that the normal wandering of the ASK system had swung the bit into slightly deeper water, and more than 1-1/2 m of APC barrel was seen between the bit and the seafloor interface. Measurement of the recovered core set the seafloor depth at 2674.3 m.

An hour's delay then occurred while the VIT was recovered to permit rotation of the pipe. Core 2H was taken from the depth of the bottom of Core 1H (2679 m), but pressure failed to bleed off, indicating incomplete stroke. Using the advance-by-recovery technique, Cores 2H and 3H advanced the hole only to 9.5 mbsf in stiff clay and sand. Core 4H also showed incomplete stroke. The APC barrel was found to be stuck upon attempts to pull it inside the bit with the coring winch.

Two hours was spent on attempts to jar the apparently bent barrel free and/or to jar down and shear the release pin on the GS pulling tool. Efforts were to no avail, as the barrel was firmly stuck and downward shocks were absorbed by the long APC rod and the copper anti-shear bushing in the GS cup. Deliberate efforts were made to break off the barrel in open hole by raising, lowering, and rotating the drill string. The APC remained stuck, necessitating a round trip.

Before the trip could begin, it was necessary to remove the coring line--which was attached to the stuck barrel--from the pipe. The Kinley sand-line cutter was used for that purpose. A clean cut was made just above the rope socket by free-dropping the cutter and following it with a drop-weight "hammer." After the cut wire was recovered, the top drive was set back, and the drill string was tripped.

On recovery of the BHA, the APC barrel was found to be broken off at the bit but still jammed in the throat of the bit at the location of the original bend. The PDC cutting structure of the bit had sustained considerable damage from contact with the broken APC barrel in the hole. About 1-3/4 hr was required to dislodge the APC, remove the Kinley tools and sinker bars, and redress the APC.

HOLE 891B

Because hard carbonates or other rocks were the suspected cause of the APC failure, the damaged 10-1/8-in PDC bit was replaced by a more durable 11-7/16-in. roller-cone XCB bit. The drill string was run back to the seafloor, and Hole 891B was spudded at 0200 hr 26 October.

Due to poor results in Hole 891A, XCB cores were taken from the seafloor. The cause of the bent core barrel turned out to be unconsolidated sand, which also was largely unrecoverable in cores. Core recovery was nil for the first 110 m. WSTP runs were made at 30, 56, 92, 136, and 163 mbsf. Because of the effects of sand and hole fill, WSTP data were not adequate to determine the geothermal gradient.

Core recovery increased to about 10% in the interval between 110 and 160 mbsf. MDCB cores were attempted at 101 and 172 mbsf, with no recovery on the first attempt and 13% recovery on the second. A further step-up to an average recovery of about 20% persisted to around 340 mbsf, where it dropped back to about 10%.

Though no serious hole problems were encountered, hole fill of 1-5 m persisted on connections throughout the coring. Severe-weather and high-heave conditions for most of the interval made control of weight on bit extremely difficult and adversely affected core recovery.

A PCS sample was requested following Core 43X at 339 mbsf. All seemed normal until the PCS core barrel landed; then the circulation path closed off quickly, and standpipe pressure increased rapidly. When repeated attempts to circulate failed, the coring line was run to retrieve the PCS barrel (backflow was noted when the pipe was broken). The sinker bar/jar assembly set down at approximately the right depth, but the pulling tool would not engage the cup on the barrel. As

attempts to engage the barrel continued, the sinker bars became stuck, and jarring action was lost. Apparently a sand/silt/water slurry had "U-tubed" into the pipe from the bottom. With the pipe beginning to stick, it was imperative to recover the coring wireline so that the pipe could be moved and rotated.

The Kinley sand-line cutter was assembled and dropped, and, after a suitable interval, a drop weight was sent down the pipe to fire it. The wire did not come free after an adequate time interval, so a second hammer was dropped. Again there was no cut. A second cutter then was dropped and followed (more closely) by a drop weight. Again the wire failed to part. The situation was becoming urgent, with the pipe now stuck and the wireline in place. Cutting the wire at the top was not an acceptable solution because the presence of the wire would interfere with severing or backoff operations, should they become necessary. The wire was being "worked," and pump pressure alternately applied and released, while the next step was pondered. After several minutes, the winch operator reported that he had pulled the sinker bars free. Normal hanging weight of the sinker bars indicated that the Kinley cutters had not detonated.

When the sinker-bar assembly and the Kinley tools had been recovered, the effort focused on freeing the drill string. After about 1/2 hr of manipulation, the string was moved with 100K lb of overpull, and rotation was regained shortly thereafter. Torque and drag remained high, and the string remained plugged, while four stands of pipe were set back with the top drive. Another run was made with the retrieving tool, but sand apparently remained above the GS cup, and there was no engagement. The pipe was "surged" by alternately pressuring up and dumping the pressure at the standpipe bleeder valve, but the tactic failed to loosen the downhole-circulation block.

A swab cup then was run on the coring line, and water was swabbed from the pipe from a depth of 500 m. When the pipe had been refilled, limited circulation was regained (high back pressure) for a brief interval before the circulation path suddenly was blocked off again. The bit then was pulled up to 79 mbsf, where pressure again was applied to the pipe. Circulation finally was established gradually, cleaning the sediment from above the core barrel and permitting wireline retrieval of the barrel.

With the PCS recovered and normal parameters regained, the drill string was run back to total depth, where 14 m of fill was encountered. The fill was flushed from the hole with a 20-bbl mud sweep, and XCB coring resumed. Heavy swells produced motion-compensator stroke of up to 16 ft and reduced weight control on the bit to about 20K lb. Alternating sand and clayey silt strata, together with the difficult environmental conditions, held core recovery to about 8%.

Average recovery increased to 23% below about 440 mbsf. Hole conditions actually improved somewhat, with only about 1 m of fill noted on connections. At 472 mbsf, drilling objectives were declared fulfilled, and preparations were begun for logging.

A wiper trip was made to 52 mbsf, with overpull of up to 60K lb experienced most of the way. Some drag persisted as the bit was run back down the hole. Three hours was required to clean 54 m of fill from the hole and to flush the hole with 50 bbl of viscous mud. A go-devil then was pumped down the pipe to lock the LFV open for logging. The pipe was "slugged" to prevent backflow, the top drive was set back, and the bit was pulled to 97 mbsf.

During the 5 hr required to lay out the upper guide horn, rig the SES, assemble the quad-combo toolstring, and start it down the pipe, a bridge formed under the bit, and free movement of the pipe was prevented. The presence of the SES prevented rotation of the pipe and restricted vertical motion even after the logging tools began their descent. A few meters above seafloor depth, the tool string came to a halt inside the pipe. Bent pipe was indicated by the nature of set-down and pickup, so the logging tools were pulled back to the surface. Loss of BHA weight was indicated when the drill string was raised as far as the SES configuration would permit. The SES and logging tools then were rigged down so that the VIT could be deployed.

The VIT was lowered until it revealed the end of the drill string at the bottom of the uppermost (7-1/4-in.) drill collar and confirmed that the break was above the seafloor. Sonar detected the circular crater of the hole about 14 m away, and the ship was moved by DP offsets to permit observation of the hole by TV. Poor visibility prevented viewing the hole or even the seafloor. The reduced visibility seemed to be the result of general water turbidity (possibly from recent inclement weather), sediment washing from the drill string and stirred up from the seafloor, and a substandard TV presentation. A review of pipe and BHA records placed the break about 7 m above the seafloor, and a bright spot inside the crater on the sonar presentation appeared to represent the broken BHA. Efforts to view the crater were abandoned due to the low visibility, and the drill pipe was recovered.

HOLE 891C

As Hole 891B could not be plugged to isolate it hydrologically from the planned reentry hole at Site 891, plans were altered to place the reentry installation at proposed site OM-7, a few miles distant. Because important logging objectives of Site 891 had not been fulfilled, and because core recovery had been low, preparations were made to drill a dedicated hole for downhole measurements as at Site 888. An additional constraining factor was the planned two-ship oblique seismic experiment (OSE) that had to be done during the window of opportunity coinciding with *R/V New Horizon*'s operations in the area. That opportunity would have been lost if the OSE had been deferred until after casing was set at the next site.

When the failed 7-1/4-in. drill collar and the bent lowermost joint of 5-1/2-in. drill pipe had been removed, a 9-7/8-in. tri-cone drill bit and drilling BHA were assembled, and the drill string was run back on an offset location about 40 m south-southeast of Hole 891B. The seafloor was "felt" at 2675 m by weight indicator, and the new hole was spudded at 0215 hr 2 November.

Drilling proceeded smoothly, with precautionary mud sweeps at 200, 300, and 400 mbsf. No excess torque, hole fill, or other indications of unstable hole were noted. At the total depth of 492 mbsf, a 50-bbl sweep of viscous mud was circulated through the hole. A wiper trip to 70 mbsf encountered only scattered minor resistance and 6 m of fill at total depth. After another mud sweep of 50 bbl, the MBR was actuated by the RST, and all terminal restrictions were released.

When the MBR had been pulled to 95 mbsf, the logging sheaves were rigged. Before the first logging-tool string could be assembled, however, the drill string began sticking. The circulating head was attached, and the pipe was "worked" for about 1/2 hr with water circulation before it suddenly came free. A lack of any residual drag suggested that the sticking had been caused by sand/silt cuttings falling into the hole around the BHA. With the pipe completely free at 103 mbsf, logging operations resumed.

The quad-combo tool string was stopped by a bridge at 295 mbsf; a good log was recorded up to the pipe from that depth. Because the lower part of the hole was the primary logging target, the SES was deployed to provide the capability of placing the logging tools deep in the hole. With the quad-combo back inside the pipe, the BHA was run into the hole to open it for the logging tool. The first resistance was met when the end of the string reached 231 mbsf; the pipe was firmly stuck when the weight was picked up. The incident seemed identical to that of Hole 888B wherein a fall of sand apparently overtook the drill string.

It was necessary to recover the long Schlumberger tool string from the SES over 100 m below the keel and hang it off in the moonpool. The first operational test of that capability was successful but was nearly foiled when the temperature-recording section at the bottom of the tool string became fouled in the SES float valve temporarily.

Overpull approaching the tensile-strength limit of the drill pipe then was required to free it after the top drive had been picked up. With the top drive providing rotation and circulation, the MBR was pulled to 138 mbsf, where the string was free in the hole and the SES was removed from the string. The top drive then was reinstalled and used to clean out the hole to total depth with the open-ended BHA. Mud sweeps were used to remove 5 m of fill and to restore the hole to apparently acceptable logging condition. The end of the pipe was pulled back to 333 mbsf for another attempt to access the lower hole interval.

With the pipe deep in the hole, the quad-combo reached a bridge at 431 mbsf (61 m off TD), and a log was recorded for most of the lower hole. The pipe stuck again as the logging tools were being changed, and nearly an hour was required to free it. Pipe was pulled against moderate drag to 280 mbsf, where the top drive again was deployed and again used to clean out to TD (7-m fill). The top drive was left attached after the string had been pulled to 315 mbsf for the two-ship oblique seismic experiment (OSE) with *R/V New Horizon*.

After one seismic line had been run, an air-compressor failure on *New Horizon* forced interruption of the OSE while the compressor aftercooler was transferred to *JOIDES Resolution* for repairs. As the Woods Hole Oceanographic Institution downhole hydrophone was already in place, a VSP was conducted using ODP seismic guns suspended over the side of the vessel from crane no. 3. Attempts to raise the pipe in the derrick for the upper VSP stations found the pipe stuck again. It was free after a few minutes and was then raised 10 m for completion of the VSP.

Though the pipe situation was precarious, the lower section of the hole remained in good condition for logging. A high risk of sacrificing the BHA was accepted in return for the opportunity to realize scientific objectives from the lower interval of the hole, and the drill string was left deep in the hole for continued logging operations. The top drive was left made up to the string to preserve full rotation capabilities. FMS and geochemical combo logs then were introduced through the top drive and recorded over about 130 m of the lower hole.

With the downhole-measurement program complete in the lower hole with the exception of the OSE, the pipe was raised for additional work in the upper hole section. When the MBR had been pulled 70 m with the top drive to 235 mbsf, tension and torque increased until the pipe was stuck fast. Two hours of attempting to free the pipe was unsuccessful, and the conclusion was that the pipe would have to be severed above the BHA to permit recovery of the drill pipe. With the pipe immobilized, the hole below it was protected from falling debris, and the pipe noise level was reduced--producing improved conditions for the OSE. Compressor repairs had been completed, and the OSE resumed. About 8 more hours was spent on OSE lines and additional VSP stations in the newly opened hole interval. Nevertheless, the scope of the OSE was limited by the inability to clamp the geophone in large-diameter hole intervals and by scheduling constraints on operating time at Site 891.

After the annulus and drill string below the seafloor had been filled with weighted mud, a severing charge was run on the logging line and exploded 143.5 mbsf in the second joint of drill pipe above the drill collars. Shooting depth was based on the caliper log recorded earlier and was selected to cut the pipe just above an interval of reduced-diameter hole suspected to be water-sensitive clay. An overpull of 200K lb then separated the pipe and freed the string above the cut. The logging line and drill pipe then were recovered, ending operations at Site 891.

SITE 892 (OM-7), SECOND RIDGE, OREGON ACCRETIONARY MARGIN

As Hole 891C could not be plugged with cement, there was doubt that it would be hydrologically isolated from the planned cased reentry installation. The reentry site therefore was relocated to proposed site OM-7 about 10 nmi east of Site 891. The move was just long enough to justify raising the thrusters and hydrophones and getting the ship under way instead of moving in DP mode. After a 1 hr transit, the ship was stopped and positioned on GPS while thrusters and hydrophones were lowered. A retrievable Datasonics positioning beacon was dropped at 1315 hr 6 November.

HOLE 892A

The APC/XCB BHA selected for coring at Site 892 included the developmental flow-control device for the XCB in an attempt to improve core recovery. Because hard carbonate deposits were expected, a 14-3/4-in. roller-cone XCB bit was used instead of the more fragile PDC drag bit. During the pipe trip, the vessel was offset north to the area of the proposed exploratory hole for the purpose of obtaining a PDR depth reading. A second beacon, a low-power Benthos expendable model, was launched at 1515 hr near the northern offset.

It again was necessary to determine the depth of soft sediments for planning the length of conductor casing, so operations began with a jetting test at the proposed reentry location. The VIT was deployed to view seafloor contact for depth determination and to observe the jetting tests. Firm resistance was encountered at only 2 mbsf by the initial test at the preferred location. An offset of 15 m east was carried out, and a second jetting attempt reached 5 mbsf before encountering hard going. An additional 35 m east offset then was entered, and the third try reached 7 mbsf using a circulation rate of 250 gpm. None of the tests was adequate for emplacing conductor pipe, so the rig was offset 200 m north to the location originally proposed for the cored hole, reversing the hole locations would have had minimal effect on the science and still maintain the required 200 m separation. Initial jetting was more successful but still required 1-1/2 hr to jet to 19 mbsf using up to 300 gpm pump rate and all available (supported) BHA weight. A final attempt was made 100 m to the east, but refusal came at only 6.5 mbsf.

Because of the firm sediment found on the jetting tests, it was not considered advisable to spud with the APC, so the XCB "wash barrel" was replaced by a clean XCB barrel while the VIT was recovered. While those changes were being made, the ship was offset back to the southern location of the original jet test attempt. The visually determined seafloor depth of 685.5 m was used, and Core 1X was cut to 9.5 mbsf.

Arrival of the first core on deck was accompanied by a strong odor of hydrogen sulfide. A hand-held monitor was used to check the gas level as the core was removed from the inner barrel and registered readings in excess of 100 ppm near the core. The core also contained a considerable amount of gas hydrates. An H_2S alert was declared, core handlers were outfitted with breathing apparatus, and retrieval of Core 2X was deferred until the situation was discussed and preparations were made. The H_2S concentration was exceptionally high, definitely hazardous, and completely unexpected. The amount of monitoring and breathing-air equipment on board was minimal for sustained operations, but supervisors agreed that coring could continue on a core-by-core basis for a limited time. Core 2X also had high H_2S readings, but Core 3X had only traces, and no further H_2S was detected in subsequent cores.

Cores continued to be gassy, with an increasing thermogenic hydrocarbon gas content, which rose sharply below the expected depth of the BSR about 68 mbsf. Beyond that depth, coring proceeded on a real-time monitoring basis with XCB cores alternating with WSTP or PCS runs to provide time for gas analysis before cutting of the next core. After the expected major fault zones had been crossed, at about 130 mbsf, the concentration of heavier gases began to decrease. Core-by-core monitoring was discontinued at 145 mbsf.

Average core recovery was fair to poor for most of the section but quite good in the interval of approximately 40-70 mbsf. Average ROP was only about 7-1/2 m/hr for the lower 100 m of hole, probably contributing to washing away the fairly soft clay/silt sediment. Hole conditions were good until the faults were crossed, then 1-4 m of fill accumulated on connections despite mud sweeps. The fill did not affect coring operations but hampered WSTP probes in the lower part of the hole.

PCS cores were attempted at 38 and 77 mbsf; both runs recovered water under hydrostatic pressure but no core. In total, 10 WSTP runs were made. That was partially due to a high interest in determining temperature as an indicator of fluid migration and partially due to the desire to avoid "dead time" while hydrocarbons were analyzed prior to proceeding with coring. The WSTP success rate was high in the upper part of the hole, but several of the deeper attempts were thwarted by fill in the hole.

Coring was discontinued at 176.5 mbsf when cores and gas samples indicated that the hole had penetrated well into the footwall of the major thrust fault. Weighted drilling mud was displaced into the lower part of the hole before the bit was pulled to 67.5 mbsf for a cement plug. A 20-bbl batch of 15 lb/gal cement slurry was emplaced at that depth and was calculated to span a minimum of 20 m of hole at the estimated hole diameter. The drill string then was pulled clear of the seafloor, flushed of cement, and recovered while the vessel was offset 200 m north to the reentry location.

HOLE 892B

Because the thrust-fault planes had been penetrated at a shallow depth, only a relatively short surface-casing string was required. It was thus concluded that even an extra-short 19 to 20-m conductor had a reasonable chance of supporting the weight of the surface casing and that the planned reentry-cone installation could proceed.

After the reentry cone had been moved into position on the moonpool doors and the casing hangers had been prepared, the 16-in. casing string was made up and hung off in the reentry cone. It consisted of only one full joint of casing plus a cutoff shoe joint and the casing hanger. To achieve the correct spacing with respect to BHA components, it was necessary to cut the shoe joint to make the casing string 21.6 m long. When the casing/cone assembly had been attached to the BHA, it was lowered through the moonpool and to the seafloor.

Jetting with the tri-cone drill bit proved to be more difficult than with the XCB core bit, and very slow progress was made to 13-3/4 mbsf, where penetration came to a stop. After over 6 hr, the attempt was abandoned and the casing was pulled clear of the seafloor. Though the rig had been positioned on the ASK offsets of the 19-m jet test, a correction of a few meters was made on the basis of ship's heading and a sonar target, indicating a small depression in the seafloor. Again jetting was slow, as it apparently was necessary to "melt" the gas hydrates in the sediments to advance the casing. A circulation rate of 500 gpm and maximum available weight were required most of the way. Progress slowed at the 13 to 14-m level but did not stop until the shoe was at 21 mbsf, very close to the depth calculated to put the "mudskirt" of the cone at the seafloor. The double-jay running tool then was released, and the bit was advanced below the casing shoe.

The 14-3/4-in. hole for surface casing was drilled to 105 mbsf in 2-3/4 hr with no hole problems. After a flush with viscous drilling mud at total depth, the bit was pulled back to the conductor casing shoe. A slight overpull of 5-10K lb was noted. Following a 30-min wait, the bit was run back to test the condition of the hole for the casing string. The hole was clean except for 9 m of fill, which was cleaned out to total depth and followed by a second 40-bbl mud flush. When the drill string had been recovered, the jetting/drilling BHA was dismantled, and preparations were made for running casing.

A short string of seven joints of 11-3/4-in. casing and the casing hanger was made up and hung off in the moonpool while the cementing "stinger" was assembled and lowered into the casing. The assembly was joined by engaging the hex-kelly running tool and was run to reentry depth. After a routine reentry, the casing was run into the hole (no resistance) and landed. Release and cementing of the casing were handled without incident, and the stinger arrived back on the rig floor at 0915 hr 11 November.

HOLE 892C

To ensure the mechanical and pressure integrity of the cement job, it was necessary to allow about 36 hr for the cement to cure. As logging and downhole instrumentation had high priority at the site, a dedicated logging hole was drilled during the interruption of operations at Hole 892B.

Because earlier BHA losses had resulted in a shortage of MBR components, an XCB BHA was used for drilling Hole 892C, and the float valve was omitted. Use of a drag-type PDC bit reduced drilling-weight requirements so that a short BHA could be used without sacrificing ROP. A standard XCB inner core barrel was in place to optimize hydraulics and to prevent sediment from entering the OCB. During the pipe trip, the vessel was offset to a location 20 m south of Hole 892A.

The 10-1/8-in hole was drilled to 176.5 mbsf in 11 hr. After the hole had been swept with mud and the inner barrel had been retrieved, the bit was pulled on doubles to 65 mbsf with the top drive in the string. No overpull was experienced, so a wiper trip was considered unnecessary. The top drive was rigged down, and preparations were made for logging.

Because the hole was shallow, the long quad-combo" tool string was divided into seismic stratigraphy (sonic-induction-gamma ray) and litho-porosity (density-neutron-gamma ray) sections. The seismic stratigraphy tool was run first and failed to pass tight hole at about 130 mbsf. A log was recorded up to the bit, which was raised an additional 30 m with the blocks. The sonic log was dysfunctional below about 68 mbsf, apparently due to the presence of gas in the hole.

The drill string then was run back into the hole in an attempt to remove the obstruction. Resistance was met at 147 mbsf, but the bit was circulated to total depth using the circulating head; top-drive rotation was not required. After a mud sweep, the bit was pulled back to 65 mbsf with no resistance.

The litho-porosity combination then was lowered to 125 mbsf before it was stopped by an obstruction. A good log was recorded up to the bit; however, the caliper on the density tool showed much of the hole to be of excessive diameter. As cores and seismic records showed the interval from 120 to 150 mbsf to be a zone of major faulting, no further effort was made to open the hole for logs. The next tool into the hole was the FMS, which reached 120 mbsf and also recorded an excellent log.

The Schlumberger WST had been deployed for a check-shot VSP when equipment problems forced the tool to be withdrawn. After a cable rehead due to armor damage, the VSP continued. Results were degraded by washed-out hole and the inability to clamp the tool in some intervals. Allotted time for downhole work expired after 2-1/2 hr and the VSP was terminated.

When the seismic guns and logging tools had been rigged down, the bit was run back into the hole for plugging. Though the circulating head was required, the bit went back to total depth with less difficulty than on the previous trip. With caliper-log information as a guide to hole volume, heavy mud was emplaced to fill the hole to about 65 mbsf. The bit was then pulled to 69 mbsf, and 15 lb/gal cement slurry was spotted from that depth to about 49 mbsf. The drill string was pulled clear of the seafloor, flushed of cement, and recovered while the ship was offset back to Hole 892B.

HOLE 892B (return)

A 9-7/8-in. tri-cone drill bit and drilling BHA were installed for the final phase of drilling Hole 892B. Reentry into the cone was routine, but the bit came to rest on the shoulder gap that resulted from modifications done to make the 11-3/4-in. casing hanger compatible with a hard-rock guide base. The problem had been anticipated but was believed to be amenable to "working" the bit past the gap. About 30 min was spent in raising and lowering the string while small DP offsets were entered. Rotating the string with chain tongs also was tried, to no avail. The VIT was left in place while the bit was pulled above the cone to permit picking up the top drive. With the intent of rotating the bit past the shoulder with the top drive, a second reentry was made into the cone. The bit was lowered past the shoulder without contacting it and without rotation. When the VIT had been recovered, the trip proceeded with the top drive deployed until cement was tagged at 88 mbsf.

Drilling of the cement, plug, and shoe took 4 hr. (The depth at which the bit "broke out" of the shoe suggested that cone and conductor casing had settled about 1.2 m before the mudskirt came to rest on the seafloor at 683.5 m from driller's datum.) An additional 5-1/4 hr was required to make 73 m of new hole to total depth at 178.5 mbsf. After a mud sweep, a short trip was made to check the condition of the hole. No resistance was noted until the bit again had been lowered to 161 mbsf. "Soft fill" was washed out for 30 m and 5 m of "hard fill" was cleaned out to total depth before another 40-bbl mud sweep was circulated. The pipe then was tripped for installation of the perforated liner.

Five joints of 5-in. range-3 perforated line pipe and one joint of unperforated pipe were made up and attached to a stand of drill collars by means of an MBR with a specially modified disconnect/liner hanger. Reentry with the rounded "bullnose" on the liner was uneventful, and the liner string was run into open hole without resistance until the hanger came to rest on the landing collar at the top of the lowermost joint of surface casing. A routine run of the RST on the coring line released the liner, and the wireline and drill string were recovered.

The TAM straddle packer (TSP) then was assembled in the dual-element configuration with a finned "tailpipe" below it to provide centralization for reentry past the casing-hanger shoulder. Two stands of drill collars were run above the packer, and the assembly was tripped to reentry position. Reentry required two or three attempts before the tailpipe passed the casing-hanger gap.

When the BHA had been lowered completely into the casing, the top drive was picked up and blanked off with the rig-floor safety valve. A pressure test of the surface equipment then was conducted before the packer go-devil was dropped. The go-devil was pumped into place with the TSP centered at 68 mbsf in the casing, and the packer set easily. High permeability was indicated and three pulse tests were followed by three constant-rate injection tests.

Weather/motion conditions were excellent, and the go-devil was retrieved while the packer remained set. While the downhole instrument data were read to determine whether further tests were needed, the sinker bars were lowered into the perforated liner to check for fill. About 5.5 m of fill was found in the liner. The sinker bars could not be pulled back into the 5-1/2-in. tailpipe, apparently due to misalignment with the centralized tailpipe. It was therefore necessary to unseat the TSP and to lower the reduced bore of the tailpipe to just above that of the liner hanger; the sinker bars then entered without difficulty.

A second go-devil had been pre-dressed with seals to save time, and the downhole pressure recorders were attached to it for deployment to the packer. Upon landing of the go-devil, the TSP could not be set, with the failure apparently due either to a leaking element or leaking go-devil seals. The go-devil was recovered, and the recorders were switched to the original go-devil (with the original seals). A good set then was obtained, and further constant-rate injection tests were conducted for 4 hr. After the packer had been deflated and the go-devil recovered, it was discovered that the electronic downhole recorder had malfunctioned, and no usable data had been collected on the second run. No irregularities were found in the go-devil that failed to set the packer.

Before the drill string was tripped, a deviation survey of the hole was conducted by running the photographic multishot instrument in a pressure case attached to the sinker bars. The survey determined that the maximum hole deviation was 2° from vertical and also that hole fill had increased to 9.5 m during the 7 hr since the earlier sounding.

Assembly of the stinger for the instrumented borehole seal (CORK) began when the TSP had been dismantled. The previously fabricated tailpipe was attached via a crossover sub to the lowermost of three 7-in. drill collars, which were in turn attached to the bottom of the CORK. As the CORK was being lowered through the rotary table, it was noticed that welds had broken on the CORK body, allowing the shroud to rotate relative to the mandrel. About 3/4 hr was spent on rewelding before the trip resumed. Two stands of drill collars again were used as BHA, and the assembly was run to reentry depth. After a smooth reentry with no hangup at the casing-hanger gap, the string was spaced out, with the CORK a few meters above the cone.

Over 4 hr was required to deploy the thermistor string, which had been doubled and redoubled to shorten it to 122 m in length. The thermistor string and data logger were run into place with the coring line, the data logger was latched into the CORK, and the overshot tool was sheared off and retrieved. When the CORK had been landed on the casing hanger, a ball was pumped down the drill string to blank off the bore and set the CORK latch hydraulically. An overpull of 20K lb verified latch-in. The ROV landing platform was bolted around the drill string and launched through the moonpool, free-falling to the cone. The VIT then was deployed to check proper landing of the platform and to view disengagement from the CORK. With all in order, the running tool was "unjayed" to release the CORK, and the VIT and drill string were recovered.

HOLE 892D

Remaining operating time at Site 892 was to be used for supplementing earlier downhole measurements, coring important intervals of low recovery in Hole 892A, and testing developmental downhole instruments. Offsets were entered to put the ship 20 m west of Hole 892A while an APC/XCB BHA was assembled. The 10-1/8-in. PDC bit used in Hole 892C was made up to a standard bit sub/float valve configuration.

Hole 892D was spudded after "feeling for bottom" and noting a reaction of the weight indicator at 681.5 m. An H_2S alert was declared because of the anticipated sour hydrate cores. Core 1X to 691 m recovered only 12 cm of sediment, a disappointment for those expecting hydrated core. Average recovery for Cores 2X-4X was 34%, and all contained gas hydrates and gave high H_2S readings. Core recovery was quite good in Cores 6X-9X to 77 mbsf, with no more H_2S but considerable hydrocarbon gas as in Hole 892A. WSTP runs were made at 54 and 77 mbsf. The interval from 77 to 100 mbsf was drilled without coring. Continuous XCB coring then proceeded to total depth at 166.5 mbsf with interruptions for WSTP runs at 109.5, 128.5, and 147.5 mbsf.

Average core recovery (54%) and average ROP were both improvements over Hole 892A, with credit given primarily to the increased drilling efficiency of the smaller drag-type bit. With increased ROP, the core was less likely to be washed away by drilling fluid. That appeared to be a more significant factor than the presence or absence of the flow-control hardware.

The hole was displaced to 12 lb/gal mud and plugged with cement in an identical manner to Hole 892A. The bit then was pulled clear of the seafloor, and the rig was offset 6 m east for additional tests and cores.

HOLE 892E

Weight indication was not noted until 685.5 m (same as Hole 892A), as Hole 892E was spudded in a final attempt to obtain a good core of the uppermost sediments. As spacing was awkward, the core was "overdrilled" to 13 mbsf before it was recovered, and the blocks were kept low to avoid pulling the bit above the seafloor during recovery. As the core barrel was being laid out for removal of the sour core, it became fouled under the top drive and broke near its midpoint (pin connection of upper section). The lower portion fell to the deck and the upper portion swung free, narrowly missing a floorhand wearing breathing apparatus. Core recovery was 3.2 m, and the core catcher contained gas hydrates.

With the presence of hydrates confirmed, the PCS was run next in an attempt to recover hydrates under in-situ pressure. H_2S precautions remained in effect as the PCS was brought on deck, but again only water under pressure was recovered.

The hole was then drilled to 33 mbsf, with a WSTP run at 30 mbsf. Two consecutive APC cores then were attempted, primarily for the purpose of temperature measurements with the "ADARA" shoe. Though stroke was incomplete, surprisingly good penetration was made into the stiff sediment, and 12.2 m of gas-assisted recovery resulted from the two cores. Liner failures occurred on both cores, with the second seriously affecting the condition of the core. Following another WSTP run and a 3-m drilled interval, the APC-deployed LAST-I tool was picked up.

The LAST-I was "fired" from a depth of 55 mbsf into quite firm sediment. Data were recorded for about 1-1/2 hr before the drill string was raised to pull the LAST from the sediment. No overpull was noted. Upon recovery, no core was recovered, and the data reflected only bottom-hole conditions, indicating that no penetration had been achieved. The test was successful in recording good data, however.

After the hole had been drilled ahead to 62 mbsf, a final WSTP run was made. The hole was pumped full of 12 lb/gal mud, and the bit was pulled above the seafloor.

The VIT then was deployed for a final visual check of the seafloor, and the Geoprops tool was run to the bit for an in-pipe calibration test. The tests and the survey had been scheduled to be performed concurrently, but turbidity resulting from the circulation required for the tests obscured the seafloor. When the successful Geoprops tests had been concluded, the ship was maneuvered for a brief look at Hole 892E, which verified that there was no fluid flow out of the hole.

With the allotted operating time running out, the drill string was recovered. The exposure of the lower drill string components to high H_2S concentrations generated concern about hydrogen embrittlement of the steel, especially in the high-strength drill pipe. The lowermost six joints of 5-in. drill pipe and the six 5-1/2-in. "transition" joints were laid down on the trip out of the hole for removal from the ship in San Diego. In addition, the connections of all BHA components in the string at the time were given a magnetic particle inspection for cracks. Results were negative.

JOIDES Resolution departed Hole 892E at 1600 hr 17 November.

SITE 892 TO SITE 893

The vessel steamed away from the site until the seismic gear had been streamed and tested, then turned and crossed the approximate position of Hole 892B on a west-southwesterly heading. After the single short tie-in seismic line had been shot, the gear was retrieved, and the ship turned south and increased speed to full.

Favorable weather conditions prevailed during the transit down the Oregon and California coasts. Strong following winds developed during the second day boosting the ship's speed to over 12 kt for a time. At 0600 hr 20 November, the vessel rounded Point Conception and entered the Santa Barbara Channel. The average speed for the voyage was 11.4 kt. A brief PDR survey of the area of the drill site was begun at 0930 hr and the ship came to a stop at the chosen location at 1030 hr. Thrusters and hydrophones were lowered while the position was refined. Assembly of the BHA had begun before the positioning beacon was launched at 1130 hr.

SITE 893 (SB-1A), SANTA BARBARA BASIN

The final site of Leg 146 was dedicated to objectives that were quite different from those of the Cascadia margin sites. All remaining operating time, about 24 hr, was to be used in APC-coring the distal turbidite sediments of the basin floor for high-resolution paleoenvironmental studies. Because the area was adjacent to a commercial hydrocarbon province, penetration was limited to 200 m or APC refusal depth, whichever would be reached first.

HOLE 893A

Hole 893A was spudded at 1345 hr with an APC core "shot" from 3 m above the corrected PDR depth of 588 m. Core recovery of 6.57 m proved the PDR to be accurate. The basin-floor sediment was easily corable, and the hole reached 196.5 mbsf without approaching refusal conditions. Full stroke was achieved on all cores, and the maximum overpull of 40K lb was recorded on the final core. Core recovery exceeded 100% because the sediment contained a large amount of biogenic methane gas. The gassy cores caused some handling problems, and the core liners had to be vented before they could be cut to avoid excessive loss of core. Gas bubbles and voids also degraded the quality of the cores for detailed studies.

When the final core had been recovered, the hole was filled with 12 lb/gal mud. Because of the shallow hole depth, the top drive was left in the string and the bit was "doubled out" to clear the seafloor.

HOLE 893B

A positioning offset of 10 m northwest was entered, and the APC corer was deployed for the initial core of the second hole. The bit was positioned 4 m higher to provide maximum vertical offset of core tops between the holes. All parameters were normal as the mud-line core was shot, but the APC was stuck in place and could not be pulled free with the coring line for retrieval.

Efforts to jar the APC loose consumed an hour and resulted in two sheared GS pins without budging the corer. The exact nature of the problem was unknown, as the core barrel could have been bent during the spud attempt or the upper portion of the APC could have been stuck in the landing/saver sub (LSS) or the seal-bore drill collar. In either case, a round trip was required to make the system operational. Because of the shallow water, only 2 hr was required to recover the OCB assembly to the rig floor. It then was found that the landing shoulder of the APC was jammed hard into the restricted portion of the LSS. Efforts to free the APC from the sub were unsuccessful, so it was necessary to torch-cut the sub away. With the sub replaced and the APC redressed, the bit was run back to the seafloor for continued coring.

Eight cores were recovered in the next 2-1/2 hr before time ran out at 68.8 mbsf. The hole was filled with heavy mud before the final pipe trip of the leg was made. The vessel departed Site 893 at 1215 hr 21 November.

SITE 893 TO SAN DIEGO

JOIDES Resolution continued to the east end of the Santa Barbara Channel, turned south between Anacapa Island and the coast, and approached San Diego by passing between Santa Catalina and San Clemente islands. The ship docked at Berth 4, 10th Street Terminal, Port of San Diego, at 0720 hr 22 November.

OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 146

Total Days (20 September 1992 - November 22, 1992)	62.88
Total Days in Port	4.94
Total Days Under Way	6.12
Total Days on Site	51.82

Trip Time	9.69
Coring Time	14.56
Drilling Time	3.88
Logging/Downhole Science Time	11.44
Reentry Time	0.76
Repair Time (ODP)	1.25
Casing and Cementing Time	3.45
Downhole Trouble Time	4.30
Wait on Weather	0.29
Other	2.20

Total Distance Traveled (nautical miles)	1453.0
Average Speed (knots)	10.7
Number of Sites	7
Number of Holes	20
Number of Reentries	11
Total Interval Cored (m)	2265.9
Total Core Recovery (m)	1190.3
Percent Core Recovered	52.5
Total Interval Drilled (m)	2232.5
Total Penetration (m)	4498.4
Maximum Penetration (m)	600.0
Maximum Water Depth (m from drilling datum)	2675.0
Minimum Water Depth (m from drilling datum)	588.0

OCEAN DRILLING PROGRAM
SITE SUMMARY
LEG 146

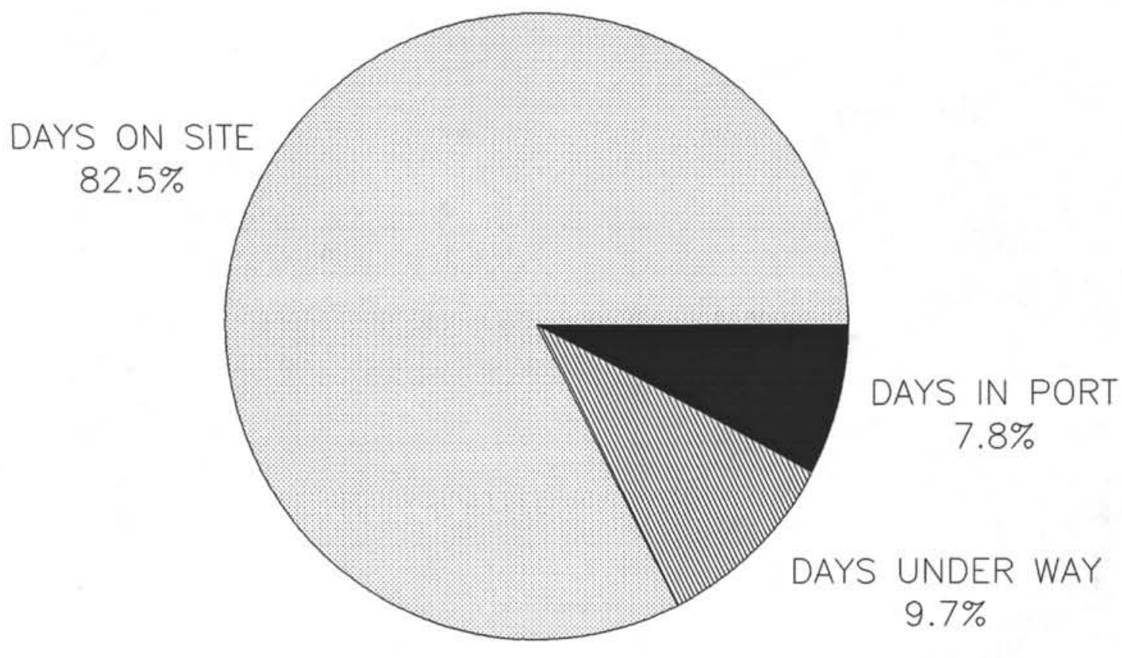
HOLE	LATITUDE	LONGITUDE	SEA FLOOR DEPTH (M)	NUMBER OF CORES	INTERVAL CORED (M)	RECOVERED CORE (M)	PERCENT RECOVERED	INTERVAL DRILLED (M)	TOTAL PENETRATION (M)	TIME (HRS)
857D	48-26.52N	125-19.57W	2431.5	0	.0	.0	.0	.0	.0	17.75
	SITE TOTALS:			0	.0	.0	.0	.0	.0	17.75
888A	48-10.01N	126-39.72W	2527.0	1	9.5	9.8	103.2	.0	9.5	8.25
888B	48-10.01N	126-39.72W	2527.0	65	566.9	364.9	64.4	.0	566.9	153.25
888C	48-09.99N	126-39.79W	2527.0	0	.0	.0	.0	600.0	600.0	58.50
	SITE TOTALS:			66	576.4	374.7	65.0	600.0	1176.4	220.00
889A	48-41.96N	126-52.10W	1322.0	44	325.8	223.1	68.5	20.0	345.8	95.00
889B	48-41.85N	126-52.39W	1327.0	21	189.5	48.0	25.3	197.0	386.5	103.25
889C	48-41.91N	126-52.23W	1326.0	0	.0	.0	.0	384.5	384.5	163.25
889D	48-41.98N	126-52.13W	1322.0	3	23.5	13.3	56.6	130.5	154.0	28.00
	SITE TOTALS:			68	538.8	284.4	52.8	732.0	1270.8	389.50
890A	48-39.75N	126-52.89W	1337.2	1	5.3	3.7	69.8	.0	5.3	6.00
890B	48-39.75N	126-52.89W	1337.2	5	45.3	37.8	83.4	2.5	47.8	12.50
	SITE TOTALS:			6	50.6	41.5	82.0	2.5	53.1	18.50
891A	44-38.65N	125-19.55W	2674.3	3	9.5	9.6	101.1	.0	9.5	28.50
891B	44-38.66N	125-19.56W	2674.0	58	472.3	54.0	11.4	.0	472.3	165.00
891C	44-38.64N	125-19.53W	2675.0	0	.0	.0	.0	491.0	491.0	113.75
	SITE TOTALS:			61	481.8	63.6	13.2	491.0	972.8	307.25
892A	44-40.45N	125-07.13W	685.5	21	176.5	62.8	35.6	.0	176.5	64.00

OCEAN DRILLING PROGRAM
SITE SUMMARY
LEG 146

HOLE	LATITUDE	LONGITUDE	SEA FLOOR DEPTH (M)	NUMBER OF CORES	INTERVAL CORED (M)	RECOVERED CORE (M)	PERCENT RECOVERED	INTERVAL DRILLED (M)	TOTAL PENETRATION (M)	TIME (HRS)
892B	44-40.54N	125-07.08W	683.5	0	.0	.0	.0	178.5	178.5	111.50
892C	44-40.44N	125-07.13W	685.5	0	.0	.0	.0	176.5	176.5	35.75
892D	44-40.45N	125-07.15W	681.5	16	143.5	77.4	53.9	23.0	166.5	31.75
892E	44-40.45N	125-07.14W	685.5	5	33.0	7.5	22.7	29.0	62.0	23.50
	SITE TOTALS:			42	353.0	147.7	41.8	407.0	760.0	266.50
893A	34-17.25N	120-02.19W	588.0	21	196.5	204.9	104.3	.0	196.5	12.25
893B	34-17.25N	120-02.20W	588.2	8	68.8	73.5	106.8	.0	68.8	11.75
	SITE TOTALS:			29	265.3	278.4	104.9	.0	265.3	24.00
	LEG TOTALS:			272	2265.9	1190.3	52.5	2232.5	4498.4	1243.50

LEG 146

TOTAL TIME DISTRIBUTION



TOTAL DAYS OF LEG = 62.9

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard JOIDES Resolution for Leg 146 were:

Wendy Autio	System Manager
Tim Bronk	Storekeeper
Jo Claesgens	Yeoperson
Bradley Cook	Photographer
John Eastlund	System Manager
Dennis Graham	Chemistry
Margaret Hastedt	Paleomagnetics
Bradley Julson	Laboratory Officer
Kuro Kuroki	X-Ray
Jaquelyn Ledbetter	Downhole Tools
Jon Lloyd	Physical Properties
Erinn McCarty	Curator
Robert McDonald	Downhole Tools
Dwight Mossman	Underway Geophysics
Anne Pimmel	Chemistry
Bill Stevens	Electronics
Mark Watson	Electronics

SCIENTIFIC OBJECTIVES OF LEG 146

Leg 146 was designed to investigate the relationship between fluid flow and tectonics in the accretionary wedge formed at the Cascadia convergent plate boundary. Leg 146 investigated fluid flow from and sediment deformation within the accretionary wedge that forms the continental margins off Oregon and Vancouver Island. This leg was dedicated to advancing our knowledge of the budget, sources, pathways, and ultimate fate of sediment, water, and dissolved chemicals in the wedge, and the relationships between accretionary tectonics and fluid regime. Near Vancouver Island, three sites were drilled to examine the progressive changes in porosity of sediments that are accreted and deformed and the associated fluid flow. Near Oregon, the channeling of the fluid outflow along faults was the focus of investigations at two sites.

PORT CALL, VICTORIA

The ship arrived in Victoria, Canada, on 20 September, a day earlier than scheduled. On the following morning, the technical staff moved aboard and crossed over with the offgoing crew. During the port call the large core shipment from Leg 145 was offloaded as well as the rest of the freight. Most of the port call was busy loading aboard the many truckloads of pipe that were sent from Texas. Loading was slowed by the use of stevedores, and for a while it looked as though the entire loading operation would be threatened by a strike. There were many tours of the ship, and most of these were led by representatives from ODP Canada. The elevator was taken out of use while cable was replaced. The ARL representative was on the ship for the entire port call, working on the XRF. It was not fixed by the time the ship sailed, and he intended to return during the next port call in San Diego. The ship sailed on 24 September.

LAB OPERATIONS

This leg was expected to be very busy, and it lived up to expectations. There was only a 12-hr steam to the first site after the abbreviated port call, and it took a while to get instruments calibrated and everyone trained on instruments and lab procedures.

An unexpected hazard was hydrogen sulfide gas. While H_2S is usually found in organic-rich sites, we did not expect to encounter as much as we did in the clathrate. Again, former training and preparations from a previous leg went into effect. When H_2S-rich cores were encountered, mixed with clathrate near the surface of Site 892, all personnel were restricted to the lab stack, with the exception of specialists with gas monitors and wearing breathing apparatus who handled the cores on the catwalk. The cores were sectioned and samples taken on the catwalk. The cores were left to degas outside, until the H_2S concentration had diminished to safe levels, before being brought into the lab. H_2S was found only in the first four or five cores at this site. All handled themselves in a very professional manner.

Due to the nature of the leg, there were many downhole experiments performed. Heat flow was studied in the soft sediments with many ADARA tool runs. Water and further temperature measurements were obtained with the WSTP tool. The pressure core sampler (PCS) was deployed to bring back sediment samples under pressure. The GEOPROPS tool was deployed for testing and calibration. Numerous "check-shot" VSP's were performed as well as a two-ship oblique seismic experiment. Two sites had CORKs deployed, and thermistor strings were also left in these holes.

Underway Lab

The lab was not used for the normal seismic survey to the sites at the co-chiefs' request. Six transit lines were run using PDRs and the magnetometer. The Doppler Sonar appeared to be working. Arrangements were also made so that the correlator and the EDO 3.5 transducer systems could be easily switched, depending on the sea conditions. All the positions were averaged using GPS readings. Most of the time was devoted to the various VSP experiments.

A complicated water/air gun array on a 12-ft boom dangling from a yoke made of slings was developed at the request of the science party. A crane was used to deploy this array over the side for "check-shot" VSP experiments. A hydrophone was also deployed off the crane and lowered to about 200 m below the ship to receive the acoustic signal. An intricate series of wires was run between the Schlumberger van, the logging winch, and the underway lab to enable a Sun workstation to record the seismic signal from the VSP tool in the hole. This was further complicated by a science request that the signal from this hydrophone be recorded on the

Schlumberger computer as well as the Sun workstation in the underway lab. It was also requested that the guns should be fired from the Schlumberger van as well as from the underway lab. Again, this was further complicated by the fact that the Schlumberger triggering voltage was too low to fire the air gun at full pressure and had to be rigged into the ODP triggering system.

This apparatus was also used with the two-ship oblique seismic experiment. This experiment was conducted with the *New Horizon* but had limited success because of time constraints and air-compressor problems on the *New Horizon*.

BRIDGE DECK

Core Lab

Due to the harsh conditions expected this time of year in the Pacific Northwest, tarps were rigged on the catwalk before we sailed. These made it possible to work for extended periods of time on the catwalk during high winds and rain.

Magnetics Lab

This leg also experienced rough seas, with the wind coming from the beam and the seas from the bow. The resulting swells caused excessive roll to the point at which the ship's drilling operations had to be suspended until the weather improved. The location of the cryomagnetometer was changed on Leg 142, and its lengthwise axis is now in line with the keel of the ship. It sees more rolls now along its length, and there was concern for the stability of the magnetometer's mounts in these rough seas. A ring-core fluxgate spinner magnetometer as well as a susceptibility anisotropy device were brought out and used this leg by the paleomagnetists. Core-barrel magnetization tests were also measured on the drill floor both before and after magnafluxing the barrels. A new tensor orientation tool was received. This was run in conjunction with the multishot orientation tool to check on the precision of the readings and to check on the reliability of the tool. There were no failures to report.

Physical Properties Lab

A number of pieces of new equipment were tested this leg for incorporation into our system. Vane-shear and resistivity systems were evaluated and parts ordered to produce these systems in the future in the lab. A recurring problem with correlation between GRAPE and pycnometer density data was found to be an error in the software calculations used on the GRAPE. There is no Boyce correction formula for the attenuation of hydrogen in water in high-porosity sediments. Permission has been requested to incorporate this correction in the GRAPE density-calculation routine.

FOC'SLE DECK

Chemistry Lab

The chemistry lab was heavily used this leg by both organic and inorganic geochemists. The inorganic geochemists were interested in the changes of concentrations of different ions in the pore water. An unusually high number of samples were squeezed for pore water.

The organic program was very busy investigating the amount and type of gas present in the sediments and the clathrate that was present in the cores. For safety considerations, the concentrations of hydrocarbons as well as H_2S were closely monitored. New PC 486 computers and new MACs were installed in the lab. The new, faster computers alleviated several problems previously attributed to problems with the software. A weighing station was upgraded to a new version of the software. A new data acquisition system known as Chemstation, consisting of both software and hardware, was installed and tried out. A new template for an EXCEL spreadsheet for hydrocarbon monitoring was designed that can be shared over the network with the Operation Superintendent in close to real time. This was put to the test when drilling operations were halted until gas results were processed at Site 892. An upgraded version of SHIPSAM, the sampling program, was received as well as an upgraded computer. A new printer was attached to the Rock-Eval, but the Rock-Eval would not work with the printer. The Rock-Eval was sent back to the beach for a complete overhaul.

X-ray

A FISONS service representative worked during the Victoria port call on the XRF. He was not able to fix the instrument and will return to the San Diego port call. The XRD was used to run samples of the interstitial-water squeeze cakes. The alignment of the XRD helped improve the intensity from the XRD tube. One of the sample changers was sent back for repairs. A vacuum system for the spare XRF tubes was also installed.

MAIN DECK

Computer Lab

The big news for the computer lab was the upgrading of the MAC systems to System 7 and the upgrading of the PCs to Windows version 3.1. The PCs are already running DOS 5.0. Upgrading the MACs was not always easy because we do not have all the most recent versions of all of our software and consequently they are not all compatible with the new System 7. The old Digital PRO-350s were officially retired. There were many new PCs and MACs received, and two SUN stations were brought out by scientists for seismic and logging interpretations. One of the SUN systems came with a thinnet-ethernet adaptor to network with our system. The underway lab (as well as the co-chiefs' office) is still not attached to the ethernet network, and the other SUN workstation could not be hooked up. The original VAX 750s are getting old and had quite a few problems. Both RA70s crashed, as well as the RA81 disk drive. Email was HEAVILY used this leg. The planned upgrade to the communication system and faster modems should realize communication cost savings. There were the usual communications problems when the radio officer tried to log onto the VAX on shore. There were also problems with people running games on the network and slowing it down. This practice was strongly discouraged.

A new copier was received and installed near the science lounge. The copier has been dedicated to making transparencies for overheads. This copier is easy to use and should assist scientists in making overheads, particularly those with a lot of fine detail such as seismics. We received a new lectern and a new projector stand for talks in the science lounge.

Curation

Curation was definitely a challenge this leg. There were a large number of whole-round samples taken: for structural analysis by the sedimentologists, for pore-water and helium studies by the inorganic chemists, for hydrocarbon analysis by the organic geochemists, and for physical properties. Biological samples were also taken for bacterial analysis. The pressure coring system (PCS) and the motor-driven core barrel (MDCB) were used and produced undersized cores for curation. Clathrate was eagerly anticipated but was found only at the last site. Pieces of clathrate were quickly sampled into freezer bags and stored in dewars of liquid nitrogen for later analysis. Small bits of the sublimating clathrate were collected in vacutainers and allowed to degas. The resulting gas was analyzed on the GCs. The new version of SAM, the sampling program, was installed on new PCs in the core lab and the curator's office.

Downhole Tools Lab

There were many deployments of downhole tools for heatflow because of the interest in the bottom-simulating reflector (BSR) and the clathrate. The ADARA heatflow tool was used in soft sediments that could be cored with the APC, while the WSTP was used in stiffer sediments. The PCS was used to try to recover hydrates and core at in-situ pressures. After it had been retrieved, the PCS was attached to a manifold to check if there were pressure increases due to the sublimation of hydrate recovered in the core. The subsequent gases were captured in cylinders for analysis. Unfortunately we were not able to capture any clathrate in the PCS. The TAM straddle packer was also used twice for downhole packer experiments. The GEOPROPS tool made its debut this leg. This tool is designed to fit into a hole drilled by the MDCB. Unfortunately, fill that was in the MDCB hole prevented full penetration of the geoprops probe during its one full development.

UPPER 'TWEEN DECK

A new "all format" VCR arrived and was installed in the science lounge. This VCR will play both PAL and NTSC format tapes and allow scientists from most of the ODP member nations to bring tapes that they have made and show them on the ship.

The storekeeper was kept busy with the frequent shipments received during the leg. Our proximity to Canada and the U.S. during the entire leg resulted in many rendezvous, by both helicopter and ship. The storekeeper also reported to be doing a brisk business in cold-weather gear from the ship's stores.

LAB STATISTICS: LEG 146

(excluding Site 893, Santa Barbara Basin)

General Statistics:	
Sites	6
Holes	15
Cored Interval (M)	2000.6
Core Recovered (M)	911.9
Total Penetration (M)	4233.1
Number of Samples	6942
Samples Analyzed:	
Inorganic Carbon ($CaCO_3$)	162
Total Carbon (NCHS)	162
Water Chemistry (the suite includes pH, Alkalinity, Sulfate, Calcium, Magnesium, Chlorinity, Potassium, Silica, Lithium)	200
Extractions	57
Gas Samples	293
Thin Sections	14
XRD:	330
MST Runs	521
Cryomagnetometer Runs:	1850
Paleomagnetic Cubes	500
Oriented Cores	12
Physical Properties Velocity	243
Thermal Conductivity	358
Index Properties	699
Underway Geophysics:	
Bathymetry	1425
Magnetics	726
DownHole Tools	
WSTP	35
ADARA	24
PCS	11