Integrated Ocean Drilling Program
Expedition 311 Scientific Prospectus

Cascadia Margin Gas Hydrates

Michael Riedel
Co-Chief Scientist
Pacific Geoscience Centre
Geological Survey of Canada
9860 West Saanich Road
PO Box 6000
Sidney BC V8L 4B2
Canada

Timothy S. Collett
Co-Chief Scientist
U.S. Geological Survey
Energy Resources Program
Denver Federal Center
Box 25046, MS 939
Denver CO 80225
USA

Mitchell J. Malone
Staff Scientist/Expedition Project Manager
Integrated Ocean Drilling Project
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA

PUBLISHER'S NOTES

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ABSTRACT

Integrated Ocean Drilling Program (IODP) Expedition 311 has been designed to further constrain models for the formation of marine gas hydrate in subduction zone accretionary prisms. The objectives include characterizing the deep origin of the methane, its upward transport, its incorporation in gas hydrate, and its subsequent loss to the seafloor. The main attention of this expedition is on the widespread seafloor-parallel layer of dispersed gas hydrate located just above the base of the predicted stability field. In a gas hydrate formation model, methane is carried upward through regional sediment or small-scale fracture permeability, driven by the tectonic consolidation of the accretionary prism. The upward-moving methane is incorporated into the gas hydrate clathrate as it enters the methane hydrate stability zone. Also important is the focusing of a portion of the upward methane flux into localized plumes or channels to form concentrations of near-seafloor gas hydrate. The amount of gas hydrate in local concentrations near the seafloor is especially important for understanding the response of marine gas hydrate to climate change. The expedition includes coring and downhole measurements at a transect of five sites across the Northern Cascadia accretionary prism. The sites will track the history of methane in an accretionary prism from (1) its production by mainly microbiological processes over a thick sediment vertical extent, (2) its upward transport through regional or locally focused fluid flow, (3) its incorporation in the regional hydrate layer above the bottom-simulating reflector (BSR) or in local concentrations at or near the seafloor, (4) methane loss from the hydrate by upward diffusion, and (5) methane oxidation and incorporation in seafloor carbonate, or expulsion to the ocean.

This expedition builds on the previous Cascadia margin gas hydrate drilling of Ocean Drilling Program (ODP) Leg 146 and more recent ODP Leg 204 off Oregon. Important experiments for this proposal include (1) logging-while-drilling, (2) wireline logging, (3) intensive coring and subsampling, and (4) pressure core sampling (PCS/HYACINTH) of gas hydrate and fluid recovery under in situ conditions. For this expedition, we plan to carry out logging-while-drilling/measuring-while-drilling operations prior to coring operations.

SCHEDULE FOR EXPEDITION 311

Expedition 311 is based on a "light" or "slim" version of Integrated Ocean Drilling Program (IODP) drilling proposal number 553-Full2 (**www.iodp-mi-sapporo.org/active_2.html**). Following ranking by the IODP Scientific Advisory Structure, the expedition was scheduled by the IODP Operations Committee for the research vessel *JOIDES Resolution,* operating under contract with the U.S. Implementing Organization (USIO). The expedition is currently scheduled to begin in Balboa, Panama, on 24 August 2005, departing after a 4 day port call (or when ready). The science party is scheduled to board the ship on 10 September 2005 during a 1 day port call in Astoria, Oregon (USA). The expedition officially concludes in Victoria, British Columbia (Canada) on 7 October 2005 (for the current detailed schedule, see **iodp.tamu.edu/scienceops/**). A total of 22 days will be available for the drilling, coring, and downhole measurements described in this report. Further details on the *JOIDES Resolution* can be found at **iodp.tamu.edu/publicinfo/drillship.html.**

INTRODUCTION

The primary objective of IODP Expedition 311, on the northern Cascadia margin, is to constrain geologic models for the formation of gas hydrate in subduction zone accretionary prisms. Natural gas hydrate occurs in marine continental slope and onshore Arctic permafrost environments. The Arctic occurrences can exhibit very high gas hydrate concentrations but appear to contain less total gas than marine gas hydrate occurrences. Recent studies have indicated that the largest occurrences of gas hydrate may lie in nearly horizontal layers several hundred meters beneath the seafloor of continental slopes, especially in the large subduction zone accretionary sedimentary prisms. Gas hydrate and underlying free gas produce the ubiquitous bottom simulating reflectors (BSRs) along numerous continental margins of the world. Gas hydrates do occur on passive margins, but they are less common and appear to usually contain lower concentrations.

The two marine gas hydrate areas that have received the most detailed scientific study, including previous drilling during the Ocean Drilling Program (ODP), are the Blake Ridge region off the east coast of the United States (a passive margin setting) and the Cascadia margin off the coast of Oregon and Vancouver Island (subduction zone accretionary prism). Important new information on Arctic gas hydrate occurrences have been obtained from the Mallik-1998 and Mallik-2002 drilling projects in northern Canada (Dallimore et al., 1999, 2002). If our conclusions for the occurrence and distribution of gas hydrate in nature are correct, gas hydrate formed within accretionary prisms is the most important both for the long-term energy potential of gas hydrate and for the role that natural gas hydrate plays in climate change. Within accretionary prisms, the largest amount of gas hydrate appears to occur in a very widespread layer located just above the BSR. However, also important is the focusing of a portion of the upward methane flux into localized migration conduits or channels to form concentrated near-seafloor gas hydrate accumulations. The amount of gas hydrate in the widespread layer above the BSR, compared to that in local concentrations near the seafloor, is especially important for understanding the response of marine gas hydrate to climate change. Near-seafloor gas hydrate accumulations will respond much more quickly to ocean temperature changes compared to gas hydrate several hundred meters below the seafloor. For the region of ODP Site 889/890, Taylor et al. (2002) calculated that a 30 m thick hydrate deposit lying at the base of the stability field would dissociate due to seabed warming in approximately 8000 years. However, near-seafloor hydrate could dissociate much more quickly and be much more responsive to human-induced global warming (e.g., Wood et al., 2002).

Off Vancouver Island a gas hydrate–related BSR occurs in a 30 km wide band parallel to the coast beneath much of the continental slope (Fig. **F1**). Gas hydrate is believed to be concentrated in a layer 50–100 m thick, just above the base of the gas hydrate stability field, which is located 200–300 m below the seafloor (mbsf). The gas hydrate concentrations, estimated from downhole logging data collected during Leg 146, may reach ~30% of pore space. The surveys and studies that have been carried out and the evidence for the presence and content of gas hydrate are summarized in two recent comprehensive review articles (Hyndman et al., 2001; Spence et al., 2000).

Models for Formation of Widespread Gas Hydrate Layer

A general model for deep-sea gas hydrate formation by removal of methane from upwardly expelled fluids was developed earlier for the Expedition 311 area (Fig. **F2**) (Hyndman and Davis, 1992). Mainly microbial methane, inferred to be produced over a thick sediment section, migrates vertically to form gas hydrate when it enters the stability field. The gas hydrate concentration is predicted to be greatest just above the BSR. A model has also been proposed for how free gas and the resulting BSR will be formed as the base of the gas hydrate stability moves upward due to post-Pleistocene seafloor warming, uplift, and sediment deposition (e.g., Paull and Ussler, 1997; von Huene and Pecher, 1998). In addition, physical and mathematical models have been developed for the formation of gas hydrate involving from upward methane advection and diffusion (e.g., Xu and Ruppel, 1999).

Testing these models and determining the appropriate model parameters requires

- Accurate definition of the vertical distribution of gas hydrate and free gas;

- Accurate formation temperatures to define the base of the stability field;
- Physical and fluid chemical data and downhole measurements that define the vertical advection rates of fluids including methane;
- Calibration of the effect of gas hydrate and gas concentrations on velocity, resistivity, and other physical parameters for interpretation of both downhole data and seafloor measurements and surveys; and
- Determination of the sediment pore pressure and permeability that control the upward advection.

Recently, evidence for focused fluid/gas flow and gas hydrate formation has been identified on the Vancouver margin. The most studied site is an active cold vent field associated with near-surface gas hydrate occurrences close to ODP Site 889/890 (e.g., Riedel et al., 2002). Studies include high-resolution bottom profiling, three-dimensional (3-D) seismic surveys, piston coring, and ocean-bottom video surveying and sampling with the remotely operated vehicle *ROPOS*. These vents represent fault-related conduits for focused fluid and/or gas migration associated with massive gas hydrate formation within the fault zone and represent, therefore, the opposite mechanism to the widespread fluid flow. It is thus far unknown how important these cold vents are in the total budget of fluid flow in an accretionary prism. Drilling at the vent field will help constrain the significance of fault-related fluid and/or gas flow.

Coring Transect

During Expedition 311, a series of five holes will be drilled along a margin-perpendicular transect (Figs. **F3, F4**) representing different stages in the evolution of the gas hydrate stability field. Proposed Site CAS-04B is situated in the deep Cascadia Basin. Next is proposed Site CAS-03B, located on top of the first uplifted ridge, followed by proposed Site CAS-02C located in the first slope-sediment basin. The fourth proposed Site CAS0-01B is located near ODP Leg 146 Site 889. The fifth site of the transect (CAS-05D) represents the eastward limit of the gas hydrate occurrence on the margin.

One additional site is located at an active cold vent (proposed Site CAS-06A). An alternate site for this cold-vent location is proposed Site CAS-06B, which is an inactive vent location.

Shortened Expedition Approach

The original proposal 553-Full2 "Cascadia Gas Hydrate" included long-term monitoring experiments using Circulation Obviation Retrofit Kit (CORK)-II, Advanced CORK (ACORK), modular formation dynamic testing (MDT), and distributed temperature sensing (DTS). An extra site for a dual-hole hydrogeologic ACORK experiment was proposed near Site 889 (proposed Site CAS-01C). With this shortened expedition approach the long-term monitoring experiments were postponed until the second expedition of this proposal.

Other components of the original proposal that had to be deferred included coring, wireline, and logging-while-drilling operations at proposed Sites CAS-04B and CAS-05B, walk-away and constant-offset vertical seismic profiling (VSP) at Site CAS-01B.

BACKGROUND

Geological Setting

The area of this investigation is on the accretionary prism of the Cascadia subduction zone (Fig. **F1**). The Juan de Fuca plate converges nearly orthogonally to the North American plate at a present rate of ~45 mm/y (e.g., Riddihough, 1984). Seaward of the deformation front, the Cascadia Basin consists of pre-Pleistocene hemipelagic sediments overlain by a rapidly deposited Pleistocene turbidite for a total sediment thickness of ~2500 m. Most of the incoming sediment is scraped off the oceanic crust and folded and thrust upward to form elongated anticlinal ridges with elevations as high as 700 m above the adjacent basin. The thrust faults near the deformation front penetrate nearly the entire sediment section (Davis and Hyndman, 1989).

ODP Leg 146 Results

During Leg 146 three sites (Fig. **F1**) were drilled that are of significance to Expedition 311. Site 888 was drilled in the deep Cascadia Basin and is near the proposed location of Site CAS-04B and served as a reference site for a "non-gas-hydrate" environment. Sites 889 and 890 were drilled midslope over a strong BSR. These two sites are most relevant to the proposed Expedition 311 Sites CAS-01B and CAS-01C. The following descriptions were taken from the Leg 146 *Initial Results* volume (Westbrook, Carson, Musgrave, et al., 1994).

Site 888 (Relevant for Proposed Site CAS-04B)

Site 888 lies in an outer part of the Nitinat Fan, 7 km seaward of the toe of the accretionary wedge. This site provides a reference for the type, age, and physical properties of sediment in the sedimentary section that is stripped from the ocean crust to form the accretionary wedge. The three holes at Site 888 penetrated into the top 600 m of the sedimentary section, which is 2.5 km thick at this location. Three lithostratigraphic units were recognized.

- Unit I (0–175.1 meters below seafloor [mbsf]): Holocene to upper Pleistocene interbedded clayey silts and fine- to medium-grained sands, with some thin beds containing pebbles, volcaniclastic fragments, and pieces of wood. Between Unit I and Unit II there is a transition zone (175.1–193.0 mbsf) in which there is a gradual increase with depth in the proportion of massive sand.
- Unit II (193.0–457.0 mbsf): upper Pleistocene thick beds of massive fine- to medium grained sand with interbeds of clayey silt.
- Unit III (457.0–566.9 mbsf): upper Pleistocene clayey silt and silt, finely laminated with interbeds of fine to coarse sand and gravel.

Magnetic polarity analyses and biostratigraphy indicate that the entire cored section at Site 888 is younger than 600 ka.

The geothermal gradient has been established as 68°C/km. Thermal conductivity increases in value downward through the uppermost 200 mbsf to a mean value of 1.23 W/m·K for the section below that depth.

Measurements of porosity and shear strength indicate that sediments in the cored section are underconsolidated. Wireline density and neutron porosity logs show that the minimum porosity of the section lies at 300 mbsf. The downward increase in porosity shown in the logs beneath 300 mbsf may be an artifact of poor hole condition. However, porosity measurements conducted on the cored material show a downward decrease beneath 300 mbsf.

The general state of undercompaction indicated by the logs and physical property measurements may be attributed to rapid deposition, especially of the sandy section in Unit II. The rate of sedimentation in the upper 100 mbsf has been close to 1 m/k.y., and sedimentation rates in the remainder of the cored section have at least matched that rate and were probably greater.

The pore water geochemistry in the section varies downward in response to bacterial sulfate reduction, carbonate diagenesis, and fluid flow within some intervals. Pore water chlorinity varies only between 543 and 571 mM. However, small-scale variation in the section may be indicative of fluid flow to maintain observed pronounced minima.

Overall, the organic carbon is at a low concentration (0.2–0.4 wt%). Concentration of methane in the upper 200 mbsf is below 5 ppmv. Ethane, propane, and butane are present only in trace amounts ($C_1/C_2 > 1000$), indicating that methane is of bacterial origin.

Sites 889/890 (Relevant to Proposed Site CAS-01B/C)

Sites 889/890 are located on the mid-continental slope off Vancouver Island at water depths of 1315 and 1326 m, respectively (Fig. **F5**). Coring began in bedded slope-basin sediments and at Site 889 extended into underlying deformed sediments of the accretionary wedge. Site 890 was cored to only 50 mbsf to sample the near-seafloor sediments. A major objective of this site was to investigate the BSR at a depth of 225 mbsf. Holes 889A, 889B, and 889C penetrated the BSR.

Sediments at Sites 889/890 range in age from late Quaternary to late Pliocene. A hiatus in the record is present at 87 mbsf, separating upper Quaternary from lower Pleistocene deposits. Three lithostratigraphic units were determined.

Unit I includes clayey silts, fine sand, and diagenetic carbonates. It extends from the surface to a depth of 128 mbsf. Unit I comprises slope and slope basin sediments that are hemipelagites, turbidites, and mass flow deposits.

Unit II is similar to Unit I, but it is noticeably more consolidated than the overlying unit and is highly fractured. Diagenetic carbonates were observed throughout the entire section. Unit II is thought to consist of abyssal plain silts and clays that were post-depositionally fractured during accretion. Unit II extends to 301.5 mbsf, beneath which the glauconite content increases sharply at the top of Unit III. The sediments of Unit III appear to be abyssal plain deposits like those in Unit II above, but the abundant authigenic glauconite suggests deposition under suboxic conditions.

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 260 mbsf (upper Unit II), the porosity decreases rapidly and the sediments become overconsolidated to the base of Unit II. There are distinct excursions from the general porosity decrease with depth that correlate with variations in the diagenetic carbonate cementation and organic geochemistry (organic carbon content, methane, N, and S concentrations). The position of the BSR falls within one of these excursions, but it is not unique. Unit III exhibits an apparently anomalous increase in porosity with increasing depth.

The inorganic chemistry of the pore waters defines two zones: within lithostratigraphic Unit I, sulfate declines to 0 at 10 mbsf, accompanied by an increase in alkalinity, and as a result Ca^{2+} and Mg^{2+} concentrations decrease rapidly from 0 to 60 mbsf. Chloride concentration declines from 550 mM at the sediment/water interface to 363 mM at the base of chemical Zone 1 (130 mbsf).

Chemical Zone 2 (130–386.5 mbsf) shows nearly constant Cl^- concentration of 370 mM. The concentration of Na^+, Mg^{2+}, and phosphate are also nearly constant, indicating that the low Cl^- concentration is a dilution effect.

Lithostratigraphic Unit I yielded elevated methane concentrations (60,000–80,000 ppmv) below the sulfate reduction zone. Methane declines to 30,000 ppmv at the base of Unit I. Over this same interval, ethane and propane were essentially absent, and the C_1/C_2 ratio was > 1000, indicating a microbial methane source. A small spike in the ethane concentration (33 ppmv) at 129 mbsf (associated with the Cl^- minimum) suggests a deeper source for fluids at that level.

Gas composition changes markedly in the interval 130–247 mbsf, with headspace (HS) samples containing 30,000–77,000 ppmv methane, 5–35 ppmv ethane, and 0.5–3.4 ppmv propane. Below 250 mbsf the methane concentrations become highly variable. Ethane increases markedly below 300 mbsf, and propane increases rapidly below 360 mbsf. Within this interval, the C_1/C_2 ratio declines from values of ~2000 to <100, indicating a mixture of thermogenic and bacterially derived gas. There is no evidence in either the logs or the cores for the accumulation of gas hydrate in massive form, but the temperature of –1.4°C measured in a core at 220 mbsf could have been produced by the dissociation of gas hydrate.

Six in situ temperature determinations were made with the Water Sampling Temperature Probe and Adara tools. Temperature increases linearly with depth, with a gradient of 54°C/km.

The BSR at Sites 889/890 is situated 276 ms two-way traveltime below the seafloor. Time-depth curves derived from the vertical seismic profile (VSP) and sonic log indicate that the BSR is located at 225 mbsf (Hole 889B). Although the acoustic 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. Velocities are lower than those of seawater and are typical of the presence of small amounts of free gas. The discrepancy between VSP and acoustic log results may be attributed to drilling disturbance, which could deplete the gas phase in the immediate vicinity of the drill hole.

Gas Hydrate Occurrence

Gas hydrate concentrations were previously estimated from the downhole acoustic and resistivity logs, multichannel seismic (MCS) core analysis, and VSP velocities and from pore water freshening (e.g., Yuan et al., 1996, 1999; Hyndman et al., 1999). Gas hydrate concentrations from the different methods vary slightly but were estimated to be on average 20%–35% of the pore space over a 100 m thick interval above the BSR.

These are high gas hydrate concentrations for a marine gas hydrate occurrence, and are not observed on other margins. ODP drilling and logging at the Blake Ridge offshore South Carolina (passive margin environment) showed gas hydrate concentrations that were on average lower than 10% (Paull, Matsumoto, Wallace, et al., 1996). Results from Leg 204 at southern Hydrate Ridge located on the southern Cascadia margin offshore Oregon, with a very similar tectonic environment to offshore Vancouver Island, showed very low gas hydrate concentrations of <5% except for the unusual summit of Hydrate Ridge (Trehu et al., 2004). An earlier approach by Ussler and Paull (2001) for interpreting chlorinity data from Leg 146 by using a smooth chlorinity baseline suggested lower gas hydrate concentrations at Sites 889/890, but were in an apparent contradiction to other geophysical results using electrical resistivity and seismic velocity.

In preparation for Expedition 311, the gas hydrate concentrations along the northern Cascadia margin were recalculated using Leg 146 acoustic/electrical resistivity logs and pore water chlorinity/salinity data (Riedel et al., in press a). New estimates show that the concentrations could alternatively be between 5% and 10% on average of the pore volume from ~130 mbsf to the BSR (at ~230 mbsf) if different baselines are used in the individual calculations.

No conclusive decision can be made on the chlorinity baseline without additional pore water chemistry data (lithium and strontium data) to confirm that the model by Torres et al. (2004) derived from Leg 204 results is also valid for the Sites 889/890. Therefore, the gas hydrate concentrations along the northern Cascadia margin based on chlorinity data may either be as low as a few percent, as suggested earlier by Ussler and Paull (2001), or as high as 40%, previously suggested by Hyndman et al. (1999).

Gas hydrate concentrations were calculated from the resistivity data using Archie's law. Archie's law consists of several empirical parameters (referred to as a, m, and n), which were determined to be a = 1.4, m = 1.76, and n = 1.0 by Hyndman et al. (1999) using the Leg 146 core data at Sites 888 and 889/890. However, Collett (2000) redefined these parameters to a = 1.0, m = 2.8, and n = 1.9 by using the Site 889 resistivity and neutron porosity logs. The differences in these empirical parameters result in highly different estimated gas hydrate concentrations. The Leg 146 logging data are of relatively poor quality and neither the new parameters nor the previous analyses fit all data well, and a large uncertainty remains in the results. However, results from Leg 204, obtained from a tectonically similar environment, suggest that the Archie parameters by Collett (2000) may be preferable.

Finally, new velocity references were calculated from the Site 889 porosities using various published empirical relations between porosity and velocity (Jarrard et al., 1995; Hyndman et al., 1993) and the Lee et al. (1993) weighted equation. All the newly proposed baselines are significantly shifted toward higher seismic velocities relative to the former baseline defined by Yuan et al. (1996) and Hyndman et al. (2001). Thus, they result in gas hydrate concentrations that are only between 5% and 10% of the pore volume. However, significant uncertainty remains in the applicability of the empirical parameters for each of the individual equations.

If the model by Torres et al. (2004) proposed for Hydrate Ridge (Leg 204) is applicable to Site 889 and if the Archie parameters by Collett (2000) are correct, these two methods (although individually very uncertain) confirm results from the acoustic velocity analyses of Lee et al. (1993). Thus, the total gas hydrate concentration at Sites 889/890 may be much lower than previously assumed.

Seismic Studies/Site Survey Data

Extensive site survey data exist on the Cascadia margin to support the operations of Expedition 311:

- Conventional MCS reflection: a regional survey in 1985 and site survey lines for Leg 146 in 1989; summaries are given in Hyndman et al. (1994) and Hyndman (1995). Seismic velocities and porosities were studied by Yuan et al. (1994) and detailed seismic studies of the hydrate and BSR by Yuan et al. (1996, 1999).
- Three-dimensional (3-D) seismic surveys: a regional MCS 3-D seismic survey was conducted in 1999 around Sites 889/890, and four high-resolution 3-D single-channel seismic (SCS) grids were acquired over the vent field (Riedel et al., 2002). Other high-resolution SCS and short-offset MCS surveys were conducted (e.g., Fink and Spence, 1999).
- Three ocean-bottom seismic (OBS) surveys were carried out in 1996 and 1997 and as part of the 1999 3-D survey.
- DTAGS deep-towed MCS system survey carried out by the Naval Research Laboratory (NRL) in 1997 in the area of ODP Sites 889/890 (Gettrust et al., 1999).
- Presite survey in 1999 with MCS, SCS, and 3.5 kHz seismic data collection over proposed sites.
- Extensive piston coring associated with physical property and geochemical data analyses (Solem et al., 2002; Novosel, 2002).
- Heat flow studies (Riedel et al., in press b).
- Seafloor video observations and sampling (Riedel et al., in press b).

SCIENTIFIC OBJECTIVES

This expedition follows the goals for gas hydrate drilling as proposed by the ODP Gas Hydrates Program Planning Group:

- Study the formation of natural gas hydrate in marine sediments.
- Determine the mechanism of development, nature, magnitude, and global distribution of gas hydrate reservoirs.
- Investigate the gas transport mechanism, and migration pathways through sedimentary structures, from site of origin to reservoir.
- Examine the effect of gas hydrate on the physical properties of the enclosing sediments, particularly as it relates to the potential relationship between gas hydrates and slope stability.
- Investigate the microbiology and geochemistry associated with hydrate formation and dissociation.

The objectives of this expedition are to test gas hydrate formation models and constrain model parameters, especially models of hydrate concentration through upward fluid and methane transport. These objectives require (1) high-quality data on the vertical concentration distributions of gas hydrate and free gas and variation landward in the accretionary prism and (2) estimates of the vertical fluid and methane fluxes through the sediment section as a function of landward distance from the deformation front.

The study will concentrate on the contrast between dispersed pervasive upward flow and focused flow of fluid and methane in fault zones. The pervasive permeability may be on a grain scale, on a centimeter scale (the scaly fabric observed in previous ODP clastic accretionary prism cores), or in closely spaced faults. Strong and continuous BSRs may occur only in coarser clastic accretionary prisms (i.e., muddy silt or coarser) where grain or other small-scale permeability allows pervasive upward expulsion. In muddy, low-permeability sediments, fluid expulsion may be focused in discrete faults so hydrate does not form a continuous layer.

Geochemistry

Geochemical measurements of gas hydrate, pore fluids, and sediments within and below the gas hydrate stability zone are essential to meet the outlined objectives. In addition to characterizing gas hydrate and free gas depth distribution and geochemistry, critical chemical and isotopic measurements summarized below will provide information on conditions of gas hydrate formation, relation to organic matter content and type, and the nature and temperature of fluid-rock reactions. The chemical and isotopic data are necessary for the understanding of (a) the origin of the methane and other hydrate forming gases, (b) the mode of formation of the methane hydrate, and (c) the source of the fluids carrying the gases sequestered in the gas hydrates, and if more than one source the ratio of sources, and testing which of the hypotheses of gas hydrate formation outlined in the proposal applies to this region. Representative samples will be recovered under in situ conditions with the ODP Pressure Core Sampler (PCS) and the HYACINTH pressure corer (depending on funding availability) to quantify gas concentrations in the gas-hydrate-bearing zone and below the BSR.

Based on previous geochemical studies, especially since ODP Leg 146, the most critical measurements include the following:

- Chloride concentrations and isotope ratios in the gas hydrates and pore fluids to determine the mode and rate of formation of gas hydrate and the fluid source from greater depths or from the in situ pore fluid (Ransom et al., 1995; Spivack et al., 2002),

- Two to three geothermometers (e.g., Fournier and Potter, 1979; Kharaka and Mariner, 1989),
- Carbon isotope ratios of dissolved inorganic carbonate along with oxygen and hydrogen isotopes of the gas hydrate structural water and pore water (e.g., Kastner et al., 1998),
- Chemical and isotopic compositions of the hydrocarbons in the hydrate and of the dissolved and free gases,
- Pore fluid pH and sulfate, sulfide, ammonium, and alkalinity concentrations (e.g., Borowski et al. 1997) and minor and trace elements concentrations and corresponding isotope ratios characteristic of fluids from a deeper source such as Li, B, and Sr (e.g., Kastner et al., 1995a, 1995b),
- Sediment mineralogy and geochemistry, and
- Amount and type of organic matter.

Microbiology

Microbiologists participating in ODP for the past decade have demonstrated that more than 10^5 cells/cm^3 consistently exist in the subsurface marine sediments even at depths of ~1000 mbsf. On the basis of these efforts, the subseafloor environment has been proposed to have the largest biomass potentials on Earth, exceeding the biomass in terrestrial and oceanic environments. However, recent data from pore water chemistry such as sulfate and methane in ODP and Deep Sea Drilling Project (DSDP) core sediments suggest that most of the microbial metabolic activity may occur in the narrow and shallow zone near the continents and that most of the deep subseafloor microorganisms are likely either inactive or adapted for extraordinarily low (or slow) metabolic activity in open ocean. Although it is currently unverified from sufficient microbiological characterizations, if it is true, the inactivity of the subseafloor microbiota is ubiquitous and is likely explained by a combination of low-temperature and low-porosity conditions coupled with the extremely slow energy and fluid fluxes conveying inorganic and organic nutrients.

Not all the deep ocean is characterized by low metabolic activity. Regions located in the subduction zones of the continental margin, often bearing a great amount of subseafloor gas hydrate deposits, are considered to be among the places for the prosperity of functionally active, metabolically diverse microbial communities. Indeed, most of the biogenic and mixed type methane hydrate is distributed around continental margins on subduction zones where the organic matter is supplied from continents and active fluid circulation is present (Cascadia margin, Nankai Trough, Black Ridge, Guatemara, Peru margin, etc.). To know which microbes specifically are responsible for producing biogenic methane and how and where they are making it is one of the most exciting challenges for subsurface microbiologists.

There have been several microbiological studies for the subsurface biosphere of biogenic methane hydrate–bearing sediments with culture-dependent or -independent techniques. Based on the vertical characterization of the biomass and activity of methanogens in the methane hydrate–bearing sediments from Blake Ridge, North Hydrate Ridge of Cascadia margin, and Nankai Trough, anomalies both in biomass and activity were observed at the methane hydrate–bearing layers in Blake Ridge and Cascadia margin. However, no satisfactory explanation has been offered for these microbiologic anomalies. The molecular phylogenetic analyses of deep subseafloor sediments in the presence or absence of methane hydrate deposits in Cascadia margin and Nankai Trough have demonstrated the potential microbial community structures inferred from ribosomal ribonucleic acid (rRNA) genes, but the relationship between the microbial community structure and the distribution of methane hydrate is still unclear because of the low analysis frequencies. Thus, the origin of the biogenic methane and the microbial processes in generation, transportation, and accumulation are still resolved.

Microbiological investigation will be conducted by interdisciplinary cooperation with geochemists, mineralogists, geophysicists, and geologists. Major microbiological objectives are (1) to obtain direct evidence of the existence of functionally active methanogens associated with formation of subseafloor methane hydrate deposit on the Cascadia margin and (2) to clarify the controversial hypotheses where and how the biogenic methane is originally produced: deep hot zones far below the present hydrate layers by hyperthermophilic methanogens from H_2 and CO_2 versus shallow cold sediments above the present hydrate layers by mesophilic methanogens from organics.

Addressing these microbiological objectives will require the following:

- High-resolution characterization of biomass, diversity, structure, and function of microorganisms at the community and population levels at different depths,

- High-resolution characterization of composition, dynamics, kinetics, and isotopic features of inorganic and organic fluid and gas chemical components at different depths, and
- Clarification of the relationship between the distribution of the microbial community and the formation of the complex subseafloor hydrogeologic structure controlling the transportation and accumulation of methane.

Strategy

Almost all the microbiological characterizations will be carried out as described below. The drilling core samples are basically collected using advanced piston corer (APC) and extended core barrel (XCB) coring. In the case that APC/XCB coring yields exceptionally poor recovery, we may attempt rotary core barrel (RCB) coring. To prevent possible external microbial contamination during sampling or preservation, the samples for microbiology and fluid and gas geochemistry will be cut into whole round cores (WRCs) according to standard protocol. The procedure for subcoring should be performed in a cool environment (~4°C). Microbial contamination from drilling fluid will be evaluated by using microfluorescent beads and perfluorocarbon as described in Smith et al. (2000). The recovered WRC will be put into a sterilized anaerobic bag filled with nitrogen and stored at less than –80°C or in liquid nitrogen prior to molecular analyses. The innermost core samples will be used for preparation of a variety of slurries for cultivation, chemical fixation of the slurries for optical and electron microscopic observation, nucleic acids extraction, and lipid and biomarker extractions. The following geomicrobiological experiments are considered.

Culture-Dependent Analyses

Quantitative cultivation experiments (most probable number [MPN] or serial dilution method) and enrichment analyses will be carried out to enumerate the viable population of microorganisms. Homogenized slurry samples will be inoculated into prepared media and then diluted in a series of liquid media. The results of cultivation show the potential population of viable cells that can grow in designed media for various types of chemolithoautotrophic, carboxydotrophic, methanotrophic, and chemolithoorganotrophic microorganisms under various pH and temperature conditions. The most intensively targeted phenotypes and metabolisms are hyperthermophilic or mesophilic methanogens using H_2 + CO_2 or organics such as acetate, methylamines, and methanols. Other phenotypes and metabolisms such as H_2-oxidizing chemolithoautrophs and anoxic methane oxidiziers (AMO) will also be targeted. Growing cells will be purified by the extinction and dilution method as quantitatively dominant viable cells, and physiological characteristics will be examined in home laboratories according to previous reports.

Molecular Ecological Analyses

To characterize the microbial community structure in a given habitat, a combined use of several molecular ecological techniques is the most reliable evaluation. Using nucleic acid and biomarker extracts from the innermost WRC samples, several molecular ecological analyses will be conducted. We will employ the following well-defined and reliable techniques for microbiological investigations in the proposed project:

- Fluorescence in situ hybridization-direct count (FISH-DC) will be performed on board or on shore to estimate the biomass of the total microbial population and targeted phylogroups of microorganisms in the core samples by fluorescence microscopy.
- Quantitative polymerase chain reaction (qPCR), a modification of the classical PCR, is essentially a fluorogenic assay used to quantity the number of target genes and cells in a given environmental sample. During this expedition, we will use qPCR to estimate the population ratio between the domains Bacteria and Archaea using the specific primers and fluorogenic probes for each domain and to estimate the metabolic activity using functional genes of key enzymes such as dissimilatory sulfate reductase (dsr), particulate methane mono-oxygenase (pmmo), methyl coenzyme M reductase (mcr), and other carbon-fixation enzymes (RuBisco, adenosine triphosphate [ATP]-citrate lyase, etc.).
- Gene sequencing provides the primary sequence of specific genes needed for both phylogenetic analysis and identification. Genes to be sequenced include 16S r-DNA genes as well as other functional genes described above.
- Lipid analysis associated with stable carbon isotope characterization will provide a great deal of information for identifying the energy and carbon metabolisms of the uncultured majority organisms not identified in elaborate cultivation tests. Bacterial fatty acids composition and archaeal glycerol dialkyl glycerol diether (GDGD) and glycerol dialkyl glycerol tetraether (GDGT) compositions will reinforce the deoxyribonucleic acid (DNA)-based microbial community characterization and make it possible to estimate the biomass of the specific phylotypes or physiotypes of the subseafloor microorganisms.

Gas Hydrate Concentrations and Physical Properties

Calibration of regional estimates of hydrate and free gas volumes based on remote geophysical surveying is of critical importance toward estimating the concentration of gas hydrate and evaluating its role in climate change and resource potential. Recent experience during Legs 146, 164, and 204 underlined the complexity of this issue (see also Riedel et al., in press a). During Expedition 311, we will drill through gas hydrates in a variety of sedimentological settings with different seismic characteristics and measure the physical properties of the gas hydrate–bearing sediments and underlying free gas zones through downhole logging and pressure coring. The downhole logging data will be complemented by visual core description and other core studies.

Gas Hydrates and Slope Stability

Because gas hydrates can be destabilized by pressure and temperature changes, they are potential seafloor geohazards. The formation and dissociation of gas hydrate has a significant influence on the mechanical properties of marine sediments. Replacement of pore water by gas hydrate increases the shear strength as well as reduces the porosity and permeability of sediments (Paull et al., 2000). In turn, during gas hydrate dissociation, free gas and water are released, decreasing the shear strength and making the sediment more prone to failure. The process of gas hydrate decomposition also affects the pore pressure of the sediments (Kayen and Lee, 1993). During gas hydrate dissociation in sediments having pore fluids saturated with methane, the water and free gas released into the pore space will usually exceed the volume that was previously occupied by the hydrate. The net effect is either an increase in pressure (if the sediments are well sealed by a low-permeability cap) or an increase in volume (if the additional pressure can escape by fluid flow). Gas hydrate dissociation can occur due to changes in the pressure/temperature conditions, as outlined above, or due to continued sedimentation. The associated increase in pore pressure, expansion of sediment volume, and the development of free gas bubbles all have the potential to weaken the sediment. Failure could be triggered by gravitational loading (continued sedimentation) or seismic disturbances (earthquakes), yielding slumps, debris flows, and slides. The possible connection between gas hydrate occurrence and submarine slides was first recognized by McIver (1982). Many authors have later related major slumps on continental margins to instability associated with the breakdown of hydrates, including surficial slides and slumps on the continental slope and rise of Southwest Africa (Summerhayes et al., 1979), slumps on the U.S. Atlantic continental slope (Carpenter, 1981), large submarine slides on the Norwegian margin (Jansen et al., 1987), and massive bedding-plane slides and rotational slumps on the Alaska Beaufort Sea continental margin (Kayen and Lee, 1993). Expedition 311 will provide critical information for testing the hypothesis that the presence of gas hydrate may lead to instability of the underlying material by constraining mechanical and hydrological properties of the gas hydrate–bearing sediments.

Cold Vents and Formation (Stability) of Near-Surface Massive Gas Hydrates

Recently, evidence for focused fluid/gas flow and gas hydrate formation has been identified on the Vancouver margin. Several seismic blank zones were observed in the seismic data (Fig. **F6**) over a frequency range from 20 to 4 kHz, where the degree of blanking increases with seismic frequency. The blank zones range from 80 m to several 100 m in width. The most studied site is an active cold vent field associated with near-surface hydrate close to ODP Sites 889/890 (e.g., Riedel et al., 2002). Studies include high-resolution bottom profiling, 3-D seismic surveys, piston coring, and ocean-bottom video surveying and sampling with the remotely operated vehicle *ROPOS*. These vents represent fault-related conduits for focused fluid and/or gas migration associated with massive hydrate formation within the fault zone and represent therefore the opposite mechanism to the widespread fluid flow.

Massive hydrate was found at several sites by piston coring within a blank zone (also referred to as Bullseye vent) at depths of 1–8 mbsf. Increased methane concentrations of up to 8 times the ocean background levels were measured in water samples taken above an active area (Solem et al., 2002). However, venting appears to be strongly episodic. Pore fluid alkalinity gradients from piston cores were converted to sulfate gradients, from which the amount of methane and related fluid flux were calculated. The calculated methane flux varies from 10–19 mol/m^{2}k.y. outside the vent to values 32-–0 mol/m^{2}k.y. inside the vent. Assuming full methane saturation, the maximum methane flux inside the vent corresponds to a fluid flux of ~1 mm/y.

It is thus far unknown how important these cold vents are in the total budget of fluid flow in an accretionary prism. Drilling at the vent field would help to constrain the significance of fault-related fluid and/or gas flow.

The nature of the seismic blanking is yet unresolved. Several differing models have been published (Wood et al., 2002; Riedel et al., 2002; Zühlsdorff and Spiess, 2004), but none of these models is able to explain all observations made at the vent field.

Detailed coring and logging will provide the necessary data to constrain mechanisms to explain seismic blanking at the cold vents.

Two sites are considered: an active cold vent (proposed Site CAS-06A) with widespread carbonate formation, massive near-seafloor gas hydrates, and abundant chemosynthetic communities, as well as an inactive cold vent (proposed Site CAS-06B), where seismic blanking has been observed over a 500 m × 1500 m area.

DRILLING STRATEGY

The original proposal for Expedition 311 included seven sites. Part of the proposed drilling program consisted of five sites to be drilled in a transect perpendicular to the continental margin across the North Cascadia accretionary prism. Located at the western edge of the transect, proposed Site CAS-04B is situated in the deep Cascadia Basin. The next site, CAS-03B, is located on top of the westernmost uplifted ridge, followed by Site CAS-02C, located in the first slope sediment basin. The fourth, Site CAS-01B, is located near Site 889. The fifth transect site (CAS-05D) represents the eastern limit of the gas hydrate occurrence on the margin. One additional site was included in the original proposal, CAS-06A, located at a cold seafloor vent. An alternate site for this cold-vent location, Site CAS-06B, was proposed, which is an inactive vent location. In addition to the proposed transect and cold vent drilling, a two-hole site (CAS-01C) for a hydrogeologic cross-hole experiment with A-CORKs was also included in the original proposal. As discussed in **"Introduction,"** the proposed two-hole (Site CAS-01C) hydrogeologic cross-hole experiment has been dropped from this initial North Cascadia drilling program. The focus of this expedition will be the proposed multisite transect and the identified cold vent site.

For this expedition, we plan to carry out logging-while-drilling (LWD) and measurement-while-drilling (MWD) operations prior to coring each site (pending Environmental Pollution and Safety Panel [EPSP] approval). There is a strong scientific need to obtain LWD/MWD data prior to coring. The coring operations will be complemented by frequent deployment of the PCS/HYACINTH pressure core systems. It is essential to know before deploying the available pressure core systems what the gas hydrate concentrations and vertical distribution are to choose the optimum depths for pressure coring operations. The coring operations are also complemented by frequent sampling for interstitial water, headspace gas, and microbiological analyses. Although those samples will be taken at relatively regular depths (e.g., every 5 m), the sampling frequency can be adjusted if gas hydrate concentrations and distribution can be forward predicted through the analysis of the LWD/MWD precore logging surveys. Without prior knowledge of this distribution, subsampling may easily undersample (or miss completely) important sedimentary sections.

After a relatively short transit from Astoria, Oregon, LWD/MWD tools will be first deployed at proposed Site CAS-03B at the far western downslope end of the proposed multisite transect running from east to west down the continental margin (Table **T1**). The LWD/MWD hole at Site CAS-03B will be advanced to a depth of 300 mbsf. Site CAS-4B is now considered an alternate drill site. The next hole to be drilled and LWD/MWD logged will be at proposed Site CAS-02C, which will also be drilled to a depth of 300 mbsf. The third LWD/MWD hole will be drilled at proposed Site CAS-01B to a depth of 380 mbsf. The fourth LWD/MWD hole will be drilled at the cold vent proposed Site CAS-06A to a depth of 300 mbsf. The final LWD/MWD hole (proposed Site CAS-05D) will be drilled to a depth of 220 mbsf at the upslope limit of the planned multisite transect.

After completing the LWD/MWD logging program, the expedition will switch to conventional and pressure-controlled coring operations at each of the sites drilled during the LWD/MWD campaign. Each core hole will also be wireline logged (triple combination [triple combo] and Formation MicroScanner [FMS]-sonic tool strings). A single zero-offset VSP survey will be conducted at proposed Site CAS-01B. A single core hole is planned for each site. The standard core hole will consist of APC coring to an expected "refusal" depth of ~200 mbsf; each hole will be advanced to their proposed total depth (TD) by XCB coring. Interspersed with the APC/XCB cores in each hole will be approximately six PCS/HYACINTH pressure cores. Each of the APC core runs will also be monitored with the APC-methane (APCM) tool, which in turn will be used to analyze and modify gas hydrate core-handling operations. The coring program will start at proposed Site CAS-05D immediately following LWD/MWD operations. The core hole sequence will proceed down the continental slope to proposed Sites CAS-06A, CAS-01B, CAS-02C, and finishing at CAS-03B (Table **T1**).

Proposed Downhole Measurement Strategy

Within the coring program special effort will be made to obtain geothermal gradient data to accurately predict the depth to the base of the gas hydrate stability zone at each site drilled during Expedition 311. Downhole temperature tool deployment will include multiple runs of the APC-temperature (APCT) tool (minimum of four runs per hole) and Davis-Villinger Temperature-Pressure Probe (DVTPP) (minimum of two runs per hole) systems both above and below the depth of the BSR.

LOGGING/DOWNHOLE MEASUREMENTS PLAN

Logging While Drilling

LWD/MWD tools will be deployed at all proposed sites, including oriented resistivity-at-the-bit (RAB) images with 360° coverage of the borehole wall. The MWD tools will allow us to monitor drilling parameters and to transfer LWD data in real time. Because LWD sensors are located immediately above the drill bit, the measurements are made before gas hydrate dissociates under drilling disturbances, and these data are critical to identify gas hydrate distribution in the formation. In addition to directly addressing the expedition objectives, RAB images will be potentially useful for identifying high-resistivity features, helping to locate intervals where the pressure coring tools might be used to recover gas hydrate samples. To optimize scheduling and drilling success, all LWD/MWD operations will be completed at the beginning of the cruise, prior to coring operations.

Wireline Logging

Because of the unstable nature of gas hydrate, wireline logging is critical to measure in situ properties of hydrate-bearing sediments. The standard triple combo (density, porosity, and resistivity) and FMS-sonic tool strings will be deployed at all sites. In addition, the three-component Well Seismic Tool (WST-3) will be used to record a VSP at proposed Site CAS-01B. Acoustic logs (along with the VSP) are critical in determining the acoustic velocity structure associated with the BSR. Both *P*-wave and *S*-wave velocity measurements will be made using the Dipole Sonic Imager (DSI) tool. Depth-to-seismic ties will also be accomplished by means of synthetic seismograms computed from the wireline density and sonic logs. High-resolution FMS electrical images will compliment the RAB images and may indicate features such as thin beds, veins, and fractures in hydrate-bearing sediments.

Vertical Seismic Profiling

A zero-offset VSP is planned for proposed Site CAS-01B. The VSP will be conducted by repeatedly shooting a generator injection (GI) gun (105 in^3 generator/45 in^3 injector) hung from the drillship 2 m below the surface for each geophone depth in the borehole. The geophone will be placed at about 10 regular intervals throughout the entire 350 m deep borehole. At each recording depth, the GI gun will be fired several times (up to 10 times) to stack the seismic signals and enhance the signal-to-noise ratio.

SAMPLING STRATEGY

General

Shipboard and shore-based researchers should refer to the interim IODP Sample, Data, and Obligations policy posted on the Web at **iodp.org/data_samples.html.** This document outlines the policy for distributing IODP samples and data to research scientists, curators, and educators. The document also defines the obligations that sample and data recipients incur. Access to data and core sampling during Expedition 311, or within the 1 y moratorium, must be approved by the Sample Allocation Committee (SAC). The SAC (composed of Co-Chief Scientists, Staff Scientist, and IODP Curator on shore and curatorial representative on board ship) will work with the Shipboard Scientific Party to formulate a formal expedition-specific sampling plan for shipboard and post cruise sampling.

Shipboard scientists are expected to submit sample requests 3 months before the beginning of the expedition. Sample requests may be submitted at **iodp.tamu.edu/curation/samples.html.** Based on sample requests (shore based and shipboard), the SAC and Shipboard Scientific Party will prepare a working cruise sampling plan. This plan will be subject to modification depending upon the actual material recovered and collaborations that may evolve between scientists during the expedition. Modifications to the sampling plan during the expedition require the approval of the SAC.

All sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the cruise objectives. Some redundancy of measurement is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests.

Cruise-Specific Sampling Plan

Because the main focus of this expedition is gas hydrates, special protocols regarding sampling and measurement strategies will be required in addition to routine analyses and procedures. Modifications to core and sample handling, based on experience gained from previous ODP and other hydrate drilling programs, will be required to quickly identify intervals containing gas hydrates. Summarized below is the anticipated measurement and sampling scheme and special hydrate sampling plan and protocol:

- Infrared (IR) imaging will be conducted via continuous scan systems and by handheld cameras for immediate hydrate identification on the catwalk.
- Organic geochemistry samples will be collected by routine headspace and void gas sampling.
- Inorganic geochemistry samples will be collected for interstitial water geochemistry.
- Physical properties will include thermal conductivity, multisensor track (MST; *P*-wave velocity, non-contact resistivity, gamma ray attenuation bulk density, and magnetic susceptibility), moisture and density, split core velocity, shear strength, and resistivity.
- Sedimentology will include core description, smear slides, color reflectance, and digital core imaging.
- Biostratigraphy.
- Paleomagnetic analyses will support sediment age determination and gas hydrate-related mineralization.
- Microbiology sampling will be integrated with the organic and inorganic chemistry sampling program; existing microbiological sampling protocols will be employed including analyses of sample contamination.
- Downhole logging data including conventional wireline and LWD will be acquired.
- Downhole tool-derived data (APCT, DVTPP, and APCM) will be recorded.
- Additional sampling requests specified by shipboard and shore-based participants will be accommodated when possible.

Special Hydrate Sampling

It is expected that gas hydrate–bearing core material will be recovered during conventional APC/XCB coring operations. It is also planned that PCS/HYACINTH coring will be employed to analyze the in situ occurrence of gas hydrate and to recover gas hydrate samples under in situ conditions. Special procedures for sampling gas hydrate–bearing cores follow:

- Sampling on the catwalk or from pressure cores will be based on an integrated sample plan, which will be developed from individual shipboard and shore-based sample requests.
- Gas hydrate sampling will be monitored by digital video and voice recording for immediate sample description.
- Specialized dissociation tests will be conducted on gas hydrate samples for volumetric and geochemical analyses.
- Recovered gas hydrate samples will be stored in liquid N_2 and/or in a repressurized sample vessel. PCS cores will be processed shipboard. HYACINTH recovered pressure cores will be maintained at pressurized conditions for shipboard and shore-based analyses.
- Special laboratory equipment designed to transfer and measure gas hydrate properties under controlled pressure conditions will be used. Specific laboratory equipment being considered includes the Geotek vertical logger, Georgia Tech MST-P, and Lawrence-Berkley X-ray computing tomography (CT) scanner (depending on funding availability).
- Because of the proximity and appropriate facilities, the Pacific Geoscience Centre (located in Sidney, British Columbia, Canada) is proposed as a clearinghouse for gas hydrate samples collected under the integrated sample plan.
- Gas hydrate samples will be distributed to approved investigators after inventory according to approved sampling requests.

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Table T1. Expedition 311 operations summary.

Site	Location (lat, long)	Seafloor depth (mbsl)	Operations description	Transit (days)	Drilling/ Coring (days)	Wireline logging (days)
	Balboa, Panama		Start of Expedition 311 4.0 days	(In Port)		
			Transit ~3800 nmi to Astoria, Oregon, at 10.5 kt	15.1		
	Astoria, Oregon		Science Party boards ship 1.0 day	(In Port)		
			Transit ~206 nmi to Site CAS-03B at 10.5 kt	0.8		
CAS-03B	48°37.058′ N, 127°02.413′ W	1780	Hole A: LWD/MWD to 300 mbsf BSR at ~230 mbsf		1.2	
			DP move ~2.8 nmi to Site CAS-02C at 1.0 kt	0.0		
CAS-02C	48°38.688′ N, 126°58.993′ W	2230	Hole A: LWD/MWD to 300 mbsf BSR at ~230 mbsf		1.0	
			DP move ~5.7 nmi to Site CAS-01B at 1.0 kt	0.2		
CAS-01B	48°41.884′ N, 126°51.924′ W	1325	Hole A: LWD/MWD to 380 mbsf BSR at ~215 mbsf		1.3	
			DP move ~0.8 nmi to Site CAS-06A at 1.0 kt	0.0		
CAS-06A	48°40.050′ N, 126°51.053′ W	1280	Hole A: LWD/MWD to 300 mbsf BSR at ~215 mbsf		0.9	
			DP move ~9.9 nmi to Site CAS-05D at 1.0 kt	0.4		
CAS-05D	48°47.367′ N, 126°40.717′ W	970	Hole A: LWD/MWD to 220 mbsf		0.8	
			Hole B: APC to ~200 mbsf, XCB to TD at 220 mbsf (APCT/ DVTPP temperature and PCS/HYACINTH pressure coring)		2.2	
			- Wireline log with triple combo/FMS-sonic (~10 h) BSR @ ~130 mbsf			0.4
			DP move ~9.9 nmi to Site CAS-06A at 1.0 kt	0.4		
CAS-06A	48°40.050′ N, 126°51.053′ W	1280	Hole B: APC to ~200 mbsf, XCB to TD at 300 mbsf (APCT/ DVTP temperature and PCS/HYACINTH pressure coring)		2.5	
	(Active Cold Vent)		- Wireline log with triple combo/FMS-sonic (~12 h)			0.5
			DP move ~0.8 nmi to Site CAS-01B at 1.0 kt	0.1		
CAS-01B (Site 889)	48°41.884′ N, 126°51.924′ W	1325	Hole B: APC to ~200 mbsf, XCB to TD at 350 mbsf (APCT/ DVTP temperature and PCS/HYACINTH pressure coring)		2.8	
			- Wireline log with triple combo/FMS-sonic (~13 h)			0.5
			- Checkshot VSP with WST-3 (~6 h)			0.3
			DP move ~5.7 nmi to Site CAS-02C at 1.0 kt	0.3		
CAS-02C	48°38.688′ N, 126°58.993′ W	2230	Hole B: APC to ~200 mbsf, XCB to TD at 300 mbsf (APCT/ DVTP temperature and PCS/HYACINTH pressure coring)		3.0	
	(First Slope Basin)		- Wireline log with triple combo/FMS-sonic (~13 h)			0.6
			DP move ~2.8 nmi to Site CAS-03B at 1.0 kt	0.1		
CAS-03B	48°37.058′ N, 127°02.413′ W	1780	Hole B: APC to ~200 mbsf, XCB to TD at 300 mbsf (APCT/ DVTP temperature and PCS/HYACINTH pressure coring)		2.9	
			- Wireline log with triple combo/FMS-sonic (~13 h)			0.6
			Transit ~134.0 nmi to Victoria at 10.5 kt	0.6		
	Victoria, B.C., Canada		End of Expedition 311	18.0	18.6	2.9
			Subtotal transit time:		18.0	
			Subtotal on-site time:		21.5	
			Total operating days:		39.5	
			Total expedition including 5.0 days of port call(s):		44.5	

Notes: LWD/MWD = logging-while-drilling/measurement-while-drilling operations. BSR = bottom-simulating reflector. APC = advanced piston corer, XCB = extended core barrel. APCT = APC Temperature tool, DVTPP = Davis-Villinger Temperature-Pressure Probe, PCS = Pressure Core Sampler. TD = total depth. Triple combo = triple combination tool string, FMS = Formation MicroScanner. VSP = vertical seismic profile; WST-3 = three-component Water Sampling Temperature tool. Assumes 24 h required for boarding of scientists in Astoria, thus limiting Balboa port call to 4.0 days maximum. Assumes drill string round trip with LWD and MWD tools (memory download and battery change) after Sites CAS-02C and CAS-06A. Approval to drill Site CAS-06A is pending. If denied, then Site CAS-06B will be drilled.

Figure F1. General location of proposed drilling transect near previous ODP Sites 889/890. A BSR is present on ~50% of the mid-continental slope (shaded area).

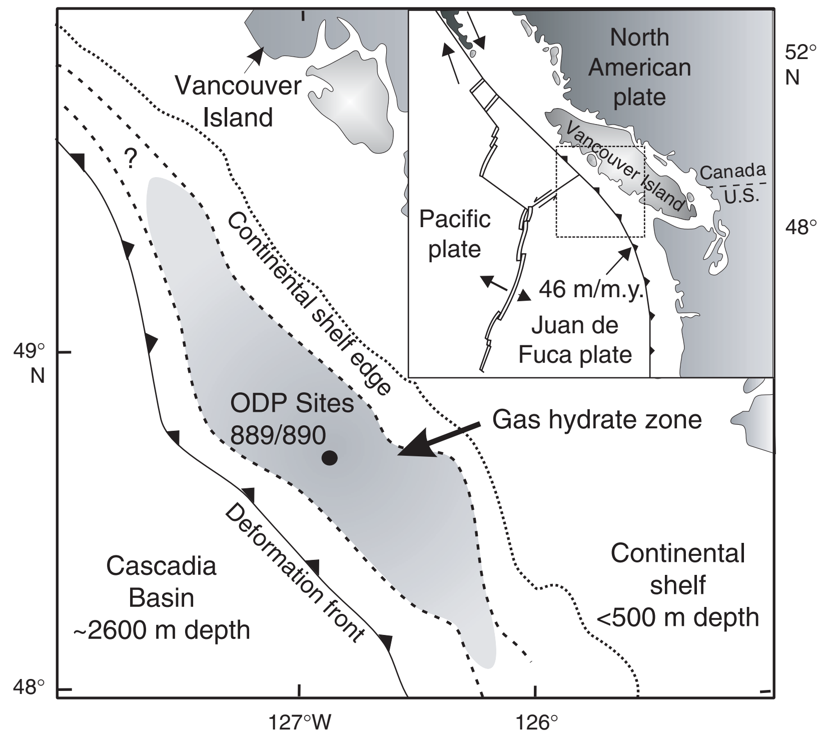


Figure F2. Marine gas hydrate cycle (after Hyndman and Davis, 1992). BSR = bottom-simulating reflector.

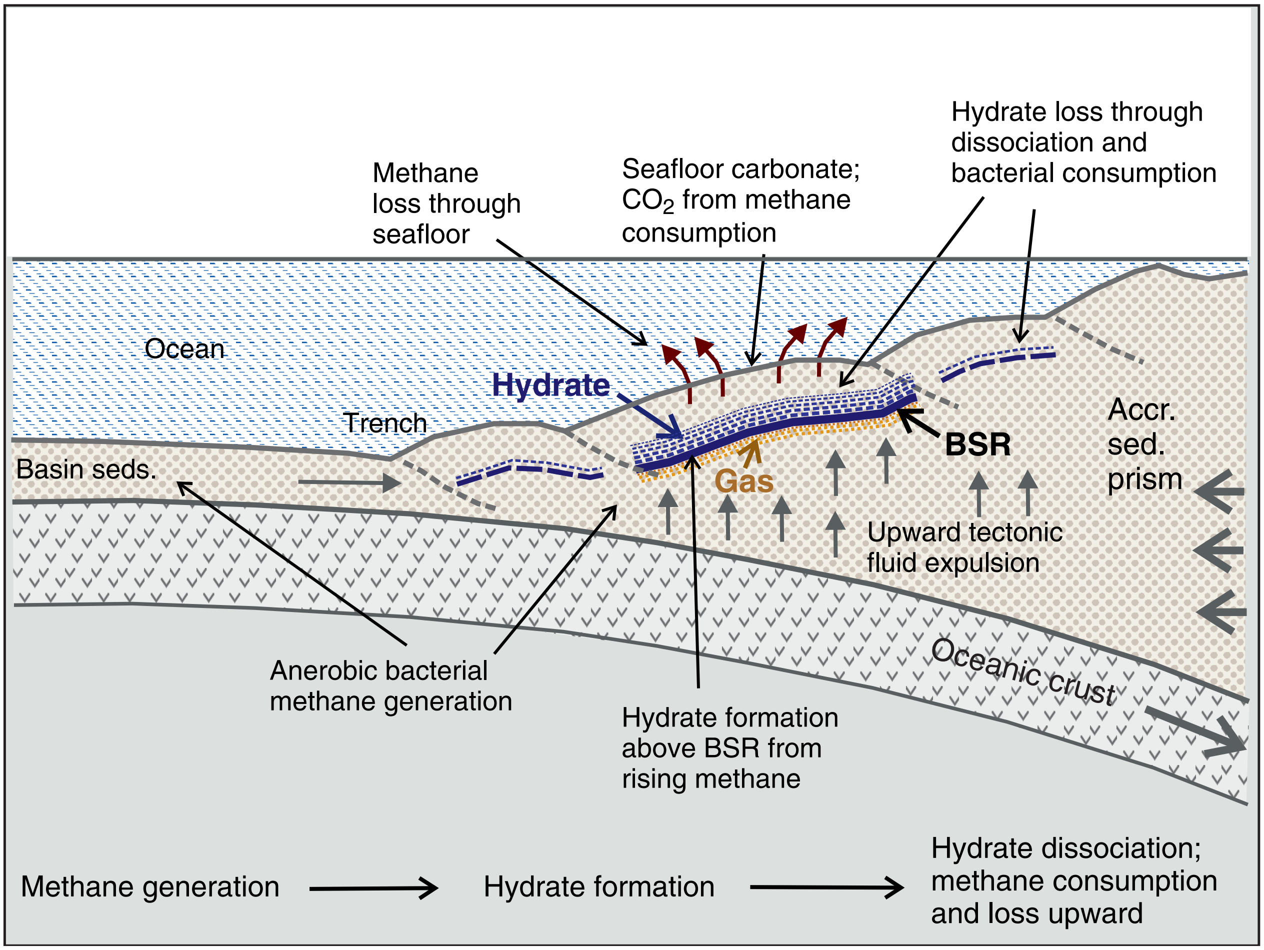


Figure F3. Bathymetry (in meters) of continental slope off Vancouver Island and locations of proposed sites of Expedition 311.

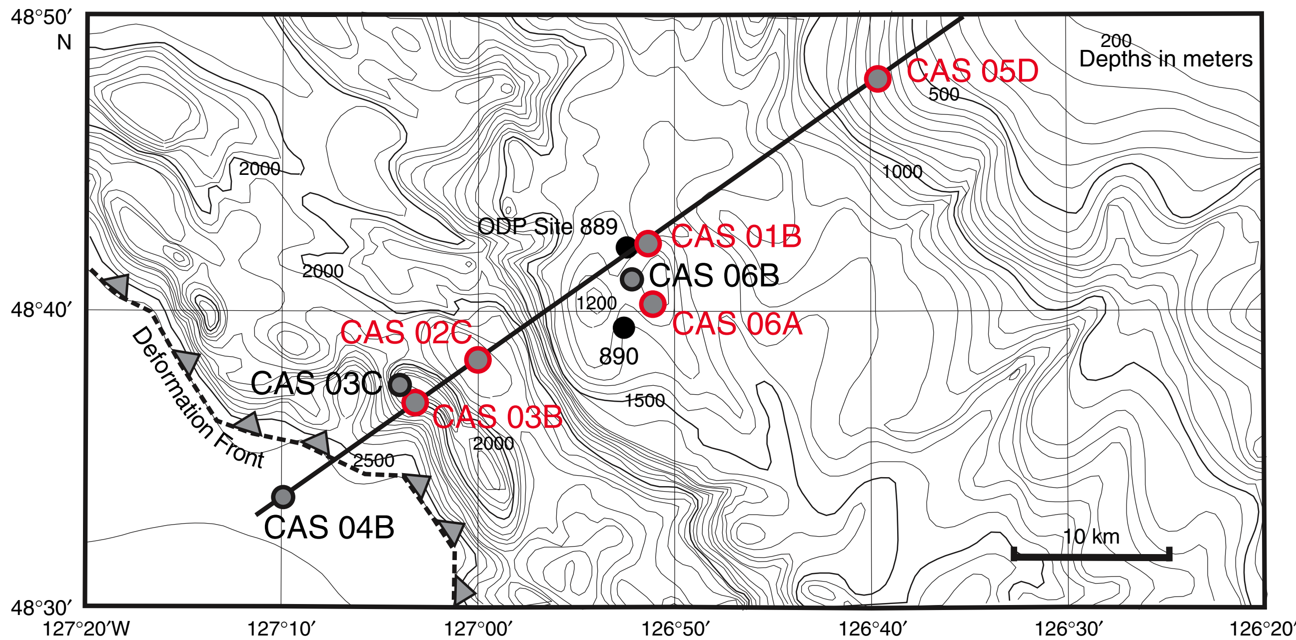


Figure F4. Seismic section (line 89-08) showing proposed Expedition 311 sites. BSR = bottom-simulating reflector.

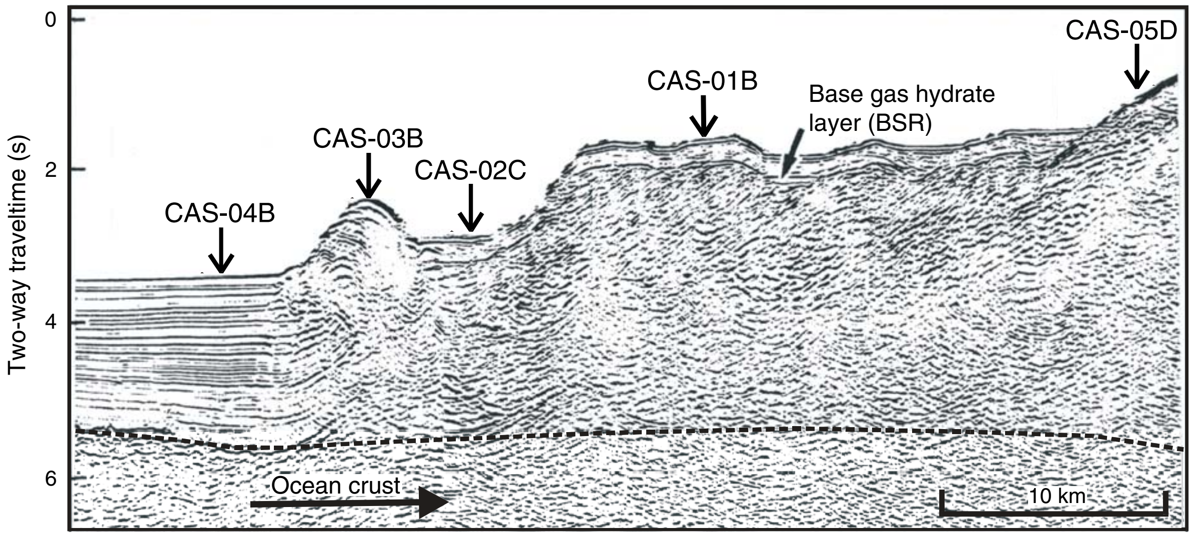


Figure F5. Seismostratigraphy and interpretation from Hole 889A (after Westbrook, Carson, Musgrave, et al., 1994). The part of inline 38 around ODP Hole 889A is shown for comparison (from Riedel, 2001). BSR = bottom-simulating reflector.

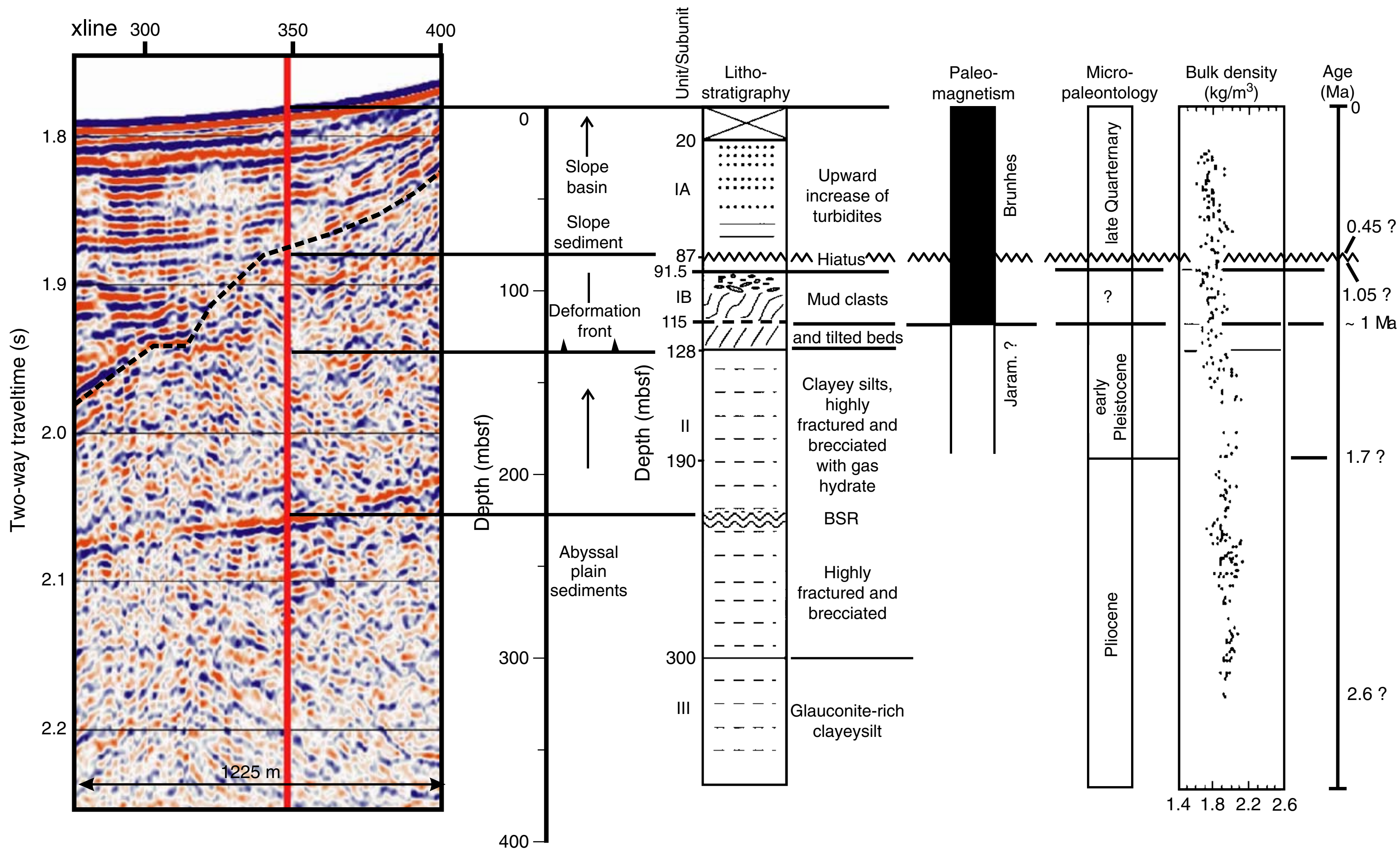


Figure F6. Seismic signature of the cold vents (blank zones) from (**A**) 3.5 kHz subbottom profiler (vertical exaggeration = 20) and (**B**) single-channel seismic data. Blank Zone 1 (proposed Site CAS-06A) is active; Zones 2–4 are inactive. Alternate Site CAS-06B is at blank Zone 4. BSR = bottom-simulating reflector.

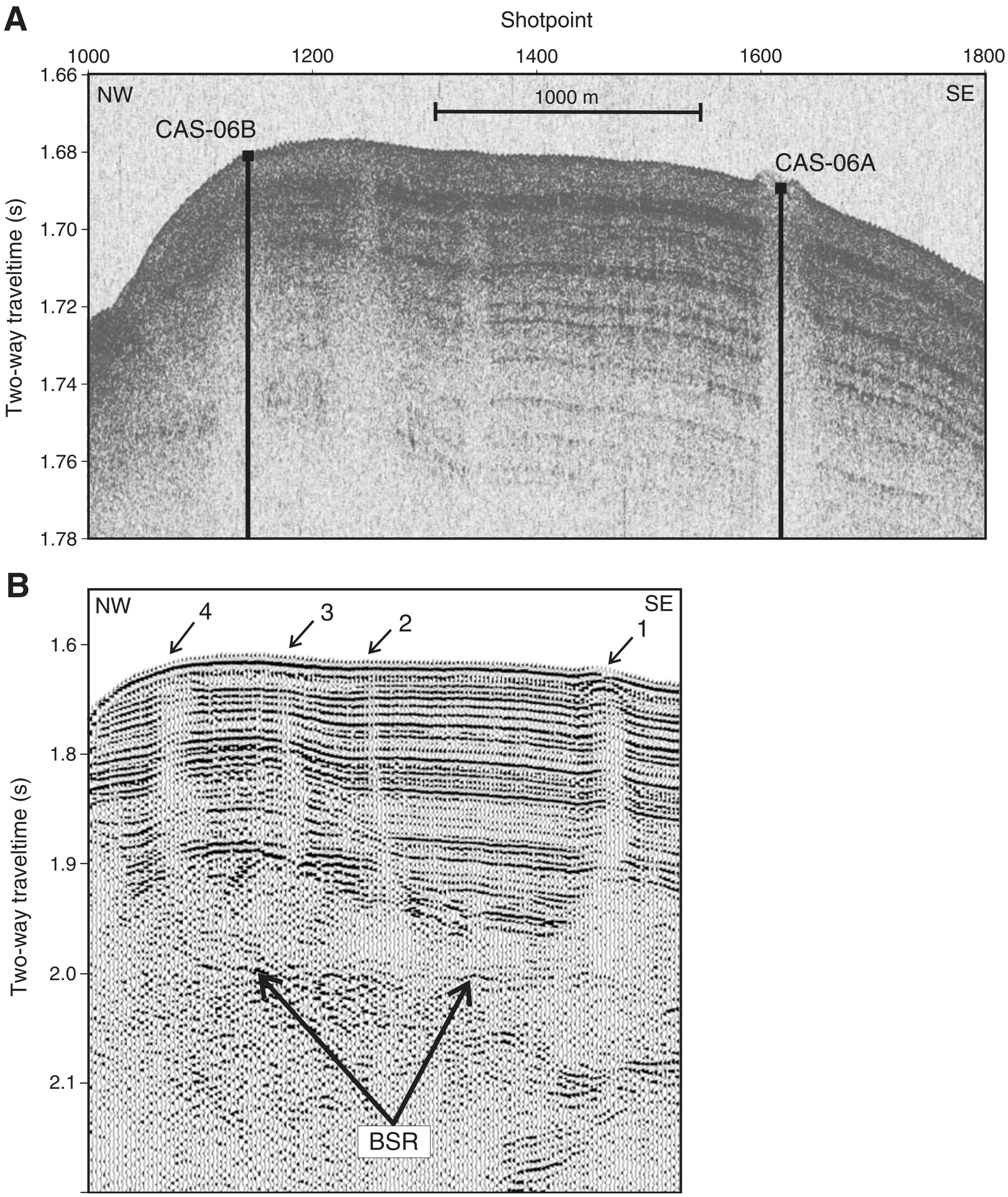


Figure F7. Seafloor bathymetry near proposed Site CAS-01B. Shown are locations of seismic lines of Figures F8 and F14A and F15.

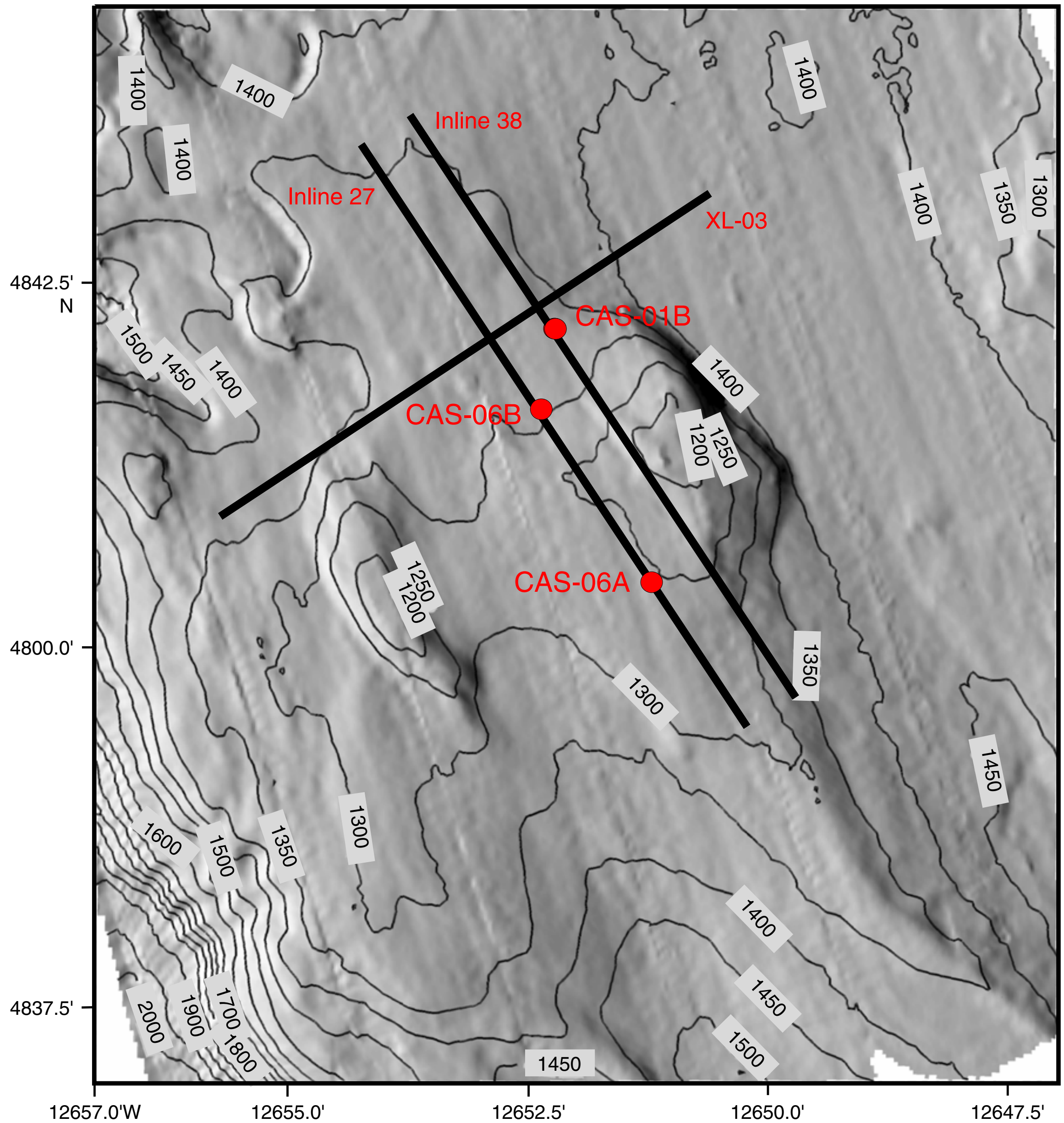


Figure F8. Site survey data at proposed Site CAS-01B. **A.** Multichannel seismic (MCS) Inline 38 from 1999 3-D cube (vertical exaggeration = 8). **B.** Regional MCS Line XL06 from 1999 survey (vertical exaggeration = 7). CDP = common depth point.

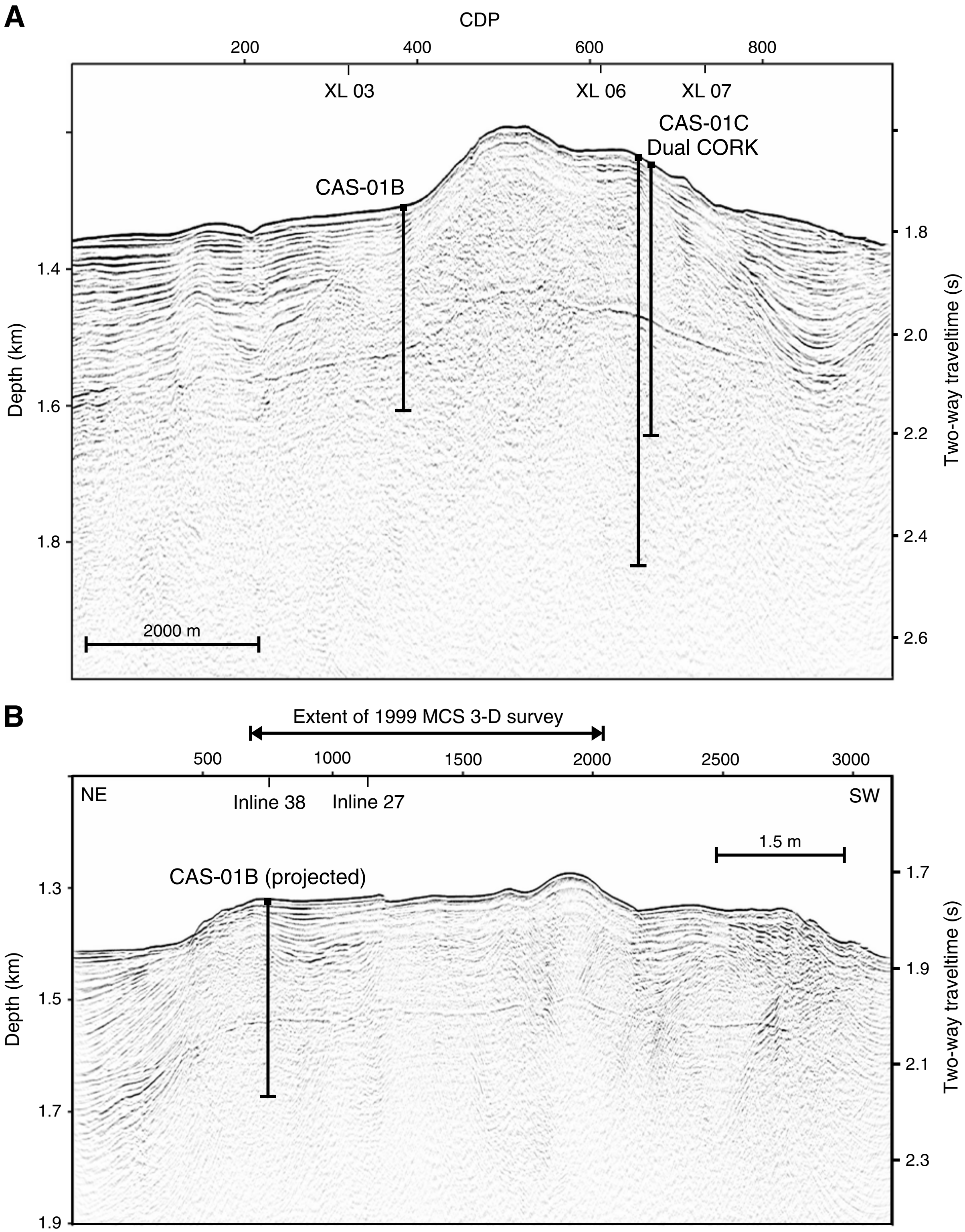


Figure F9. Site survey data for proposed Site CAS-02C. **A.** conventional MCS data of Line 89-08 (Leg 146 presite survey) (vertical exaggeration = 4). **B.** MCS data of Line PGC9902_ODP07 acquired in 1999 (vertical exaggeration = 4.5). **C.** SCS Line PGC0408_CAS02B_05, crossing A and B perpendicularly (vertical exaggeration = 5). CDP = common depth point.

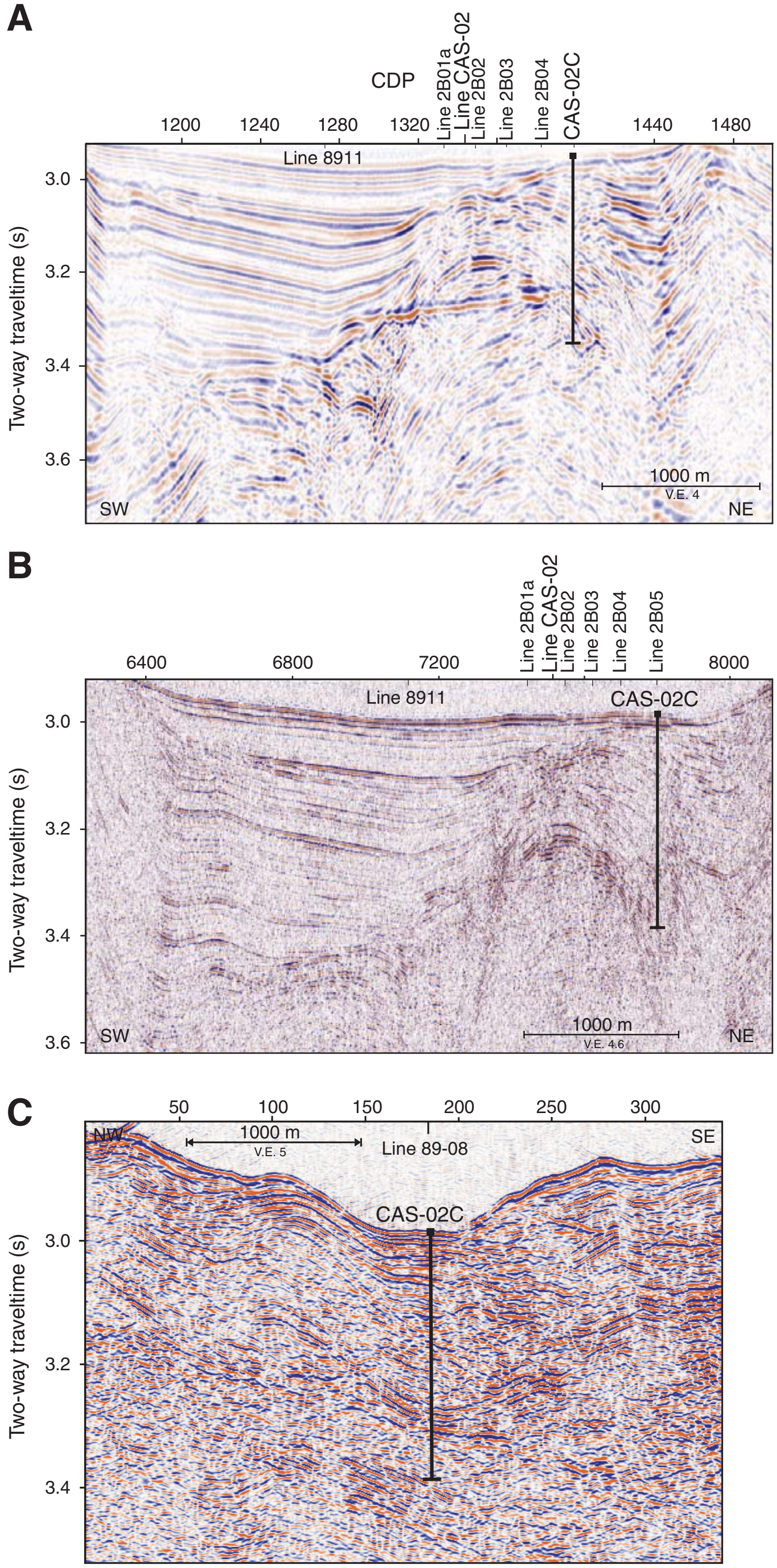


Figure F10. Site survey data for proposed Sites CAS-03B and CAS-03C. **A.** Conventional MCS data of Line 89-08 (Leg 146 presite survey) (vertical exaggeration = 4.3). **B.** SCS data of Line PGC0408_CAS03B_X04 (vertical exaggeration = 3.7). **C.** MCS data of Line CSA-03 crossing A and B perpendicularly (vertical exaggeration = 6.5). CDP = common depth point.

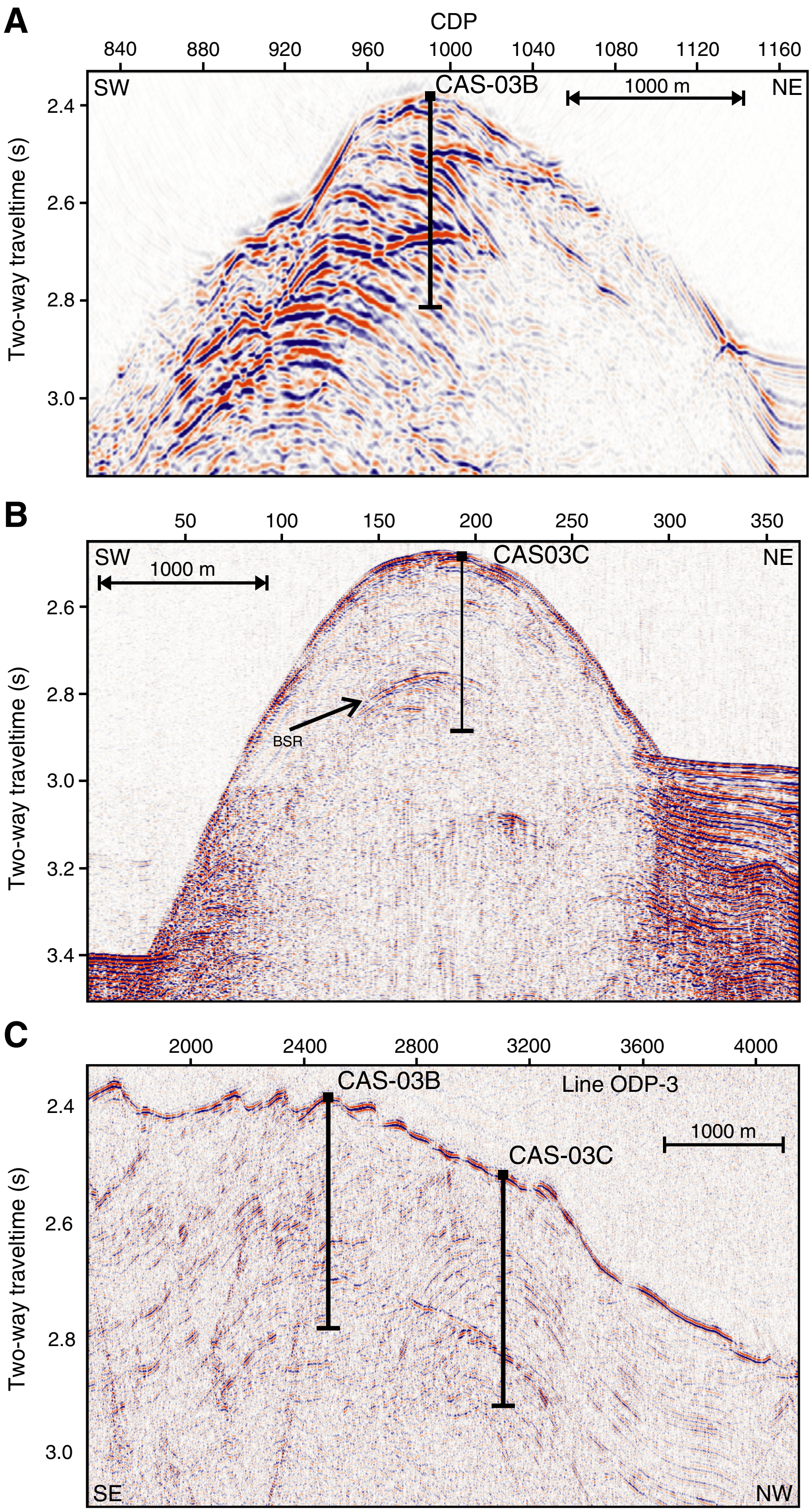


Figure F11. Site survey data for proposed Site CAS-04B. **A.** SCS data of Line PGC9902_ODP07. **B.** SCS data of Line PGC9902_CAS04.

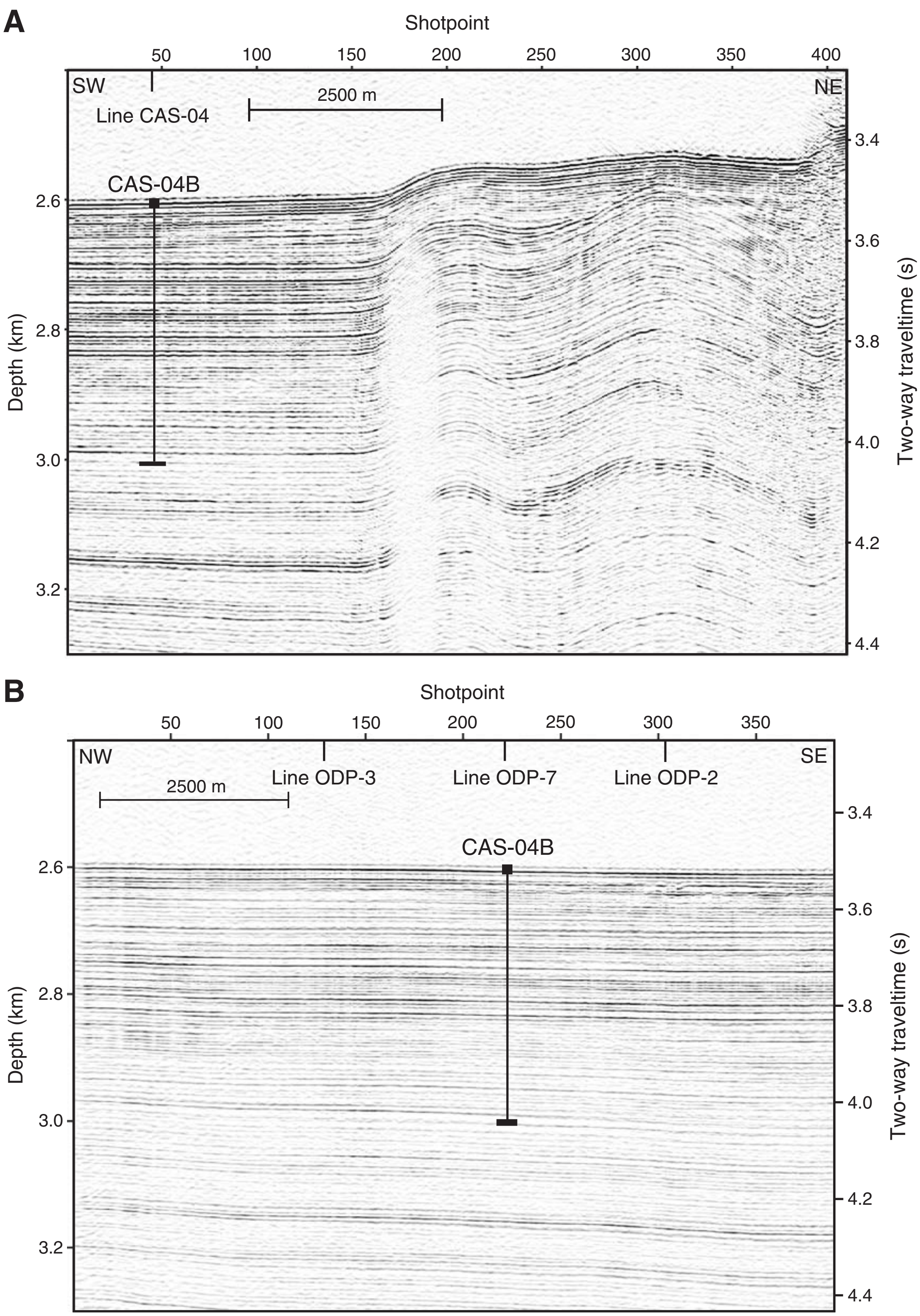


Figure F12. Site survey data for proposed Site CAS-05B. **A.** Conventional MCS data of Line 89-08. **B.** MCS data of Line PGC9902_ODP7. **C.** MCS data of Line PGC9902_CAS05a.

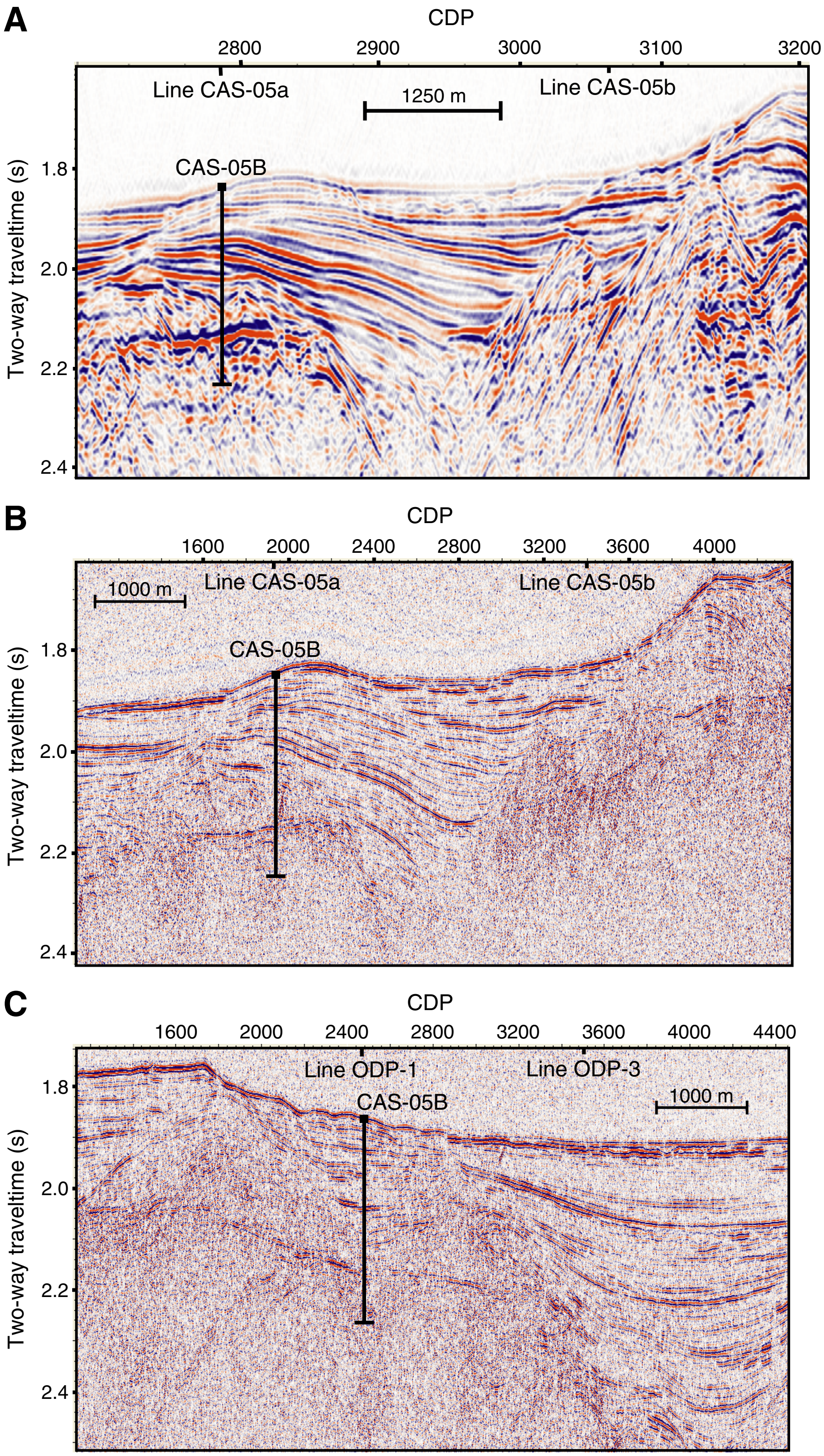


Figure F13. Site survey data for proposed Site CAS-05D. **A.** Conventional MCS data of line 89-08. **B.** MCS data of Line PGC9902_ODP01. **C.** SCS data of Line PGC0408_CAS05D_04.

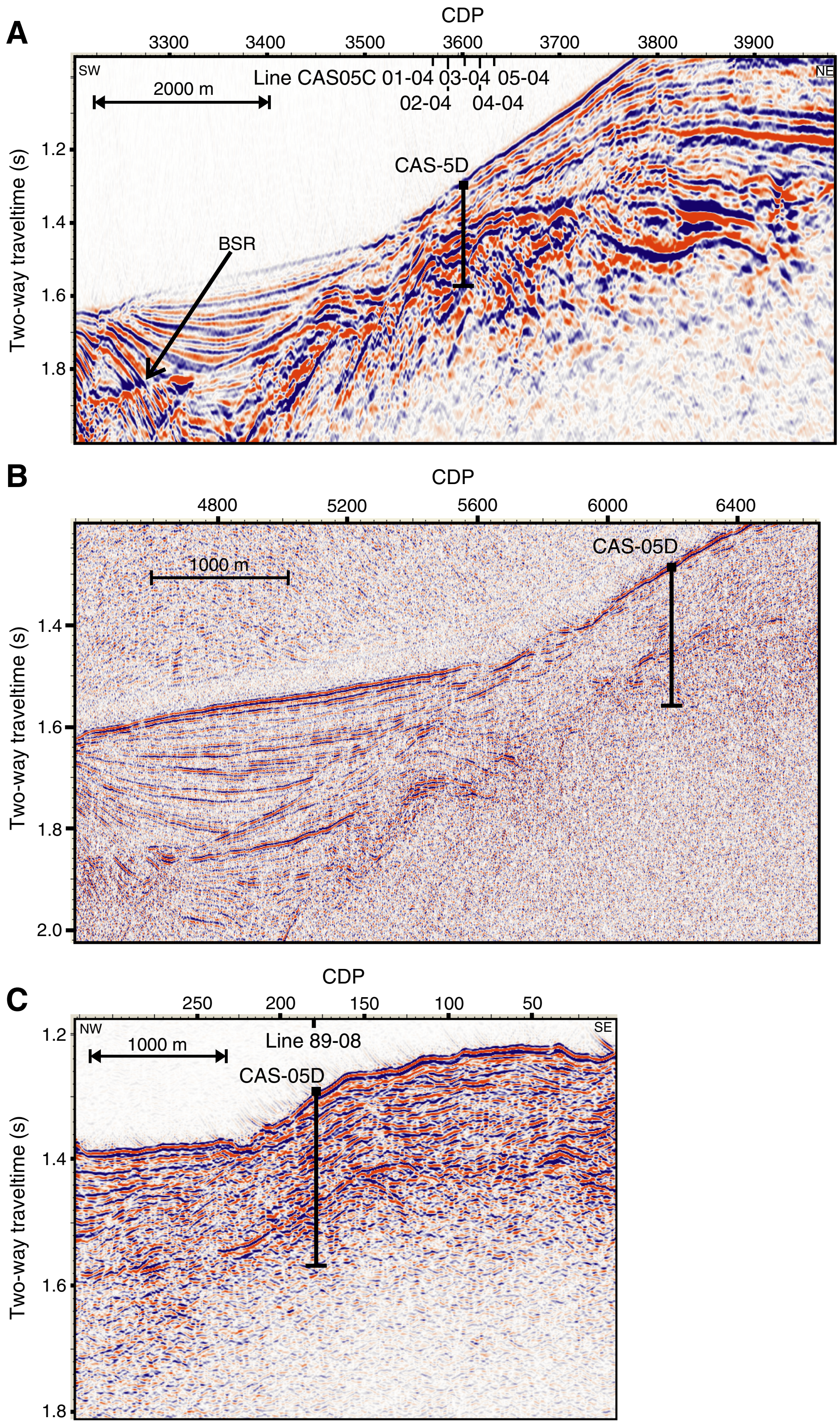


Figure F14. Site survey data for proposed Site CAS-06A. Inline 27 from 1999 3-D MCS data cube. **A.** MCS data (stacked). **B.** 3.5 kHz subbottom profiler data.

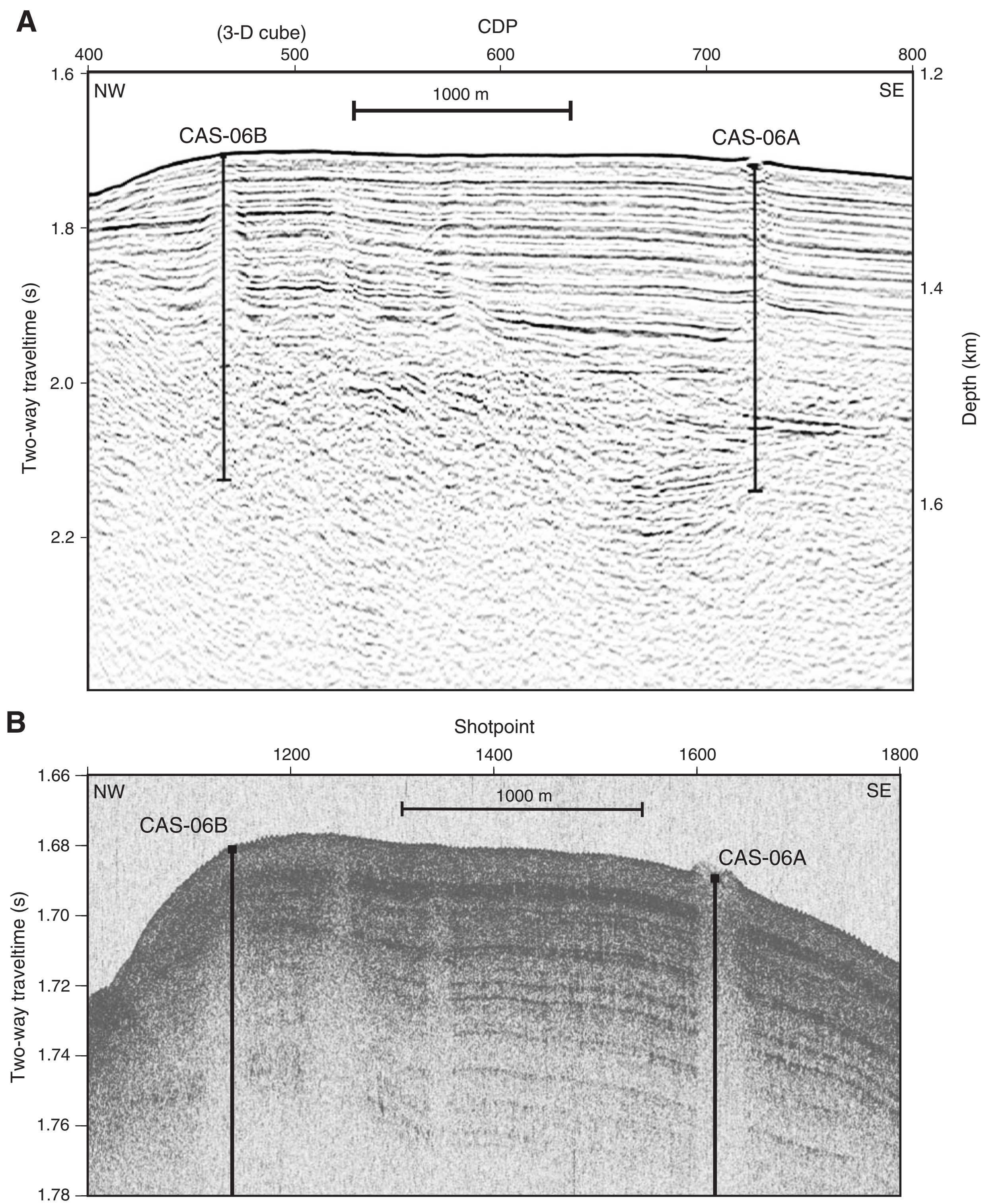


Figure F15. Site survey data for proposed Site CAS-06A. Inline 16 from 2000 SCS 3-D cube. **A.** SCS data. **B.** 3.5 kHz subbottom profiler data.

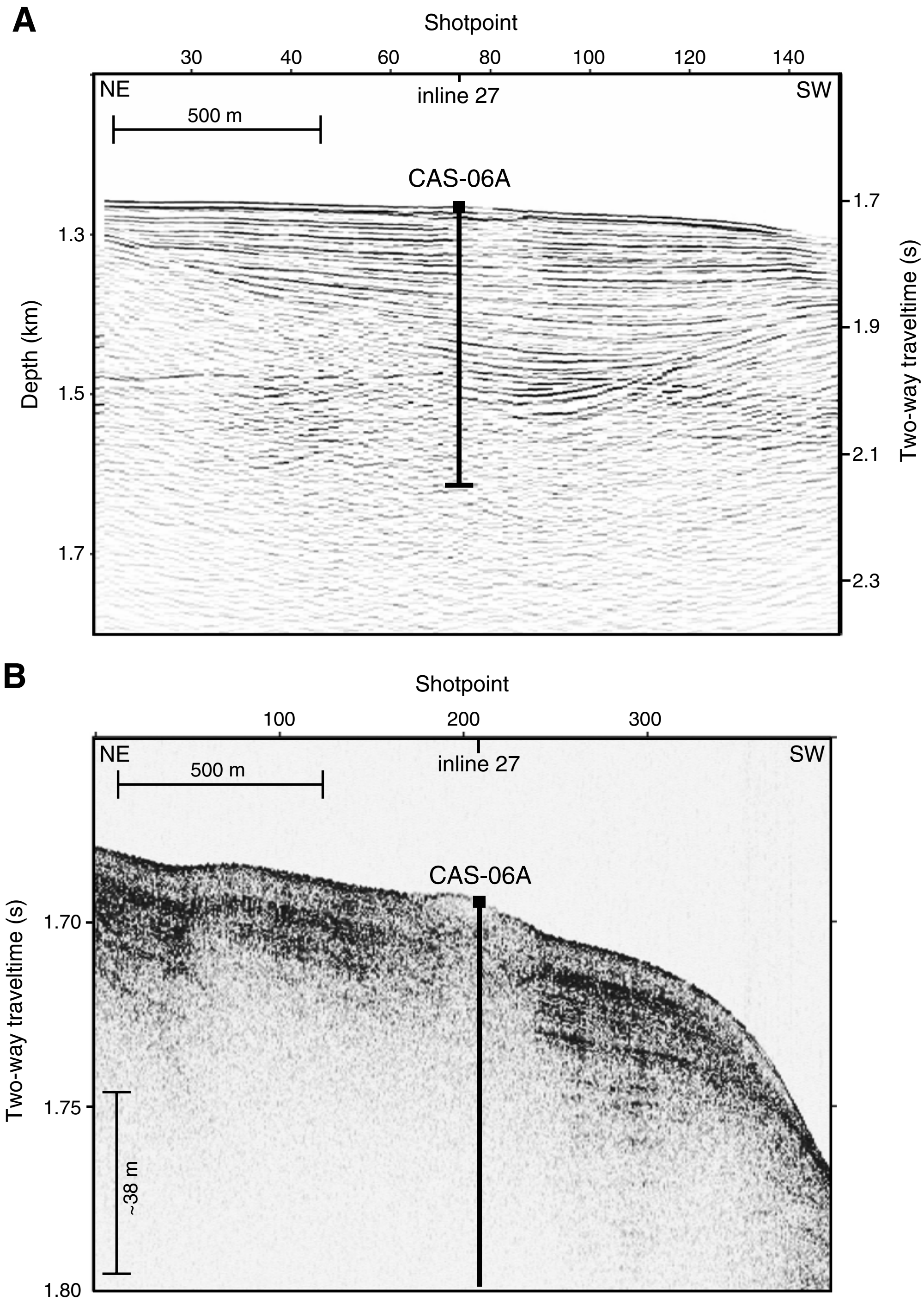


Figure F16. A–H. Bottom video photographs taken with *ROPOS* in the area around proposed Site CAS-06A.

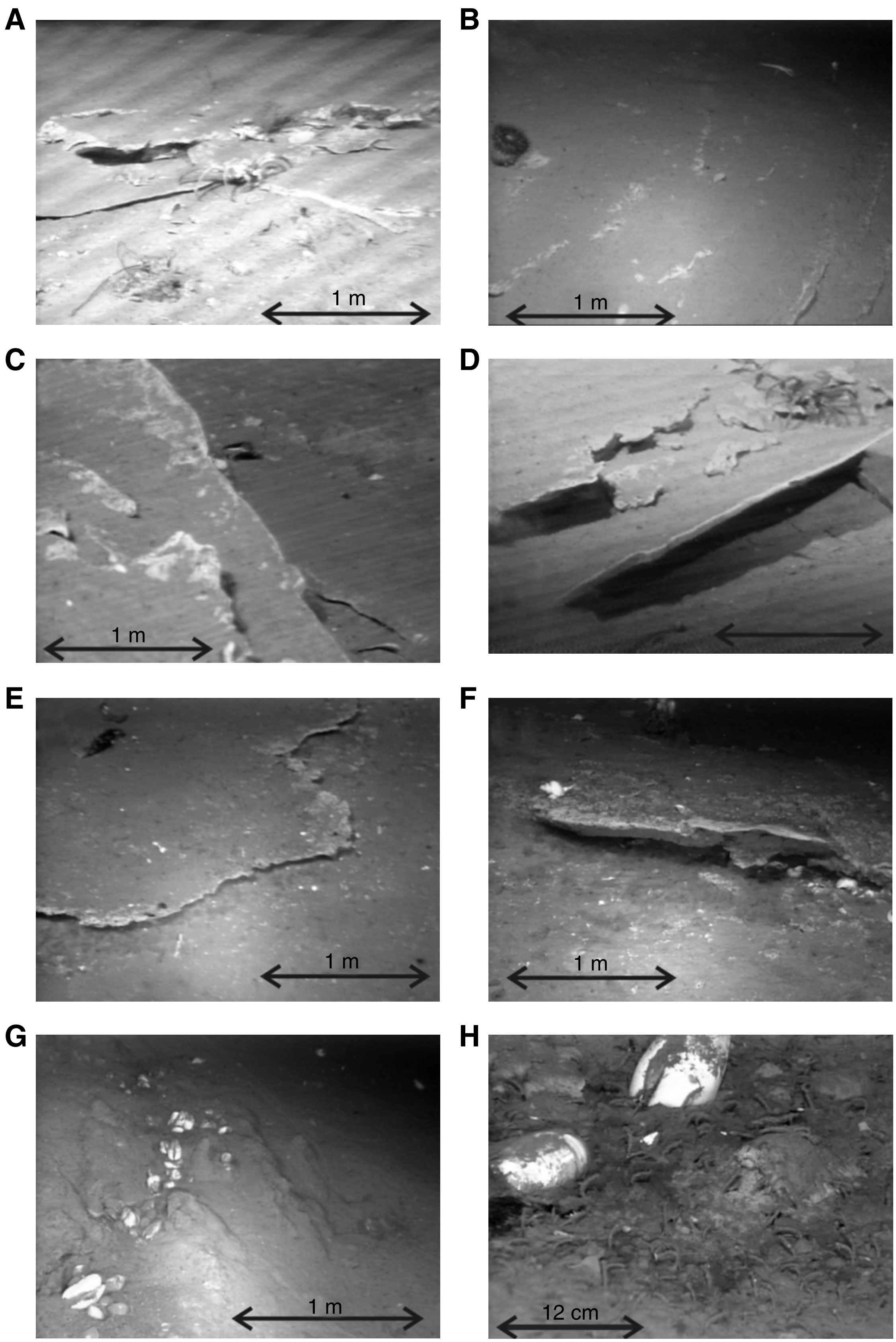


Figure F17. A–C. Samples of massive gas hydrate recovered with piston cores from the area around proposed Site CAS-06A.

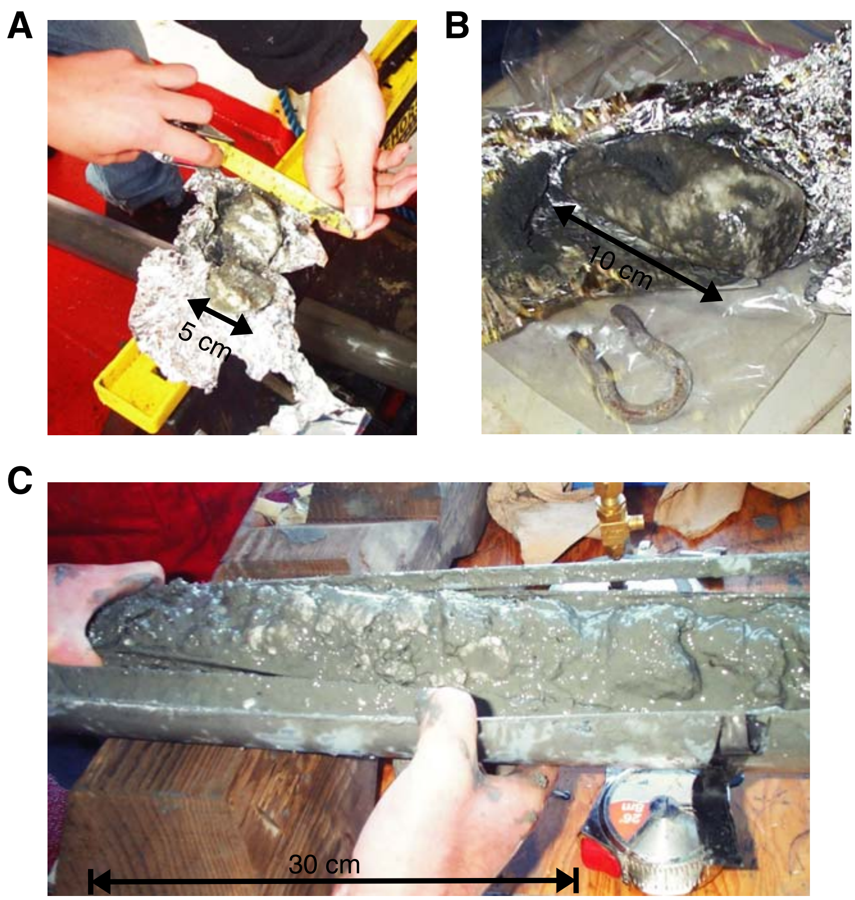


Figure F18. Site survey data for proposed Site CAS-06A. **A.** Map showing seafloor reflection coefficient from 2000 SCS data with location of piston cores near CAS06A. **B.** Map showing time slice of instantaneous amplitude from 2000 SCS 3-D data and depth of massive gas hydrate cap reflector. **C.** Crossline 75 through 2000 SCS 3-D data cube showing gas hydrate cap reflector. Open circles are location of piston cores taken in 2000.

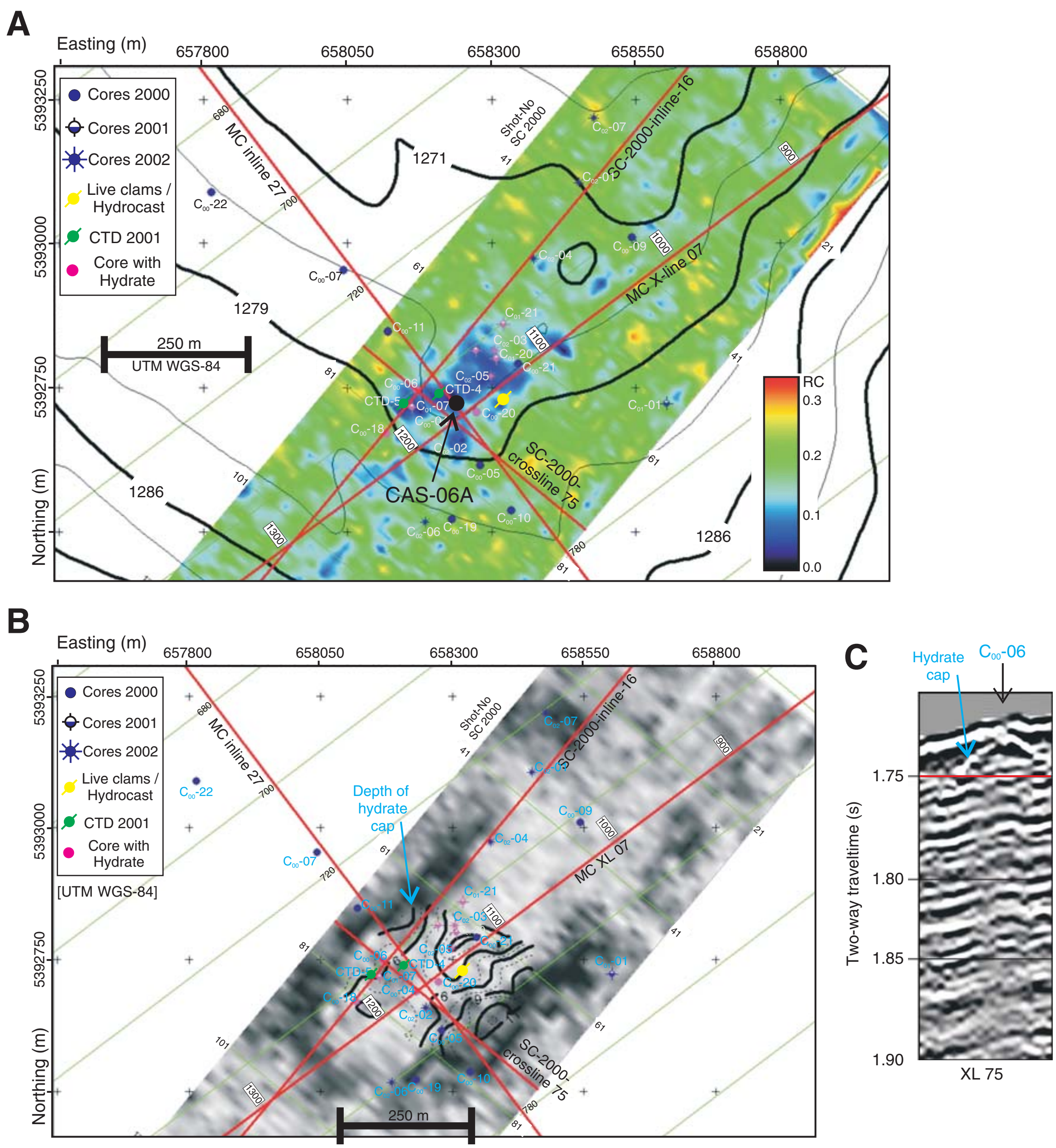


Figure F19. Site survey data for proposed Site CAS-06B. **A.** SCS data of Line PGC0408_BZ4_22. **B.** SCS data of Line PGC0408_BZ4_X05b.

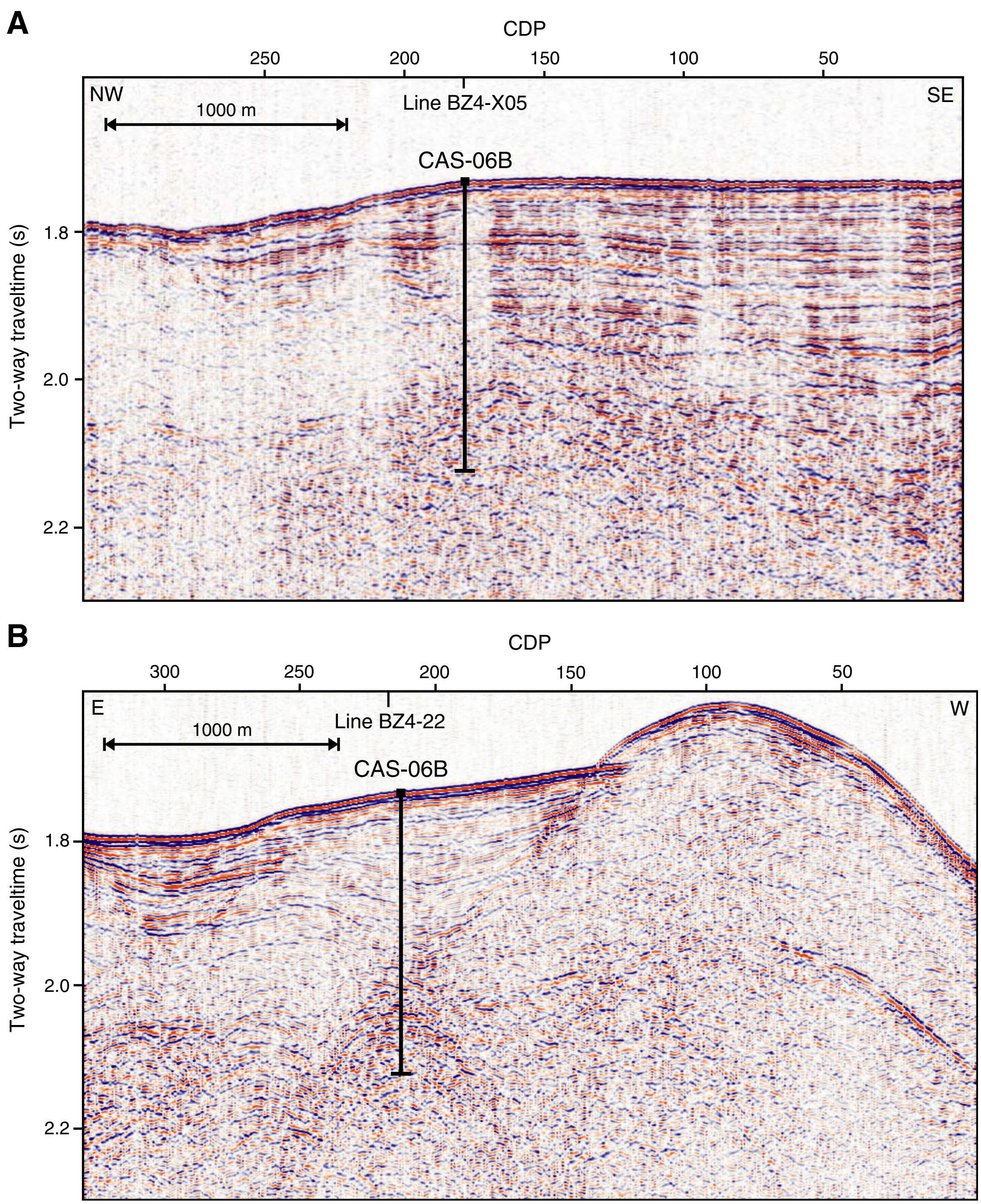
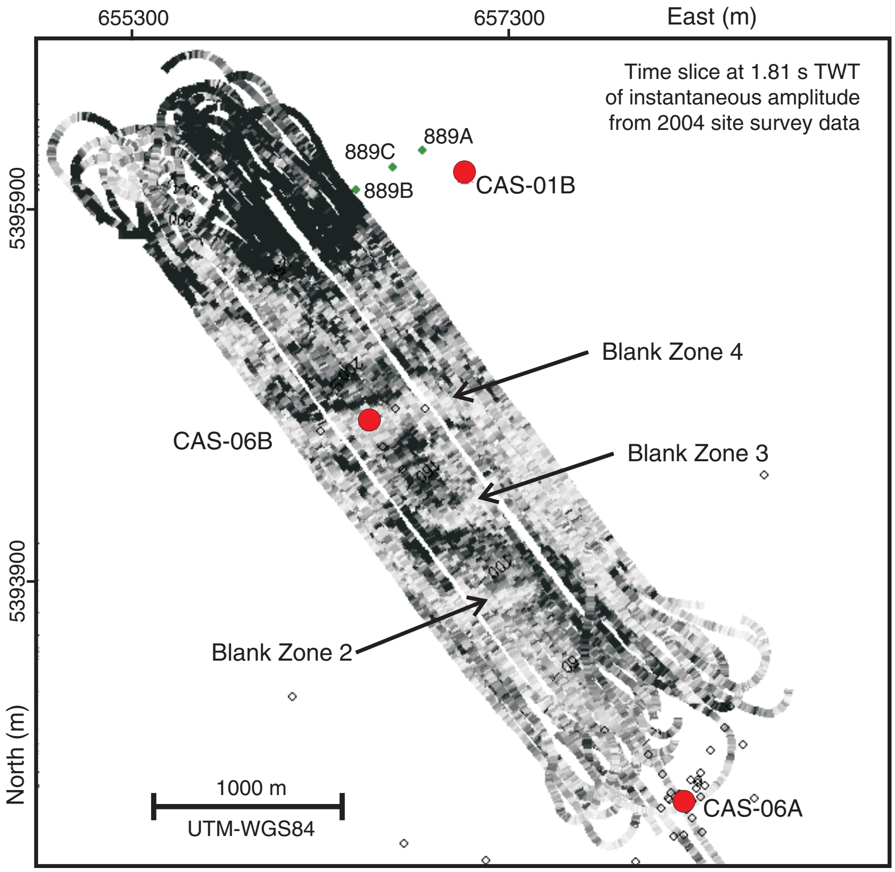


Figure F20. Site survey data for proposed Site CAS-06B. Time slice of instantaneous amplitude calculated from 2004 SCS data at 1.81 s two-way traveltime (TWT) showing extent of blank Zone 4 (CAS-06B).



SITE SUMMARIES

Site CAS-01B

Proposed site:	CAS-01B
Priority:	Primary
Position:	48°41.884′ N, 126°51.924′ W
Water depth (m):	1325
Target drilling depth (mbsf):	350
Approved maximum penetration (mbsf):	400
Survey coverage:	Regional site survey lines • Line 89-08 • MCS 3-D (inline 38) • MCS Line XL03 Figure **F8**
Objective:	Site CAS-01B is a revisit to Sites 889/890. A strong BSR is apparent in regional, low-frequency seismic data (Line 89-08), but higher frequency data reveal a reduction in the BSR reflection strength. Main objectives include characterization of • pore fluid chemistry • core physical properties • gas hydrate concentration estimates A further objective is to determine the nature of the BSR reflection and the thickness of the free gas zone (if any) underneath the BSR by wireline and LWD logging and by a zero-offset VSP.
Drilling and Logging program	APC to refusal; XCB; PCS and HYACINTH (pending funding) pressure cores
Logging program	LWD, triple combo, FMS-sonic, zero-offset VSP, multiple use of APCT, DVTPP
Nature of rock anticipated:	Interlayered silts and clays, some authigenic carbonates

SITE SUMMARIES (CONTINUED)

Site CAS-02C

Proposed site:	CAS-02C
Priority:	Primary
Position:	48°38.688′ N, 126°58.993′ W
Water depth (m):	2230
Target drilling depth (mbsf):	300
Approved maximum penetration (mbsf):	300
Survey coverage:	Regional site survey lines • PGC9902_CAS02_SC • PGC9902_CAS02_MCS • PGC9902_ODP7_MCS • Line 89-08 • Line PGC0408_CAS02B_04 Figure F9
Objective:	Site CAS-02C is located within the first slope basin along the transect eastward of the deformation front. A BSR is located at 290 ms TWT (~230 mbsf). The BSR reflection strength is frequency dependent. The low-frequency data of Line 89-08 (~40 Hz) show a much stronger and continuous reflection than the high-frequency MCS data from 1999 (~100 Hz). The objective is to determine the nature of the BSR reflection and the thickness of the free gas zone (if any) underneath the BSR by wireline and LWD logging.
Drilling and Logging program	APC to refusal; XCB; PCS and HYACINTH pending funding) pressure cores
Logging program	LWD, triple combo, FMS-sonic, multiple use of APCT, DVTPP
Nature of rock anticipated:	Interlayered silts and clays, some authigenic carbonates

SITE SUMMARIES (CONTINUED)

Site CAS-03B

Proposed site:	CAS-03B
Priority:	Primary
Position:	48°37.058′ N, 127°02.413′ W
Water depth (m):	1780
Target drilling depth (mbsf):	300
Approved maximum penetration (mbsf):	300
Survey coverage:	Regional site survey lines • PGC9902_CAS03_SC • PGC9902_CAS03_MCS • PGC9902_ODP7_MCS • Line 89-08 Figure **F10**
Objective:	Site CAS-03B is located on the first uplifted ridge of accreted sediments. A BSR is located at 290 ms TWT (~230 mbsf). Objectives include detailed characterization of • pore-water chemistry • core physical properties • logging (LWD and wireline) The BSR reflection strength appears frequency dependent. The low-frequency data of Line 89-08 (~40 Hz) show a much stronger and continuous reflection than the high-frequency MCS data from 1999 (~100 Hz). The objective is to determine the nature of the BSR reflection and the thickness of (if any) free gas zone underneath the BSR by wireline and LWD logging. If time permits, a zero-offset VSP will be performed.
Drilling and Logging program	APC to refusal; XCB; PCS and HYACINTH pending funding) pressure cores
Logging program	LWD, triple combo, FMS-sonic, multiple use of APCT, DVTPP
Nature of rock anticipated:	Interlayered silts and clays, some authigenic carbonates

SITE SUMMARIES (CONTINUED)

Site CAS-05D

Proposed site:	CAS-05D
Priority:	Primary
Position:	48°47.367′ N, 126°40.717′ W
Water depth (m):	970
Target drilling depth (mbsf):	220
Approved maximum penetration (mbsf):	220
Survey coverage:	Regional site survey lines • PGC9902_ODP1_MCS • Line 89-08 • PGC0408_CAS05B_03 Figure F13
Objective:	Site CAS-05D is the shallowest water depth site on the transect. A relatively weak BSR is present at a depth of 160 ms TWT (~130 mbsf). The BSR becomes rapidly shallower in the vicinity of Site CAS-05D and represents the end-member of the gas hydrate regime on the margin. Objectives of this site include characterization of • pore-water chemistry and gas chemistry (head-space and voids) • core physical properties • gas hydrate occurrence (distribution, concentration). An additional objective is to determine the nature of the BSR reflection and the thickness of the free gas zone (if any) underneath the BSR by wireline and LWD logging.
Drilling and Logging program	APC to refusal; XCB; PCS and HYACINTH (pending funding) pressure cores
Logging program	LWD, triple combo, FMS-sonic, multiple use of APCT, DVTPP
Nature of rock anticipated:	Interlayered silts and clays, some authigenic carbonates

SITE SUMMARIES (CONTINUED)

Site CAS-06A

Proposed site:	CAS-06A
Priority:	Primary
Position:	48°40.050′ N, 126°51.053′ W
Water depth (m):	1280
Target drilling depth (mbsf):	300
Approved maximum penetration (mbsf):	300
Survey coverage:	• SCS 3-D data 2000 (inline 16) • MCS 3-D data 1999 (inline 27) • Regional MCS Line PGC9902_XL07 Figures **F14, F15, F16, F17, F18**
Objective:	Site CAS-06A is located in an active cold vent area. There are shallow massive gas hydrate occurrences, carbonate outcrops, and chemosynthetic communities. The primary objectives are to characterize • gas hydrate and free gas occurrence throughout the cold vent • nature of the fluid flow regime • pore-water chemistry • core physical properties A further objective is to determine the nature of the BSR reflection and the thickness of the free gas zone (if any) underneath the BSR by wireline and LWD logging. A main open question from previous analyses is if a BSR is present underneath the vents (model by Riedel et al., 2002) or if the BSR is elevated (model by Wood et al., 2002).
Drilling and Logging program	APC to refusal; XCB; PCS and HYACINTH (pending funding) pressure cores
Logging program	LWD, triple combo, FMS-sonic, multiple use of APCT, DVTPP
Nature of rock anticipated:	Interlayered silts and clays, some authigenic carbonates

SITE SUMMARIES (CONTINUED)

Site CAS-03C

Proposed site:	CAS-03C
Priority:	Alternate
Position:	48°37.633′ N; 127°03.033′ W
Water depth (m):	1875
Target drilling depth (mbsf):	300
Approved maximum penetration (mbsf):	300
Survey coverage:	Regional site survey lines • PGC9902_CAS03_SC • PGC9902_ODP7_MCS • Line 89-08 • Line PGC0408_CAS03B_X03 Figure **F10**
Objective:	Site CAS-03C is an alternate location for Site CAS-03B. A stronger BSR can be seen in the MCS data from 1999 than underneath CAS-03B. This site is also unaffected by the presence of faults. Objectives of this site include detailed characterization of • pore-water chemistry • core physical properties • logging (LWD, wireline) • gas hydrate concentration estimates
Drilling and Logging program	APC to refusal; XCB; PCS and HYACINTH (pending funding) pressure cores
Logging program	LWD, triple combo, FMS-sonic, multiple use of APCT, DVTPP
Nature of rock anticipated:	Interlayered silts and clays, some authigenic carbonates

SITE SUMMARIES (CONTINUED)

Site CAS-04B

Proposed site:	CAS-04B
Priority:	Alternate
Position:	48°33.461′ N, 127°09.934′ W
Water depth (m):	2560
Target drilling depth (mbsf):	400
Approved maximum penetration (mbsf):	400
Survey coverage:	Regional site survey lines • PGC9902_CAS04_SC • PGC9902_ODP7_MCS • Line 89-08 Figure **F11**
Objective:	Site CAS-04B is the reference site for the transect. It is located in the Cascadia abyssal plain, ~3 km west of the deformation front. It is similar to Site 888 of ODP Leg 146. Primary targets are determining the pore water chemistry profile and sediment physical properties from core and logging data.
Drilling and Logging program	APC to refusal; XCB; PCS and HYACINTH (pending funding) pressure cores
Logging program	LWD, triple combo, FMS-sonic, multiple use of APCT, DVTPP
Nature of rock anticipated:	Interlayered silts and clays, some authigenic carbonates

SITE SUMMARIES (CONTINUED)

Site CAS-05B

Proposed site:	CAS-05B
Priority:	Alternate
Position:	48°44.161′ N; 126°47.537′ W
Water depth (m):	1360
Target drilling depth (mbsf):	350
Approved maximum penetration (mbsf):	350
Survey coverage:	• MCS Line ODP-01 • MCS line CAS-05a • Line 89-08 Figure **F12**
Objective:	Objectives of this site include characterization of • pore water chemistry and gas chemistry (head-space and voids) • core physical properties • gas hydrate occurrence (distribution, concentration) An additional objective is to determine the nature of the BSR reflection and the thickness of the free gas zone (if any) underneath the BSR by wireline and LWD logging.
Drilling and Logging program	APC to refusal; XCB; PCS and HYACINTH (pending funding) pressure cores
Logging program	LWD, triple combo, FMS-sonic, multiple use of APCT, DVTPP
Nature of rock anticipated:	Interlayered silts and clays, some authigenic carbonates

SITE SUMMARIES (CONTINUED)

Site CAS-06B

Proposed site:	CAS-06B
Priority:	Alternate
Position:	48°41.178′ N, 126°52.363′ W
Water depth (m):	1280
Target drilling depth (mbsf):	300
Approved maximum penetration (mbsf):	300
Survey coverage:	• SCS 3-D data 2004 (line 22, line X05b) • MCS 3-D data 1999 (inline 27) Figures **F19, F20**
Objective:	Site CAS-06B is the inactive vent site, which shows widespread seismic blanking, with blanking increasing with seismic frequency. No chemosynthetic communities nor massive gas hydrate near seafloor have been observed. Objectives include characterization of • focused fluid-flow regime, • pore water chemistry, • core physical properties • nature of the BSR reflection and the thickness of the free gas zone (if any) underneath the BSR by wireline and LWD logging
Drilling and Logging program	APC to refusal; XCB; PCS and HYACINTH (pending funding) pressure cores
Logging program	LWD, triple combo, FMS-sonic, multiple use of APCT, DVTPP
Nature of rock anticipated:	Interlayered silts and clays, some authigenic carbonates

SCIENTIFIC PARTICIPANTS

Co-Chief Scientist
Timothy S. Collett
U.S. Geological Survey
Energy Resources Program
Denver Federal Center
Box 25046, MS 939
Denver CO 80225
USA
tcollett@usgs.gov
Work: (303) 236-5731
Fax: (303) 236-0459

Co-Chief Scientist
Michael Riedel
Pacific Geoscience Centre
Geological Survey of Canada
9860 West Saanich Road
PO Box 6000
Sidney BC V8L 4B2
Canada
mriedel@pgc-gsc.nrcan.gc.ca
Work: (250) 363-6451
Fax: (250) 363-6565

Staff Scientist/Expedition Project Manager
Mitchell J. Malone
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
malone@iodp.tamu.edu
Work: (979) 845-6329
Fax: (979) 845-0876

Logging Staff Scientist
Gilles Guèrin
Lamont-Doherty Earth Observatory
Columbia University
Borehole Research Group
PO Box 1000, 61 Route 9W
Palisades NY 10964
USA
guerin@ldeo.columbia.edu
Work: (845) 365-8671
Fax: (845) 365-3182

Microbiologist
Yowsuke Higashi
Biological Resources and Functions
National Institute of Advanced Industrial Science and Technology (AIST)
Tsukuba Central 6
1-1-1 Higashi 1-Chome
Tsukuba-shi, Ibaraki-ken 305-8566
Japan
y-higashi@aist.go.jp
Work: (81) 29-861-6068
Fax: (81) 29-861-6417

Microbiologist
Leena D. Palekar
Scripps Institution of Oceanography
University of California, San Diego
Marine Biological Grade
4305 Hubbs Hall
LaJolla CA 92093-0202
USA
lpalekar@ucsd.edu
Work: (858) 534-5233

Microbiologist
Hideyoshi Yoshioka
Institute for Geo-Resources and Environment
National Institute of Advanced Industrial Science and Technology (AIST)
Central 7
1-1-1 Higashi
Tsukuba 305-8567
Japan
hi-yoshioka@aist.go.jp
Work: (81) 298-61-3810
Fax: (81) 298-61-3666

Inorganic Geochemist
Miriam Kastner
Scripps Institution of Oceanography
University of California, San Diego
Geoscience Research Division
9500 Gilman Drive
La Jolla CA 92093-0212
USA
mkastner@ucsd.edu
Work: (858) 534-2065
Fax: (858) 822-4945

Inorganic Geochemist
Ji-Hoon Kim
Petroleum and Marine Resources Research Division
Korea Institute of Geoscience & Mineral Resources (KIGAM)
30 Gajeong-dong
Yuseong-gu, Daejeon 305-350
Korea
save@kigam.re.kr
Work: (82) 42-868-3276
Fax: (82) 42-862-7275

Inorganic Geochemist
Marta E. Torres
College of Oceanic and Atmospheric Sciences
Oregon State University
104 Ocean Adminstration Bldg.
Corvallis OR 97331-5503
USA
mtorres@coas.oregonstate.edu
Work: (541) 737-2902
Fax: (541) 737-2064

Inorganic Geochemist
Ulrich G. Wortmann
Department of Geology
University of Toronto
22 Russell Street
Toronto, Ontario M5S 3B1
Canada
uli.wortmann@utoronto.ca
Work: (416) 978-7084
Fax: (416) 978-7084

Pressure Core Specialist/ Organic Geochemist
Verena Heuer
DFG-Research Center for Ocean Margins (RCOM)
Universität Bremen
PO Box 330 440
D-28334 Bremen
Germany
vheuer@uni-bremen.de
Work: (49) 421-218-65702
Fax: (49) 421-218-65715

Organic Geochemist
Masanori Kaneko
Department of Earth Sciences
Okayama University
Tsushima-Naka 3-1-1
Okayama 700-8530
Japan
triplem@ms5.megaegg.ne.jp
Work: (81) 86-251-7887

Organic Geochemist
John Pohlman
Virginia Institute of Marine Science
Department of Physical Sciences
Gloucester Point VA
USA
johnp@ccs.nrl.navy.mil
Work: 202-404-3365
Fax: 202-404-8175

Paleontologist (Diatoms)
Fumio Akiba
Diatom Minilab Ltd.
Iwasawa 632-12
Hanno, Saitama 357-0023
Japan
akiba357@hanno.jp
Work: (81) 42-974-4066
Fax: same

Physical Properties Specialist
Michelle Ellis
School of Ocean and Earth Science
Southampton Oceanography Centre
European Way
Southampton
SO14 3ZH
United Kingdom
mhe1@noc.soton.ac.uk
Work: 44 (0) 2380 592574

Physical Properties Specialist
Hiroko Kitajima
Department of Geology and Geophysics
Texas A&M University
College Station TX 77843-3115
USA
hkitajima@geo.tamu.edu
Work: (979) 845-3407

Physical Properties Specialist
Philip E. Long
Environmental Technology Division
Pacific Northwest National Laboratory
902 Battelle Boulevard
Richland WA 99354
USA
philip.long@pnl.gov
Work: (509) 372-6090
Fax: (509) 372-6089

Physical Properties Specialist
Anne M. Tréhu
College of Oceanic and Atmospheric Sciences
Oregon State University
104 Ocean Admin. Building
Corvallis OR 97331-5503
USA
trehu@coas.oregonstate.edu
Work: (541) 737-2655
Fax: (541) 737-2064

Sedimentologist
Marie-Madeleine Blanc-Valleron
Laboratoire de Géologie
Museum National d'Histoire Naturelle
43 rue Buffon
Paris 75005
France
valleron@mnhn.fr
Work: (33) 1407-9-3473
Fax: (33) 1407-9-3739

Sedimentologist
Yoshitaka Hashimoto
Department of Natural Environmental Science
Kochi University
Faculty of Science
Akebonocyo 2-5-1
Kochi 780-8520
Japan
hassy@cc.kochi-u.ac.jp
Work: (81) 88-844-8318
Fax: (81) 88-844-8356

Sedimentologist
Jiasheng Wang
Faculty of Earth Sciences
China University of Geosciences
Lumo Road 388
Wuhan, Hubei 430074
P.R. China
js-wang@cug.edu.cn
Work: (86) 27-6788-3001
Fax: (86) 27-6788-3002

Sedimentologist
Barbara Teichert
Bundesanstalt fuer Geowissenschaften & Rohstoffe (BGR)
Stilleweg 2
D-30655 Hannover
Germany
b.teichert@bgr.de
Work: (49) 511 643 2785
Fax: (49) 511 643 3663

Logging Scientist
Peter D. Jackson
Geophysics and Marine
British Geological Survey
Kingsley Dunham Centre
Keyworth, Nottingham NG12 5GG
United Kingdom
pdj@bgs.ac.uk
Work: (44) 115-9363379
Fax: (44) 115-9363145

LDEO Logging Scientist
Alberto Malinverno
Lamont-Doherty Earth Observatory
Columbia University
61 Rpute 9W
Palisades NY 10964
USA
alberto@ldeo.columbia.edu
Work: (845) 365-8577
Fax: (845) 365-3182

LDEO Logging Scientist (LWD portion)
Greg Myers
Lamont-Doherty Earth Observatory
Columbia University
Borehole Research Group
Palisades NY 10964
USA
gmyers@ldeo.columbia.edu
Work: (845) 365-8772
Fax: (845) 365-3182

LWD Engineer (LWD portion)
Derek Buster
Schlumberger Drilling and Measurements
135 Rousseau Road
Youngsville LA 70592
USA
dbuster@youngsville.oilfield.slb.com
Work: (281) 440 7408

LWD Engineer (LWD portion)
Lake Loh
Schlumberger Drilling and Measurements
135 Rousseau Road
Youngsville LA 70592
USA
lloh2@youngsville.oilfield.slb.com
Work: (337) 837-9803
Fax: (337) 837-0976:

Pressure Coring Engineer (HYACINTH)
Martin Rothfuss
Institute of Petroleum Engineering
Technische Universität Clausthal
Agricolastrasse 10
38678 Clausthal-Zellerfeld
Germany
martin.rothfuss@tu-clausthal.de
Work: (49) 5323 72 2889
Fax: (49) 5323 72 3146

Pressure Coring Engineer (HYACINTH)
Floris Tuynder
Fugro Engineers B.V.
Leidschendam
The Netherlands
f.tuynder@fugro.nl
Work: (31) 70 3111241
Fax: (31) 70 3203640

Pressure Core Specialist (HYACINTH)
Melanie Holland
GEOTEK
3 Faraday Close
Drayton Fields
Daventry
Northants
NN11 8RD
United Kingdom
melanie@geotek.co.uk
Work: (44) 1327 311666
Fax: (44) 1327 311555

Pressure Core Specialist (HYACINTH)
Peter Schultheiss
GEOTEK
3 Faraday Close
Drayton Fields
Daventry
Northants
NN11 8RD
United Kingdom
peter@geotek.co.uk
Work: (44) 1327 311666
Fax: (44) 1327 311555

Schlumberger Engineer
Steven Kittredge
911 Center Point Rd.
Carrollton GA 30117
USA
kittredgesw@yahoo.com
Work: (281) 480-2000
Fax: (281) 480-9550

Operations Superintendent
Michael Storms
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
storms@iodp.tamu.edu
Work: (979) 845-2101
Fax: (979) 845-0876

Drilling Engineer
Derryl Schroeder
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
schroeder@iodp.tamu.edu
Work: (979) 845-8481
Fax: (979) 845-2308

Drilling Engineer
Bob Aduddell
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
aduddell@iodp.tamu.edu
Work: (979) 845-3207
Fax: (979) 845-2308

Laboratory Officer
Roy T. Davis
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
davis@iodp.tamu.edu
Work: (979) 845-2496
Fax: (979) 845-0876

Assistant Laboratory Officer
Timothy Bronk
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
bronk@iodp.tamu.edu
Work: (979) 845-0879
Fax: (979) 845-0876

Assistant Laboratory Officer
Paul Teniere
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
teniere@iodp.tamu.edu
Work: (979) 458-1067
Fax: (979) 845-0876

Marine Curatorial Specialist
Philip Rumford
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
rumford@iodp.tamu.edu
Work: (979) 845-5056
Fax: (979) 845-0876

Imaging Specialist
William Crawford
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
crawford@iodp.tamu.edu
Work: (979) 862-7757
Fax: (979) 458-1617

Yeoperson
Katerina Petronotis
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
petronotis@iodp.tamu.edu
Work: (979) 845-1199
Fax: (979) 862-3527

Marine Laboratory Specialist: Chemistry
Christopher Bennight
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
bennight@iodp.tamu.edu
Work: (979) 845-7209
Fax: (979) 845-0876

Marine Laboratory Specialist: Chemistry
Lisa Brandt
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
brandt@iodp.tamu.edu
Work: (979) 845-3602
Fax: (979) 845-0876

Marine Laboratory Specialist: Core
Lisa Hawkins
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
Work: (979) 845-3602
Fax: (979) 845-0876

Marine Laboratory Specialist: Downhole Tools/Thin Sections
Peter Kannberg
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
kannberg@iodp.tamu.edu
Work: (979) 845-3602
Fax: (979) 845-0876

Marine Laboratory Specialist: Paleomagnetism
Jennifer Henderson
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
henderson_j@iodp.tamu.edu
Work: (979) 845-3602
Fax: (979) 845-0876

Marine Laboratory Specialist: Physical Properties
Heather Paul
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
paul@iodp.tamu.edu
Work: (979) 845-3602
Fax: (979) 845-0876

Marine Laboratory Specialist: Underway Geophysics
Karen Johnston
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
johnston@iodp.tamu.edu
Work: (979) 845-3602
Fax: (979) 845-0876

Marine Laboratory Specialist: X-Ray
Jason Deardorff
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
deardorff@iodp.tamu.edu
Work: (979) 845-2481
Fax: (979) 845-0876

Marine Instrumentation Specialist
Randy Gjesvold
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
gjesvold@iodp.tamu.edu
Work: (979) 845-3602
Fax: (979) 845-0876

Marine Instrumentation Specialist
Mike Meiring
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
kleinmeiring@yahoo.com
Work: (979) 845-3602
Fax: (979) 845-0876

Marine Computer Specialist
Paula Clark
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
clark@iodp.tamu.edu
Work: (979) 845-3897
Fax: (979) 458-1617

Marine Computer Specialist
David Morley
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
morley@iodp.tamu.edu
Work: (979) 862-4847
Fax: (979) 458-1617

Applications Developer
David Fackler
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
fackler@iodp.tamu.edu
Work: (979) 845-3036
Fax: (979) 845-2308