OCEAN DRILLING PROGRAM

LEG 169S SCIENTIFIC PROSPECTUS

SAANICH INLET

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

ABSTRACT

The objectives of ODP coring in Saanich Inlet are to

1. Obtain an ultra-high-resolution record of Holocene climate, oceanography, marine productivity, ecology, and terrestrial vegetation;

2. Attempt to establish the frequency of earthquakes (particularly very large events; which are greater than magnitude 8 in this region of the Cascadia convergent margin);

3. Advance the understanding of diagenesis in organic-rich sedimentary basins and especially of the role of microbial processes. The predominantly finely laminated (varved) sediments that are believed to have accumulated in the inlet since deglaciation will be cored at two sites in the deeper axial region of the fjord; these two sites (at 200 and 225 m water depth) have significantly different organic contents and accumulation rates. Saanich Inlet will provide an important companion to the high-resolution Site 893 drilled in Santa Barbara Basin.

Approximately 100 to 125 m of Holocene diatomaceous silts and clays and upper Pleistocene glaciomarine muds will be cored with the advanced hydraulic piston corer (APC) to refusal at the two sites. Both sites will be triple APC cored. Only the A hole from each site will be measured using the multi sensor track (MST), split, and photographed on board. The B and C holes will be measured using the MST during Leg 169 and returned to the Gulf Coast Repositiory for further work. Temperature measurements will be made in the lowermost part of Site SI-02B if time permits.

INTRODUCTION

An improved understanding of the climate-ocean system, and in particular the global carbon cycle, will require ultra-high-resolution studies of rapidly deposited sediments in a variety of geographic settings. Because such sites record climatic and oceanographic conditions on an annual or seasonal basis, they will allow calibration and refinement of fully ocean-coupled general circulation models as well as lead to a better appreciation of the links among oceanographic processes, climatic parameters, terrestrial vegetation, and marine biota in coastal areas of the world.

Sediments of Saanich Inlet, British Columbia, contain a virtually continuous record of Holocene climatic and oceanographic change, with seasonal resolution, together with a possible record of paleoseismicity associated with the Cascadia convergent margin. Situated in a fjord near Victoria, British Columbia, the proposed sites record both terrestrial floral change since deglaciation (9000 to 11,000 m.y. ago) as well as marine biological productivity variations in a temperate latitude coastal setting. The Saanich Inlet sites will provide an important complement to the high-resolution record obtained at Leg 146 Site 893 in the Santa Barbara Basin.

Study Area

Saanich Inlet, a fjord in southeastern Vancouver Island, lies at $48^{o}35'$N and $123^{o}30'$W (Fig. 1). Its width varies from 0.4 to 7.6 km over its 26-km length. The average depth is 120 m and the maximum depth is 236 m. Unlike most other fjords in British Columbia and Alaska, the drainage basin for the Saanich Inlet is relatively small and contains no significant rivers. While a small amount of sediment enters from the south, at the head of the inlet, through the Goldstream River, most of the 9 ¥10^{4} tons of terrigenous sediment deposited annually in the fjord comes from the sediment plume of the Cowichan River, which enters Satellite Channel to the northwest of the head of the inlet (Gross et al., 1963); a minor amount comes from the Fraser River plume which, on rare occasions, penetrates into the inlet.

A bedrock sill at the north end of Saanich Inlet rises to within 70 m of the surface and restricts normal water circulation. As a result, the lower part of the water column in the inlet is anoxic; the boundary between oxygenated and anoxic waters lies between 70 m water depth in October and 150 m in December (Gross et al., 1963). The sill also prevents any axial input of coarse sediments into the fjord as turbidity currents from the north (Gucluer and Gross, 1964).

Sediments

Holocene sediments in Saanich Inlet consist primarily of silt and clay deposited during fall and spring freshets and diatoms deposited during spring and summer blooms. Sediments are rhythmically laminated; individual couplets have been shown to be annual deposits and are thus termed varves (Gross et al., 1963; Sancetta and Calvert, 1988; Bobrowsky and Clague, 1990; Blais, 1992). The varved sequences are interbedded with sporadic massive beds from a few centimeters to tens of centimeters thick (Buddemeier, 1969; Powys, 1987; Bobrowsky and Clague, 1990; Bobrowsky et al., 1993; Blais, 1992) (Figs. 2-4). These beds are coarser than the laminated sequence and have been interpreted as the products of sediment gravity flows (Bobrowsky and Clague, 1990; Blais, 1992). Because of the prevailing anoxic conditions there is an absence of epifauna and infauna, accounting for the excellent preservation of strata observed in piston and gravity cores from the fjord.

There is a trend from more organic-rich basinal sediments in the southern part of the inlet to less in the north, reflecting the greater influence of terrigenous sediment coming from the Cowichan River to the northwest of the mouth of Saanich Inlet and possibly from the Fraser River. Between latitudes 48^{o}34'N to 48^{o}38'N, there is a decrease in the average organic carbon value in the upper 2.5 m of sediment from 4.57% to 2.56% (Brown et al., 1972). The greater contribution of terrigenous sediment in the northern part of the inlet is reflected in the 20% to 25% greater thickness of Holocene sediments compared with the southern part (Figs. 3,4).

Surficial sediments are extremely unconsolidated such that precise determination of the sediment/water interface is often difficult. As a result of the high water contents of surficial sediments, approximately 25 to 50 yr of the sediment record are commonly missed during conventional piston coring (A. Blais, person. comm., 1994).

Based on a single sample obtained in coring from a barge in the 1960s, it is anticipated that the Holocene sediments described here in are immediately underlain by stiff gray glaciomarine muds. It is expected that beneath, and possibly interstratified with, these glaciomarine muds are glacial outwash sands and gravels related to regional deglaciation 10,000 to 13,000 m.y. ago The possibility that interstadial and even interglacial deposits are preserved in this section also exists, though this is unlikely. Because of the high strength of the glaciomarine sediments and the likely abundance of sand, gravels, and boulders of ice-rafted and ice-contact origin, it is unlikely that piston coring will be possible much below the base of the Holocene muds.

Accumulation Rates

Sedimentation rates for the varved sediments have been estimated, based primarily on relatively short cores representing at most 4,600 yr, to have been between 4 and 6 mm/yr (Gucluer and

Gross, 1964). These authors estimate that between 0.24 and 0.36 g of dry sediment are deposited annually per square centimeter. Bobrowsky and Clague (1990) reported an average couplet (varve) thicknesses over the past 1400 yr of 4 mm; overall sedimentation rates during this period, including the intercalated more massive silty units, averaged about 8.84 m/1000 yr. Gucluer and Gross (1964) presented radiocarbon data for the past 3100 yr that yield sedimentation rates of 4.1 to 6.3 m/1000 yr. Buddemeier (1969), from a core located slightly closer to the Goldstream River delta at the southern end of the inlet, obtained average varve thicknesses (i.e., annual accumulation) of 5.7 mm at about 18 m depth in the core to about 14.2 mm at 3 m depth; this difference was found to be in general accord with sediment compaction. He determined average accumulation rates based on radiocarbon dating over the past 3860 years to be 4.89 m/1000 yr. Blais (1995) showed that uncompacted varves range from about 4.5 mm in the southern inlet to 12.7 mm in the north, whereas compacted varves range from 4.4 to about 9.0 mm. Between the two proposed sites there is approximately a twofold increase in varve thickness, most of which is attributable to a greater input of terrigenous sediment from the Cowichan River.

Sediment Thickness

Buddemeier (1969), reporting on a site in the narrowest part of the inlet, estimated a thickness of 30 to 50 m based on geophysical results and in one composite core obtained from a drilling barge, encountered indurated gray muds (presumably glaciomarine) at about 38 m with overlying sediments dated at 9000 m.y. ago. Although the thickness of sediments in the deeper and broader regions of the inlet are somewhat greater than this (Figs. 2-4), it is unlikely that the total Holocene thickness will be much greater than 100 to 120 m.

SCIENTIFIC OBJECTIVES

Paleoenvironmental Investigations

Continuous coring through the Holocene sediments offers the rare opportunity of sampling at a seasonal resolution both terrestrial and oceanographic temperate latitude changes over the past 10,000 -12,000 yr. There has been considerable interest expressed in being able to continue these investigations back through to deglaciation to understand better the succession of floras in this wet temperate region following deglaciation, climatic cyclicity during the Holocene, and the links among oceanographic, climatic, and terrestrial environmental conditions. Previous studies have looked at modern processes controlling the accumulation of diatoms in Saanich Inlet (Sancetta, 1989), at the annual cycle of sedimentation in the fjord (Sancetta and Calvert, 1988), and at various other aspects of faunal (e.g., changes in fish communities; V. Tunnicliffe, pers. comm. 1995) and terrestrial flora (R.J. Hebda, pers. comm., 1995). Other signals, such as the prevalence of fire and the human occupation of coastal sites, have also been detected in piston cores.

The Saanich Inlet sediments offer a unique opportunity to develop one of the world's most detailed, possibly continuous, Holocene, paired terrestrial and marine paleoecological records. These records will provide critical insight into the relationship between long- and short-term environmental fluctuations on land and sea and their link to climatic and other factors. In particular, detailed studies of inter- and intra-annual characteristics of the well-documented early to middle-Holocene warm and dry interval (Hebda, in press) may shed light on the potential impacts of global climate change in marine and adjacent coastal systems.

The objective of the interdisciplinary investigation is to develop an ultra-high-resolution paleoecologic record of the inshore northeast Pacific Ocean for the last 10,000 yr using organic remains preserved in Saanich Inlet sediments. This sequence would be related year-by-year to a 9000 yr tree-ring climate record and regional terrestrial environmental framework that has been developed for a lake site only 5 km distant on climatically sensitive southeast Vancouver Island (Hebda, in press).

Building on several decades of research, a small Joint Global Ocean Flux Study (JGOFS) project is being completed on annual and seasonal carbon accumulation and microfossil characteristics for the last century and a half in the inlet. This project has

- adapted techniques and technology to ultra-high-resolution studies of laminated sediments;
- confirmed that laminae are deposited annually;
- developed an absolute lamina chronology;
- using diatoms, pollen, and dinoflagellates, identified seasonal succession and cycles by comparison with concurrent water column studies;
- integrated organic and inorganic sediment characteristics with recorded instrumental climate data and tree-ring indices;

- linked dinoflagellate (including toxic types) fluctuations to El Niño events; and
- identified changes in diatom, dinoflagellate, and terrestrial plant assemblages with increased European settlement.

So far Saanich Inlet sediments have proven to be extremely sensitive to recording even relatively minor events, such as the establishment of a small saw mill in the 1800s. Both the tree-ring and the annual layered-sediment series extend for millennia into the Holocene (Heusser, 1993; Hebda, in press).

Specific goals of a study of the complete Holocene record from Saanich Inlet are to

- examine the relationship of annual vegetation records (through pollen analysis) recorded in inlet laminae to long-term vegetation records from nearby lakes (nearly completed);
- characterize pre- and post-European settlement vegetation as reflected by annual pollen records;
- characterize the annual fire history from charcoal analysis and relate to climatic and documented aboriginal land management;
- estimate the record of marine productivity, including fish;
- use dinoflagellates to infer the record of El Niño cycles;
- document biogenic and inorganic indicators of sustained basin oxygenation as a proxy for upwelling processes offshore;
- conduct measurements of stable isotopes to infer long-term changes in carbon sources;
- document the character and relative abundance of organic detritus to estimate changes in rainfall patterns; and
- correlate terrestrial proxy climate data with diverse characteristics of laminae to develop a model of atmosphere/ocean coupling.

Paleoseismicity

Driven by the concern that a great subduction earthquake or major crustal earthquake in south-western British Columbia or northwestern Washington could cause widespread damage, several investigators have focused their attention on the geologic record for evidence of past events that could provide insight into the frequency and magnitude of future earthquakes. The paucity of large earthquakes within historical time in the region has required researchers to search for proxy data in order to ascertain whether such events have, in fact, occurred and, if so, with what frequency. Because of the remarkable stratigraphic preservation and resolution in the Saanich Inlet sediments, several recent studies have been undertaken focusing on the more silty massive units in the sequence as possible indicators of past earthquake events (e.g., Bobrowsky and Clague, 1990; Bobrowsky et al., 1993; Blais, 1992). These units have been interpreted as seismically triggered sediment gravity flows and, in the uppermost part of the sediment column (last 1500 yr), would indicate an average of one flow every 100 yr (Blais, 1995); this estimate appears compatible with projections made from historical seismicity data and are compatible with the rate of liquefaction events seen in Pleistocene lake deposits 100 km to the south in Washington State (Sims, 1975). Based on other evidence from the region, larger earthquakes (greater than magnitude 8 and believed to be of subduction origin) have a return period of about 600 yr. Clearly, however, to date neither the historical nor the geological records are sufficiently long to determine confidently the frequency of great subduction earthquake events or major crustal events.

Considerably more work is required to improve the confidence in this set of proxy data; much would be added by demonstrating that this rate has been consistent over a longer time interval, such as throughout the Holocene. A continuous record of seismically induced events over a long period would be an extremely valuable contribution to seismic hazard assessment in the region.

Sediment Diagenesis

Saanich Inlet has long been recognized as a model environment for studies of organic diagenesis and low-temperature remineralization reactions in a shallow, temperate, isolated, anoxic basin. The combination of restricted water circulation, seasonal stratification, and moderate rates of organic matter accumulation has led to dysaerobic bottom waters and anoxic sediments. This proposal is a good companion and comparative site to the ODP drilling of Santa Barbara Basin on Leg 146.

Benchmark studies were undertaken more than 20 yr ago (e.g., Gross et al., 1963; Gucluer and Gross, 1964; Nissenbaum et al., 1972; Presley et al., 1972; Brown et al., 1972). Saanich Inlet was selected for these studies for many reasons: (1) the sediments contain significant amounts of organic carbon (up to 5%), making it a possible recent analogue of black shales; (2) high sedimentation rates (4-5 times faster than in Santa Barbara Basin, for example) enabling detailed studies of early diagenetic processes; and, (3) two distinct sources of organic material, humus-rich soil from highly forested areas around the inlet and phytoplankton, primarily diatoms. Studies looked at major, minor, and trace element concentrations in interstitial waters and various sediment fractions, dissolved carbon dioxide, phosphate, sulfate, methane and ammonia, carbon isotopes, various hydrocarbons, and amino, humic, and fulvic acids. Most of these investigations, however, focused only on the upper 2 to 3 m of the sediment column.

Several geochemical factors make Saanich Inlet particularly attractive as a drilling site for ODP. The broad spectrum of diagenetic stages, including aerobic through to sulfate reduction and methanogenic fermentation, are represented and well characterized in the various Saanich Inlet sediments. Climatic variations during the Holocene (see above) are intricately recorded in the sediments as varvelike sedimentary structures. In addition to the sedimentologic evidence, initial organic and stable isotope geochemical investigations suggest that the signals of seasonal and climatic changes are faithfully recorded in the sediments. Significant climatic and redox shifts are recorded in Saanich Inlet sediments, enabling isotopic and molecular biomarker studies of proxy signals. Furthermore, long-term geochemical and ocean chemical measurements in Saanich Inlet have been made of the dissolved and particulate constituents in the water column and in the uppermost 3 m of sediment. These determinations, which include nutrients, gases, and inorganic solids as well as intensive surveys of biological populations, are distinct advantages of the location. Analysis of sediments from Saanich Inlet affords a unique opportunity for microbiologists and geochemists to provide detailed work on diagenesis of deeper seated sediments. Previously, most of the microbial work has been severely compromised by standard ODP operating conditions, such as (1) long periods at sea without shore laboratory contact (difficult to send critical fresh samples to shore-based labs) and (2) insufficient facilities available or accessible aboard JOIDES *Resolution* for specialized work-up of bacterial cultures, unstable compounds, and certain tracers.

These reasons make Saanich Inlet extremely well suited for advanced research in marine biogeochemistry. This is especially true for the investigation and application of molecular and stable isotope techniques to biomarker molecules as proxy signals to assess climatic changes. The drilling at this site is also a superb biogeochemical opportunity to investigate the microbial processes of methanogenesis and methylotrophy. Again, the site offers a unique chance to investigate organic compound classes, such as lipids and amino acids, and their response to changing redox and climatic conditions.

Saanich Inlet is also a rare and fundamental opportunity for marine microbial ecologists to obtain deeper sediment samples with which they can investigate the activities and processes of bacterial assemblages. Previously, this aspect of the ODP program has been restricted because of the special space and laboratory requirements of the biologists (e.g., radio-labelling, rapid access to microbiological laboratories); the drilling sites in Saanich Inlet, however, are very close to both federal and provincial government laboratories and to the University of Victoria. In addition, the requirement for rapid and frequent transport of samples from JOIDES *Resolution* (e.g., for shore-based incubations, gene probes, enzyme assays) has previously hampered and limited ODP-related microbiological work. Again, the location of Saanich Inlet has significant advantages in these respects.

OPERATIONS STRATEGY

JOIDES *Resolution* would proceed from Victoria to proposed Site SI-01B, the more southerly of the two sites in Saanich Inlet. This site would be triple cored with the Advanced Hydraulic Piston corer (APC) to refusal or to 20 m into the glaciomarine unit beneath the Holocene laminated mud sequence. The ship would then proceed to Site SI-02B, which would again be triple APC cored to refusal or until 20 m of glaciomarine sediment are penetrated.

At proposed Site SI-02B, if time permits either additional coring will be undertaken to fill any known gaps or a complete fourth hole will be obtained. As a lower priority, temperature measurements will be made in the lowermost two or three cores at this site.

Two security vessels will be provided by the Institute of Ocean Sciences on a 24-hr basis to ensure that pleasure craft remain at least 300 m away from the drilling vessel at all times.

The drilling sites will be occupied based on Global Positioning System (GPS) coordinates. No seismic profiling will be undertaken during this leg.

CORE HANDLING

The A hole at each site will be measured using the multisensor track (MST) on board the ship, split and photographed. The core will not, however, be described. Split cores will be wrapped in "Glad Wrap" prior to storage in D-tubes. The A hole cores will be offloaded in Victoria at the conclusion of Leg 169S and transported to the Pacific Geoscience Centre for cold storage for a period of 1 yr.

The B and C holes will be retained unsplit on the ship. They will be measured using the MST during Leg 169 but will not be split or described. These cores will be offloaded at San Diego, California, and shipped to the core repository at ODP-TAMU for subsequent splitting, photography, desciption, and sampling.

SAMPLING

Shipboard Sampling

Head-space and vacutainer samples from each core will be taken on the catwalk for hydrocarbon monitoring.

Samples for microbiology will be taken from the split A hole cores and will be offloaded from the ship during daylight hours for processing at shore-based laboratories.

Samples for pore-water chemistry will be taken from the lower 20 cm of each core. The sample will be one-quarter of the core. Samples will be squeezed on board under nitrogen.

Residues from squeezing will be taken ashore with the A hole cores for subsequent analysis.

Shore-based Sampling

Extensive, high-resolution sampling of the laminated sediments in these cores is essential to meeting the objectives of this cruise. This sampling will be done on the A hole cores at the Pacific Geoscience Center, and will include lamina-by-lamina studies of paleontology and sedimentology on long continuous sections of the cores, which will exceed the normal sampling limits of (1) not sampling the archive half, (2) sampling only 1/2 of the working half and (3) allowing only 50 cm^3/m of core per investigator. Sampling of the massive layers for sedimentology and paleontology will follow the standard sample guidelines. Intervals not recovered in the A hole will be sampled in the B and C holes according to the procedures for the A hole. In the event that a C hole is cored at each site, this extensive sampling scheme will fall within the established guidelines for sampling triple-cored sequences.

U-channel samples will be taken from the B holes and possibly the C holes at the Gulf Coast Repository for magnetic property and X-radiography studies.

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SITE TIME ESTIMATES

LEG 169S-Saanich Inlet

Victoria to Victoria, 18-20 August 1996

Site name	Latitude N, longitude W	Water depth (m)	Penetration (mbsf)	Location	Operations	Transit 10.5 kt (days)	Coring time (days)	Log (days)	Total (days)
Leg 169 Port Call, Victoria. 16-18 August 1996									
Transit Victoria to Saanich Inlet: Deptart 1200, 18 Aug. -- Arrive 1800, 18 Aug.						0.3			0.3
SI-01B	48°35.433′N 123°30.201′W	225	100 sed	Saanich Inlet	APC 100 m APC 100 m APC 100 m		0.3 0.25 0.25		0.3 0.25 0.25
SI-02B	48°38.00′N 123°30.00′W	200	125 sed	Saanich Inlet	APC 125 m APC 125 m APC 125 m	0.1	0.3 0.25 0.25		0.4 0.25 0.25
Transit to Saanich Inlet to Victoria: Depart 0600, 20 Aug. -- Arrive 1200, 20 Aug.						0.3			0.3
					Est Time=				2.3
					Available Time =				2.0

Figure 1.Location map showing seismic profiles and proposed drilling Sites SI-01B and SI-02B.

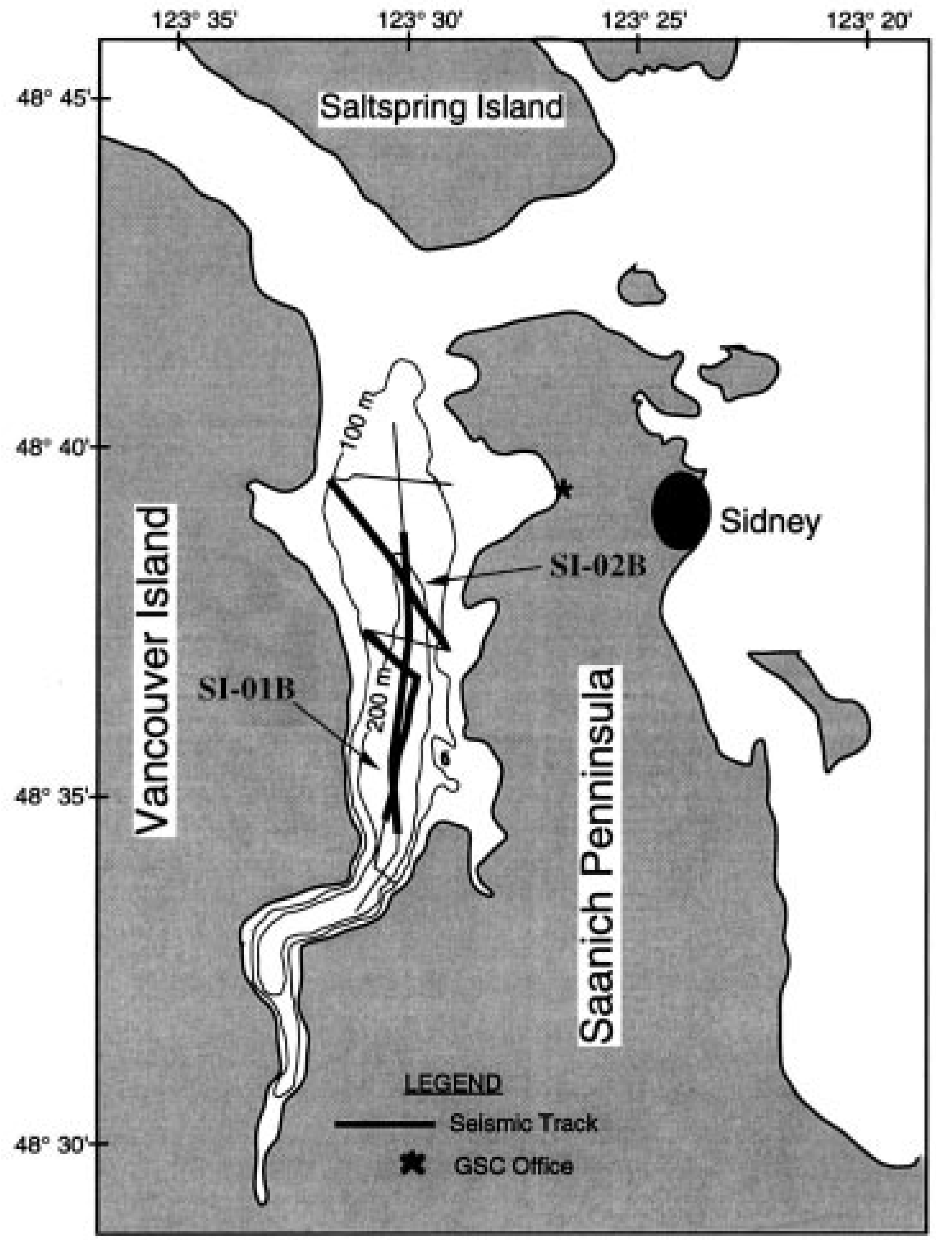


Figure 2. Core photograph showing rhythmically laminated sediments (varves) and a typical massive interval from Saanich Inlet . (Blais, 1995).

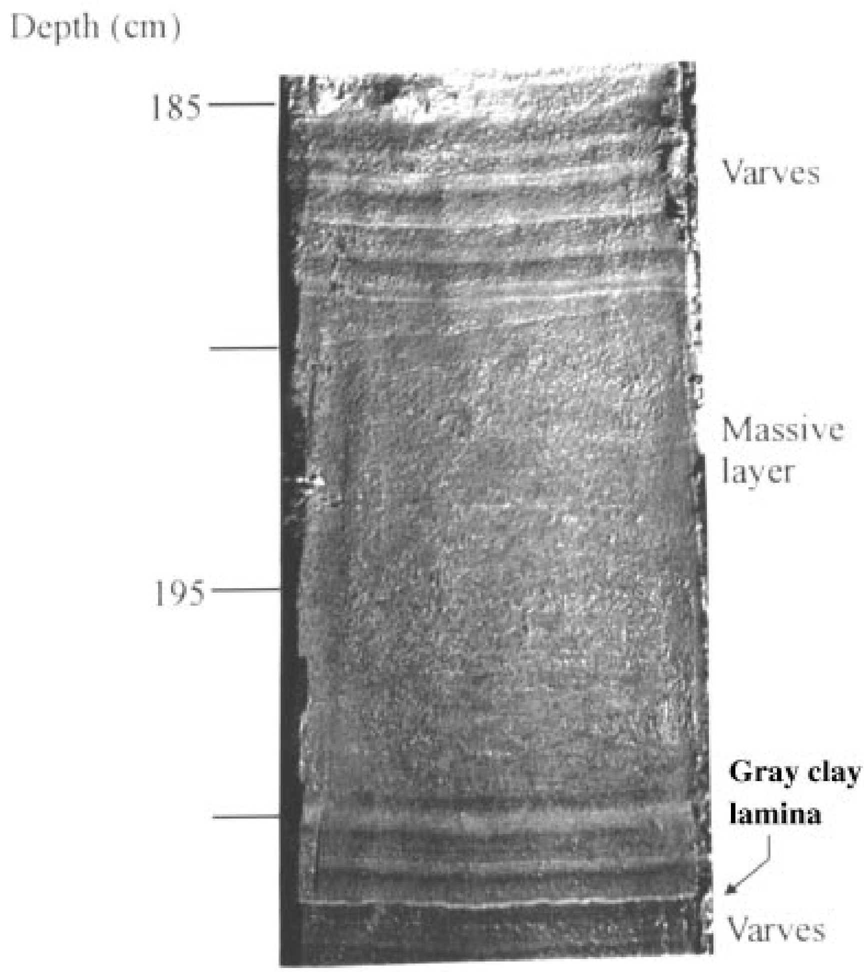


Figure 3. Location map of piston cores illustrated in Figure 4 (Blais, 1995).

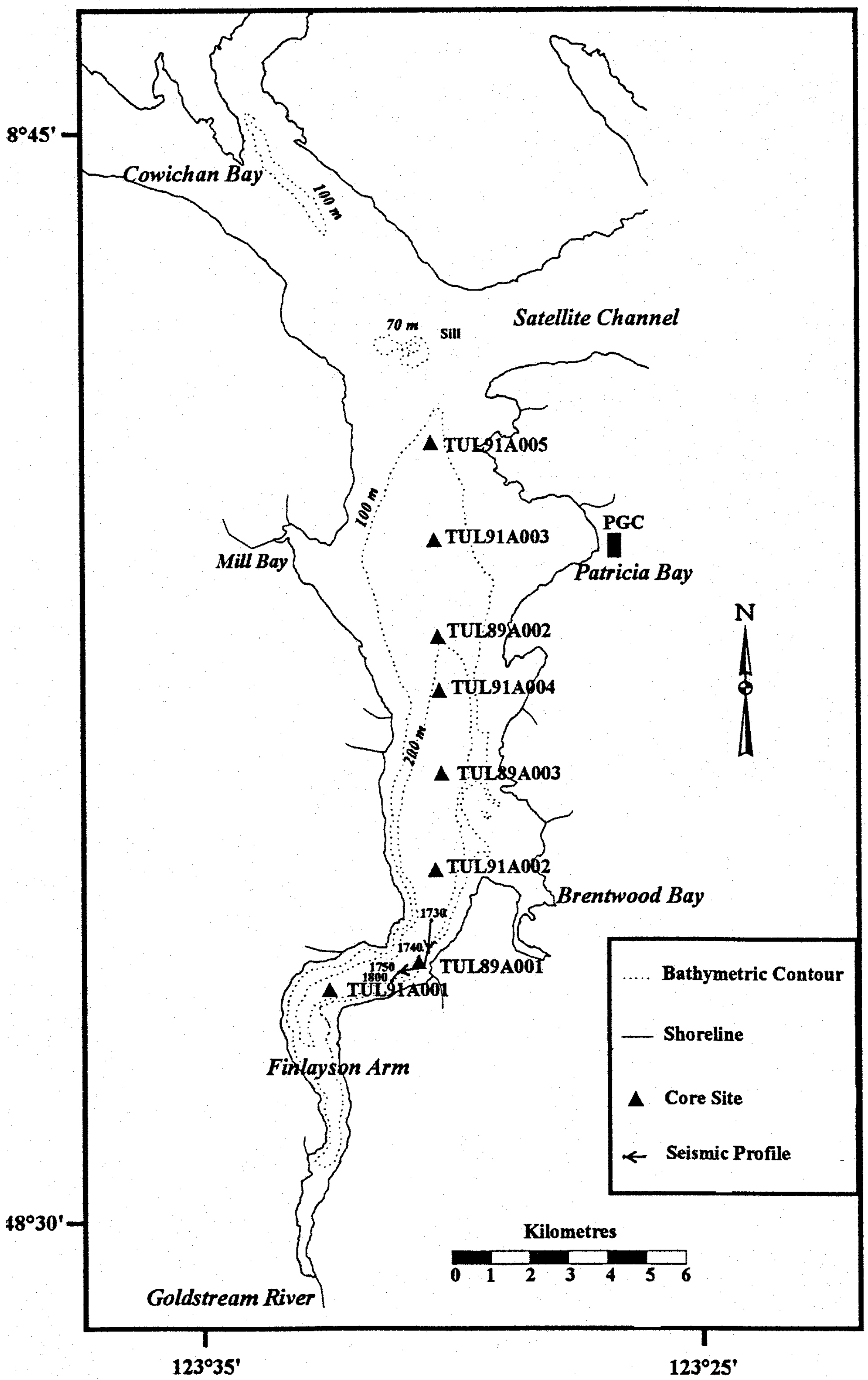
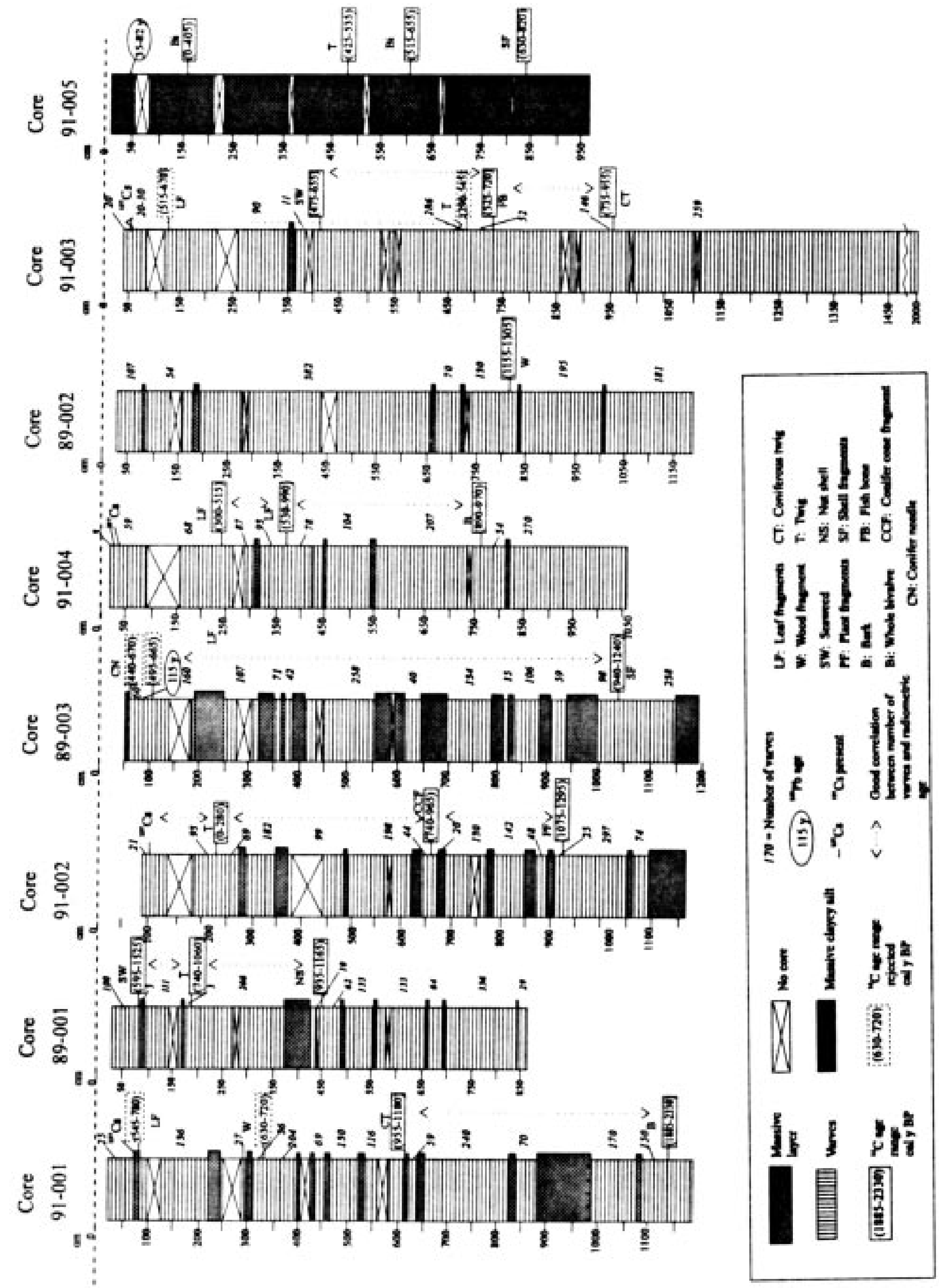


Figure 4. Piston core logs showing laminated and massive intervals and radiocarbon dates (Blais, 1995).



SITE INFORMATION

Site: SI-01B
Location: Saanich Inlet**,** British Colombia, Canada
Priority: 1
Position: 48°35.433′N, 123°30.201′W
Water Depth: 225 m
Sediment Thickness: 296 m
Total Penetration: 100mbsf
Seismic Coverage: Single channel

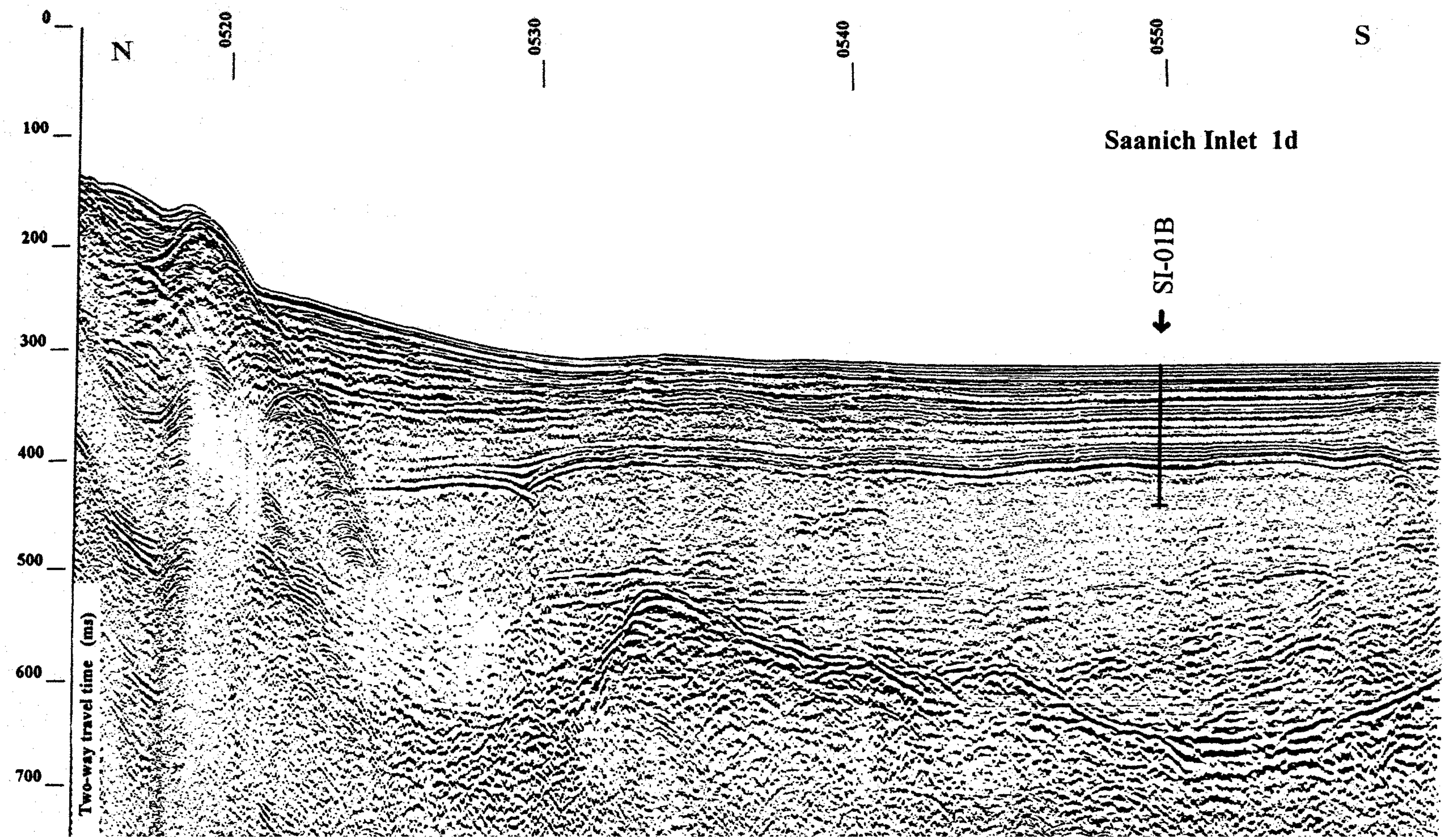
Objectives:

1. Ultra-high-resolution (annual) terrestrial and marine paleoenvironmental record since glaciation
2. Frequency of large earthquake events, Cascadia subduction margin
3. Sediment diagenesis in an isolated anoxic basin

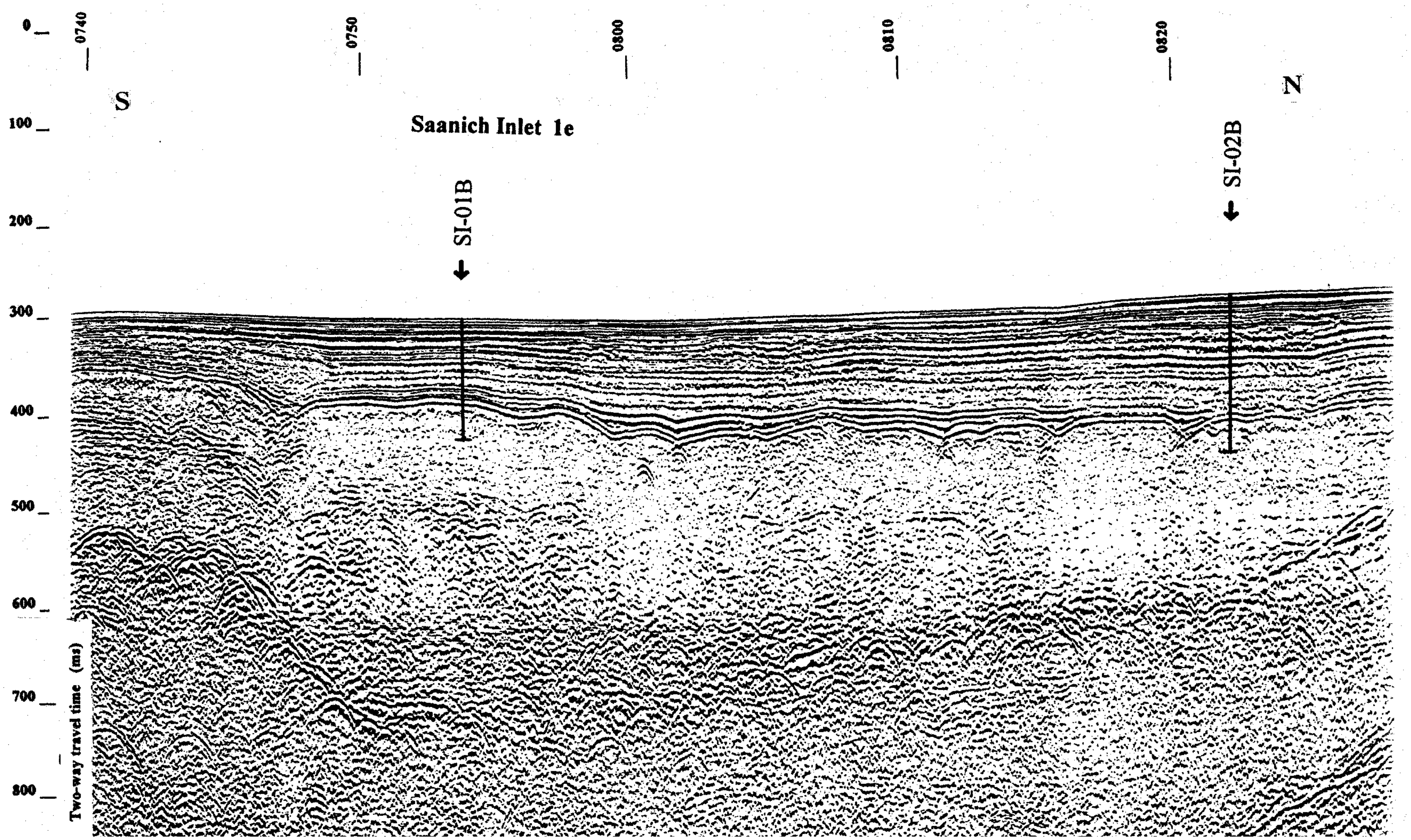
Drilling Program: Triple APC core

Logging and Downhole Operations: None

Nature of Rock Anticipated: Organic-rich terrigenous muds, stiff glaciomarine muds, abundant ice-rafted debris



0
100
200
300
400
500
600
700
Two-way travel time (ms)
N
0520
0530
0540
0550
S
Saanich Inlet 1d
SI-01B



Saanich Inlet 1e
S
N
0740
0750
0800
0810
0820
SI-01B
SI-02B
0
100
200
300
400
500
600
700
800
Two-way travel time (ms)

Site: SI-02B
Location: Saanich Inlet**,** British Colombia, Canada
Priority: 1
Position: 48°38.00′N, 123°30.00′W
Water Depth: 200 m
Sediment Thickness: 260 m
Total Penetration: 124mbsf
Seismic Coverage: Single channel

Objectives:

1. Very high resolution (annual) terrestrial and marine paleoenvironmental record since glaciation

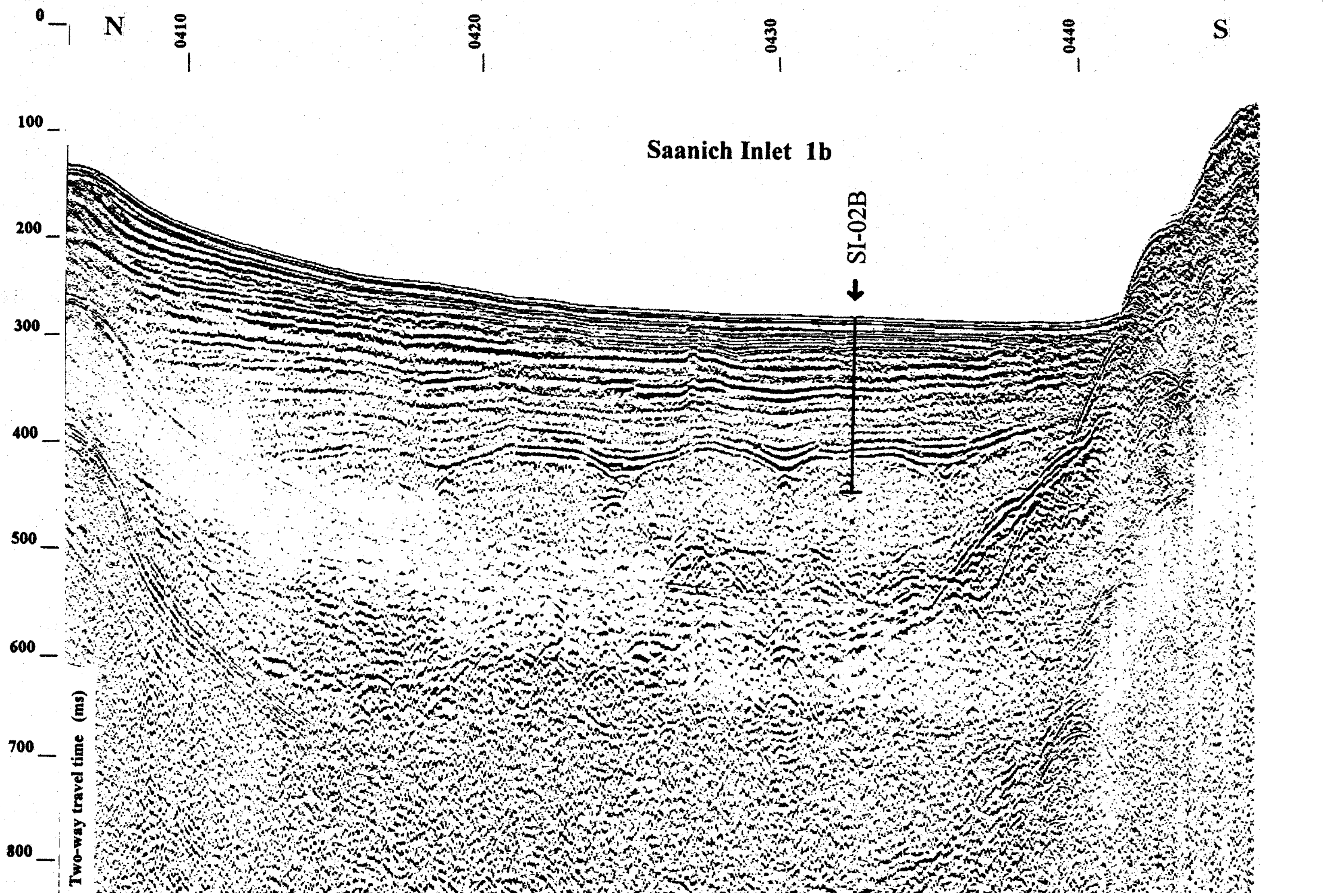
2. Frequency of large earthquake events, Cascadia subduction margin

3. Sediment diagenesis in an isolated anoxic basin

Drilling Program: Triple APC core

Logging and Downhole Operations: None

Nature of Rock Anticipated: Organic-rich terrigenous muds, stiff glaciomarine muds, abundant ice-rafted debris



Saanich Inlet 1b
N
S
0410
0420
0430
0440
SI-02B
0
100
200
300
400
500
600
700
800
Two-way travel time (ms)

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TECHNICAL STAFF SUBJECT TO CHANGE