NEPTUNE Canada

University of Victoria

Principal Investigator: Riedel / Hyndman

Family Name (25 characters)

Date: 2005-01-17

YYYY-MM-DD

OCEAN OBSERVING SYSTEMS COMMUNITY EXPERIMENT GRANT PROPOSAL

Title: Hydrates-II: Monitoring of sub-seafloor fluid and gas processes, and gas hydrate formation using IODP boreholes and seafloor geophysical imaging

Descriptive title of the experiment (Maximum 200 characters)

1. *Science Summary* **(Maximum 1,000 characters)**

Hydrates-II: (complementary to Hydrates-I) will monitor upward fluid and gas fluxes as well as changes in gas hydrate concentrations in the subduction zone accretionary sedimentary prism, using instrumentation on the seafloor and in IODP 553 boreholes (Aug-Oct. 2005) (Sites ODP 889, Bullseye vent, and Nootka fault). Pore-pressure, permeability, temperature, and pore-water chemistry will be monitored. These parameters are crucial for assessing the processes that form natural gas hydrate, its potential for energy, and its role in climate. Geophysical imaging systems will monitor sediment physical properties (electrical resistivity, P&S-wave velocity, and shear&bulk moduli) within and below the gas hydrate stability zone, monitor the evolution of the hydrate and the underlying source of gas. Optical and temperature observations will be monitored at the seafloor. The relationship of earthquake shaking on fluid and gas flux will be monitored at the seismically active Nootka Fault.

Equipment to be Deployed **(Maximum 500 characters)**

IODP Bore-hole monitoring devices include CORKs (pressure-permeability), OSMO-samplers, and distributed temperature cables (DTS). Seafloor imaging and monitoring instrumentation include controlled source electro-magnetics (CSEM), seismo-acoustic arrays, gravity/pressure-compliance package, heat-flow probes, and panorama digital cameras.

Sites **(Maximum 350 characters)**

Four sites on the continental slope: (a) Three sites off central Van. Is. near existing ODP Site 889, to monitor IODP boreholes and adjacent areas, and (b) the Nootka Site off Nootka Island to examine the connection between fluid expulsion, hydrate formation and strong earthquake shaking.

Annual Budgets

Pre-Deployment $ 1,594,000 **(12 characters)**

Post-Deployment $ 865,000 **(12 characters)**

	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013
Desired	$140,000	$687,000	$767,000	$245,000	$155,000	$155,000	$155,000	$155,000
Minimum	$	$	$	$	$	$	$	$

(Maximum 9 characters per entry)

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Title: Hydrates-II: Monitoring of sub-seafloor fluid and gas processes, and gas hydrate formation using IODP boreholes and seafloor geophysical imaging

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NEPTUNE Canada

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Title: Hydrates-II: Monitoring of sub-seafloor fluid and gas processes, and gas hydrate formation using IODP boreholes and seafloor geophysical imaging

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Title: Hydrates-II: Monitoring of sub-seafloor fluid and gas processes, and gas hydrate formation using IODP boreholes and seafloor geophysical imaging

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Title: Hydrates-II: Monitoring of sub-seafloor fluid and gas processes, and gas hydrate formation using IODP boreholes and seafloor geophysical imaging

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Title: Hydrates-II: Monitoring of sub-seafloor fluid and gas processes, and gas hydrate formation using IODP boreholes and seafloor geophysical imaging

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3. *Proposed Scientific Program* (Maximum 32,000 characters)

In language appropriate for a multidisciplinary committee, use this page and up to six additional pages to address the following:

- **outline the scientific program;**
- **explain how the proposed research is innovative; and,**
- **describe the research opportunity and how the proposed research will capitalize on this opportunity.**

Naturally-occurring, ice-like gas hydrates form when gases (mainly biogenic methane) combine with water at low temperature and high pressure. These conditions are found in the sediment section on deep sea continental slopes where the water depth is greater than about 600 m, including offshore Vancouver Island (N. Cascadia). Natural gas hydrates represent a very large global reservoir of natural gas, mainly methane. Globally they are estimated to contain more organic carbon than all other fossil fuel sources combined. Hydrate is important because of its potential as a large source of future clean energy, but also because of potential risks associated with these deposits. These include the potential for a significant impact on climate change (methane is a strong greenhouse gas) and its role in seafloor stability hazard. The Canadian west coast has large and well-mapped occurrences of marine hydrate in the large subduction zone accretionary sedimentary prism on the continental slope. The recognized importance of natural hydrate is indicated by the large hydrate programs in Japan, U.S.A., Korea, Taiwan, China, India etc., and a new GSC program, mainly directed at a future clean energy source. With modest expenditures Canada has played an impressive lead scientific role internationally. This leadership has included the ground-breaking Mallik gas hydrate test wells on the Arctic Mackenzie Delta largely funded internationally, but led by Canada, and secondly, studies off the west coast of Vancouver Island in the area of this proposal. Under Canadian leadership, the latter has included intensive survey and study over 15 years, with participation by 5 countries and over 15 institutions, as well as previous ODP drilling (Leg 146). The region off Vancouver Island is now one of the most comprehensively studied gas hydrate occurrences in the world. NEPTUNE provides the opportunity for unprecedented advances including detailed assessment and long-term monitoring of the rising fluids and gas that form the hydrate and how these change with time, as well as the evolution of gas hydrate deposits themselves. The work also will determine the reservoir properties and characteristics needed to develop strategies for extracting methane gas from the hydrate.

The presence of gas hydrates at depth in the sediment and at the sea floor is well established from previous research over the past 15 years on the northern Cascadia Margin offshore Vancouver Island (see summaries by Hyndman et al. (2001) and Spence et al. (2000)). Seismic surveys have mapped the distribution of hydrates over the area by the characteristic bottom simulating reflector (BSR). The BSR is a bright, negative-polarity reflector marking the base of the hydrate stability zone. There is hydrate in the overlying sediments and free gas in the underlying sediments. Intensive geophysical and geological studies have been carried out, including, regional 2D and detailed pseudo-3D seismic imaging (e.g. Fink and Spence, 1999; Yuan et al., 1999; Riedel et al., 2002), ODP Leg 146 coring and logging (Westbrook et al., 1994), piston coring and related physical property and geochemistry studies (Novosel, 2002; Solem, 2002), heat-flow studies (e.g. Ganguly et al., 2000), bottom video observations (e.g. Riedel et al., 2002), seafloor controlled-source electromagnetic (CSEM) surveys (Yuan and Edwards, 2000; Edwards, 1997) and compliance studies (Willoughby and Edwards, 2000). Special analyses of gas hydrate concentrations near ODP Site 889 were carried out using multichannel seismic velocities, sonic logs, electrical resistivity and pore-water chlorinity (e.g., Hyndman and Spence, 1992; Hyndman et al., 1999; Yuan et al., 1996). Gas hydrate concentrations may be as high as 30% near the BSR over a 100 m thick interval.

The occurrence of gas hydrate is postulated to result from upward fluid and gas flow due to consolidation of the accretionary sedimentary prism (e.g., Hyndman and Davis, 1992), that forms as the thick sediment section is scrapped off the incoming oceanic plate. Biogenic methane generated within the thick sediment section is concentrated upward into the stability field of hydrate in the top several hundred metres below the seafloor. Hydrate appears in two forms, (a) a widespread layer up to 100 m thick just above the BSR, and (b) concentrated occurrences in local fluid/gas plumes, especially near the seafloor. NEPTUNE provides the opportunity to investigate these two mechanism of formation:

(1) Hydrates form at the seafloor in areas of high fluid or gas flux, which implies local conduits of high permeability.

(2) In regions of lower fluid and gas flux, hydrate is concentrated near the BSR and decreases toward the seafloor. There must be adequate pervasive permeability and regional high pore pressure to produce a regional layer of hydrate overlying free gas.

For both type of hydrate formation there is indication, both from previous CORK data gathered elsewhere and from indications of live and recently dead clam colonies etc., that the upward fluid flow and deposits themselves have substantial time variability.

There are several fundamental science questions:

- What factors control the formation and dissociation of hydrate at depth in the sediment and at the sea floor?
- How are these deposits evolving in time?
- What is the response of the hydrate system to periodic time variations in the sub-seafloor and near seafloor environment, and to episodic events caused by tectonic forces and earthquakes?
- What is the flux of methane and other hydrocarbons at the sea floor?
- What are the relationships with microbial processes in the sediment and in the water column?

Earthquakes in the subduction zone are inferred to have a profound effect on many geological processes in the accretionary prism, especially the great megathrust subduction events (of order magnitude 9). Such events occur only rarely, but smaller more frequent events may illustrate the process. Also, slow slip events recently identified on the underlying subduction thrust fault may apply transient tectonic stresses. Shaking may release large volumes of methane into the ocean and the atmosphere. The effect of ground shaking, plate deformation and changes in bottom water temperature on gas-charged and gas-hydrate bearing sediments of accretionary complexes are to be monitored and quantified. The volatile fluxes expelled from subduction zones may represent major, time-variable movements of carbon into the ocean and atmosphere. Determining the importance of subduction zone methane emissions from gas hydrates in such scenarios needs long-term in situ recording.

The gas hydrate initiative for NEPTUNE is separated into two proposals: The first proposal (HYDRATES-I) lead by Dr. Ross Chapman, focuses on seafloor observations and monitoring at the Barkley Canyon Site where there is a field of massive gas hydrate outcrops. Our second gas hydrate proposal (HYDRATES-II) focuses on monitoring sub-seafloor rising fluid and gas processes and changes in the gas-hydrate concentration using IODP boreholes instrumented with long-time monitoring devices as well as geophysical imaging techniques on the seafloor (CSEM sounding, acoustic arrays, compliance, and heat-probe measurements).

This proposal is closely linked with the new IODP Leg 310 drilling, sampling and downhole measurements on the northern Cascadia margin (lead by M. Riedel) directed at constraining models for the formation of deep sea gas hydrate in subduction zone accretionary prisms. The first part of this IODP leg has been scheduled for August-October 2005, followed by another leg within the next 2-3 years. Hyndman and Davis (1992) developed a general model for deep sea gas hydrate formation by removal of methane from upwardly expelled fluids. Mainly biogenic methane, inferred to be produced over a thick sediment section, is carried up to form hydrate when it enters the stability field. The hydrate concentration is predicted to be greatest just above the BSR, as is usually observed.

The IODP expedition consists of a margin-perpendicular transect of 5 Sites with an additional cold-vent location. The sites along this transect were chosen to represent different stages in the accretionary prism development, and thus different stages in the formation of gas hydrates and related fluid flow. From the deep Cascadia Basin (serving as a reference for no-gas/no-hydrate), the sites extend towards the top of the continental slope. The sites show different maturity in the stage of hydrate formation and subsequent dissociation. They can be seen as snapshots in the time evolution of the hydrate field. This transect also represents a crosscut through the margin that will tell us about the lateral heterogeneity of the hydrate

stability field and its relation to local geological structures at a given time. The borehole downhole measurements also will provide a calibration regional geophysical measurements and the interpretation of these data in terms of hydrate concentration.
A remarkable rich data set has been obtained from new systems of long-term monitoring of deep sea floor boreholes (Davis and Becker, 2001). A system for sealing and instrumenting ODP boreholes was developed 10 years ago to allow interstitial fluids to be sampled, and natural fluid pressures and temperatures to be monitored over long periods of time. The capabilities of these CORK (Circulation Obviation Retrofit Kit) observatories have been expanded recently to allow monitoring and sampling in multiple isolated horizons, and to allow installations to be completed by wireline in previously drilled holes. To date, 16 hydrologic observatory sites have been established in ridge crest, ridge flank, and accretionary prism settings. Observations at these sites have provided precise constraints on the primary driving forces for, and thermal consequences of, sub-seafloor fluid flow caused by tectonic consolidation and thermal buoyancy. Deep in accretionary prisms, high formation pressures have been observed, confirming that plate boundary faults possess little strength. In young ocean crustal settings, surprisingly low lateral temperature and pressure gradients have been documented, implying that the extrusive rocks of the oceanic crust permit efficient fluid, heat, and chemical transport over distances of many kilometres. CORK observations have also revealed pressure variations and associated fluid flow resulting from co-seismic plate deformation, and from tidal, oceanographic, and barometric loading of the seafloor. The characteristics of the formation response to seafloor loading provide constraints on elastic and hydrologic properties, and allow quantitative estimates of crustal strain to be made from tectonic-strain-related pressure transients. Strain events have been observed up to 150 km away from several seismogenic dislocations along transform and seafloor spreading plate boundaries.

A key element of the IODP expedition is the installation of long-time monitoring instruments. Those instruments are:
1) CORK-II (include Osmo-samplers, thermistor temperature probes and down-hole pressure gauges),
2) A-CORK (for active cross-hole hydro-geologic experiments),
3) Distributed Temperature Sensors (fibre-optic cable for high-resolution, continuous down-hole temperature profiling).

The goal of this proposal is to establish a versatile measurement and monitoring infrastructure that will:
(A) Identify and monitor the background fluid and gas concentrations and movement that control hydrate formation and stability at the site;
(B) Provide a seafloor laboratory for new experimental work carried out within the NEPTUNE system.

These seafloor laboratories are equipped with a variety of geophysical imaging instruments (some of which are linked to IODP bore-hole devices):
1) CSEM,
2) gravimeters and pressure gauges,
3) Seismo-acoustic arrays,
4) panorama digital cameras,
5) temperature probes.
Gas hydrates affect the shear- and bulk moduli, P- and S-wave velocities as well as the electrical resistivity of sediments. An increase in gas hydrate concentration results in an increase in those properties. Continuous (and simultaneous) measurements of (1) the P- and S-wave velocity profile with 4C ocean-bottom seismometers, (2) the electrical resistivity with the CSEM system, as well as (3) compliance measurements with the gravimeters provide complete information about the presence and concentration of gas hydrate and their changes with time.

In this proposal we plan to instrument four sites: (a) ODP Site 889, (b) adjacent IODP CORK Site, (c) Bullseye vent, and (d) Nootka Fault:

(a) The ODP Site 889 is the best studied site on the Northern Cascadia Margin, where ODP Leg 146 demonstrated the presence of gas hydrate by intensive coring and geophysical logging (Westbrook et al., 1994; Hyndman et al., 2001 and references therein). Gas hydrate concentrations may be as high as 30% of the pore-space at this site over an interval of 100 m above the BSR. Site ODP 889 represents a location of regional pervasive low upward fluid flux, where gas hydrates form slowly from upward migrating fluids that are expelled from greater depth by the overall tectonic compression and thickening of the accretionary prism. This site is a key element in the new IODP expedition 553. Bore-hole monitoring devices will be installed including, DTS fibre-optic cables for down-hole temperature measurements and CORK instruments for pressure-and very-high resolution temperature measurements and fluid sampling. We further propose to link a permanent seismo-acoustic array to the NEPTUNE cable at this node for monitoring variations in gas hydrate concentrations in the subsurface. With these experiments we will be able to measure sediment physical properties (electrical resistivity, seismic shear and compressional-wave velocity, and shear- and bulk-modulus) over a larger area around the IODP borehole (approximately in a square of 500 m by 500 m).

(b) Near ODP Site 889 a special cross-hole hydro-geologic experiment is planned by installing CORK instruments in two nearby bore holes as part of the IODP 553 expedition. The CORK Site is about 3 km SE of ODP Site 889 and can easily be reached by an extension cable. No other equipment is proposed to be installed at this site. An interface to connect the CORK to the NEPTUNE cable needs to be developed.

(c) The Bullseye vent is about 4 km SE of ODP Site 889 and is a location of moderate-high fluid/gas flux. It has been intensively investigated since 1998 (e.g. Riedel et al., 2002; Novosel 2002; Solem et al., 2002). At this site massive sub-seafloor gas hydrate was detected seismically and recovered by piston coring. Water-samples taken from the remotely-operated vehicle ROPOS showed increased methane concentrations in a 200-m high plume above the cold vent with concentrations 20-times ocean-background at the sea-bottom. Wide-spread carbonate formations, chemical alteration of the sediments, and the occurrence of chemosynthetic communities confirmed focused, active methane advection at this Site. This site is also part of the IODP expedition 553. It is planned to install a CORK borehole seal device as well as DTS cables. Fieldwork in 2004 reveal substantial resistive and shear moduli anomalies over the massive gas hydrate occurrence (K. Schwalenberg, pers. com., 2004) previously imaged and mapped by high-resolution 3-D seismic survey (Riedel et al., 2002). We plan a permanent CSEM electrical sounding array, seafloor compliance installation, and an acoustic array to monitor changes in the hydrate deposit, and in the underlying fluid/gas plumbing. Since this site has a distinct seafloor expression with carbonate formations, chemosynthetic communities and episodic methane expulsion, we plan to install surface heat-probe instruments, and 360-degree digital cameras to detect and monitor seafloor processes of methane venting. The presence of a massive (near-seafloor) gas hydrate cap offers special opportunities for measuring sub-seafloor physical properties to monitor changes in the thickness of this hydrate cap (accumulation and dissociation).

(d) The Nootka Site offers a unique opportunity to study the relation between earthquake shaking, fluid and gas expulsion and gas hydrate formation. Although this site as yet has less site survey information, the Nootka Site has received high scientific priority in NEPTUNE planning discussion. Great earthquakes along the margin may provide the most important long-term intense shaking, but they are very infrequent: ~500 years, so cannot be easily studied. The Nootka transform fault between the Juan de Fuca and Explorer plates underthrusts the accretionary prism approximately orthogonally to the margin. It is very seismically active so provides a frequent localized shaking source almost as strong as from great events. It thus provides a unique opportunity to monitor the effects of earthquake shaking on fluid, gas and hydrate processes. We propose a minimal instrumentation of an EM system, compliance measurements and a simplified acoustic array of only 10 receivers.

Our Hydrate-II proposal is linked (in addition to the Hydrate-I proposal) to other NEPTUNE proposals, especially (a) the Earthquake monitoring proposal, and (b) the Ridge-EM proposal. Gas hydrate formation and linked fluid expulsion may be enhanced by ground shaking. Furthermore the proposed 4C acoustic arrays may also be used for complementary passive monitoring of earthquake activities.
The CSEM and compliance systems for the Hydrates-II proposal are identical to the systems described in the Ridge-EM proposal. Thus there are many shared scientific objectives and engineering challenges (e.g. in the overall system development, interfacing, & DMAS).

Although the high-resolution seafloor gravity and pressure systems in this proposal are presented as a method to determine the concentrations of gas hydrate and its time variation (through gravity-pressure compliance as a function of frequency), the very high resolution gravimeters and pressure gauges have important additional values. The recording gravimeters have an important observatory function. Some of the gravity applications include tectonic deformation events such as slow slip on the subduction thrust near the toe of the accretionary prism, monitoring of very low frequency seismic waves from large earthquakes, and seafloor earth tides. The recording gravimeters are very complementary to the other Neptune 'observatory' instruments of seafloor seismograph stations, and seafloor magnetic observatories. Similarly the high-resolution pressure gauges provide important additions to the proposals for tsunami monitoring and for data constraining large-scale oceanographic processes.

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4. *Site Summary* **(Maximum 1,500 characters)**

Outline the characteristics of the location(s) of operation (including physical description and geographical):

- **name of location;**
- **latitude and longitude; and,**
- **depth.**

This proposal is for instrumenting four Sites:ODP Site 889, IODP CORK-Site, Bullseye vent, and the Nootka Site. (a) ODP 889 (water depth: 1350 m; 048 41.884N, 126 51.924W); Gas hydrate is present at depth, with concentrations as high as 30% of the pore space over a 100 m thick interval above the BSR. The seafloor is flat and lacks evidence of cold-vent activity.(b) IODP CORK Site (water depth: 1250 m; 048 41.682N, 126 51.630W); At this Site a cross-hole hydro-geologic experiment will be conducted. CORKS will installed in two near-by bore-holes. This Site is 3 km SE of the node ODP 889. (c) Bullseye vent (water depth 1280m; 048 40.050N, 126 51.053W); This Site is a location of moderate fluid flux plume structure. The Site shows evidence of active methane venting over an area 500 m in diameter: carbonate formations, chemo-synthetic communities, chemical alterations of the sediments in the upper 6 - 8 m below seafloor, and episodic methane expulsion. A sub-seafloor massive gas-hydrate cap is present in the centre of the cold vent as detected seismically and piston cored. The seafloor shows a 8 m variation in height. This site is about 4 km SE of the node ODP 889. (d) Nootka Site (water depth about 1200 m, location to be determined). This site is to be in the area of active seafloor cold vents on the mid continental slope.

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5. Collaboration with Other Partners (Academia, Government, Industry, International)

(Maximum 2,000 characters)

The proposed research will create or strengthen (check all that apply):

X 1. collaborations among researchers (e.g. collaboration on funded projects, co-authorship);
X 2. collaborations among researchers from different disciplines, institutions, sectors or countries;
X 3. partnerships among research institutions.

Using the space below address all of the following aspects:

- **what collaborations or partnerships already exist;**
- **what collaborations or partnerships are planned;**
- **what steps have been taken or will be taken to create or strengthen collaborations or partnerships; and,**
- **how the research is essential to the collaborations or partnerships.**

The N Cascadia Hydrate Research Team has developed over the past 15 yrs. It is informally but effectively coordinated, and represents a broad integrated multidisciplinary study group. Scientists come from Canadian government and university groups (Geol. Surv. Canada, Univ. Victoria, Univ. Toronto, U.B.C., Dalhousie Univ., McMaster Univ.), and international institutions (Navy Res. Laboratory, Scripps Inst. Oceanog., Univ. Bremen, Univ. Wash., Oregon State Univ., USGS, Japan, China, Korea). This team has been extremely succesful and is very well recognized in the international marine hydrate research community. There is special collaboration as part of the ongoing IODP expeditions with a list of multi-disciplinary scientists from the GSC, Univ. Victoria, USGS, Scripps Inst. Oceanof., and JAMSTEC Japan, covering a wide range of geophysics, geology, geochmistry and micro-biology.

For this NEPTUNE proposal a group of collaborating scientists was formed that include individuals from University of Victoria (George Spence, Ross Chapman, Roy Hyndman; acoustics), Geol. Survey Canada (Michael Riedel, Roy Hydman, Ele Willoughby, Earl Davis, Scott Dallimore, Fred Wright, Dave Mosher; IODP, compliance, acoustics), U of Toronto (Nigel Edwards, Katrin Schwalenberg; EM sounding), Oregon State University (Adam Schultz: Temperature probes), Scripps Inst. (Miriam Kastner: geochemistry, IODP), and Texas A&M Univ. (Ian MacDonald: Digital cameras).

The development of a seafloor compliance package has been an on-going collaboration between U of T and the Canadian high-tech geophysical instrument maker, Scintrex Ltd., who has provided in-kind contributions including R&D and operation of gravimeters and lab facilities. There are also significant opportunities for industrial collaboration on controlled-source electromagnetic instrumentation, being persued by the U of Toronto.
The most significant collaboration is with IODP sampling, downhole measurements, and monitoring instruments.

Principal Investigator: Riedel/Hyndman

Family Name

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6. *Equipment to be Deployed* (Maximum 3,000 characters)

In language appropriate for a multidisciplinary committee address the following:

- **describe the equipment that will be acquired or developed;**
- **indicate where the equipment will be located; and,**
- **why the equipment is needed.**

1. CORKs. These bore-hole instruments monitor pressure and temperature in the borehole (and infer permeability), fluid sampling, and measure fluid flow rates into the borehole. Initial versions were deployed successfully elsewhere, ODP Legs 205 and 301. For ODP Site 889 and at Bullseye vent.

2. Distributed Temperature Sensors (DTS). The borehole-installed fibre-optic DTS system can measure formation temperatures over the entire cable length with a minimum sampling interval of 0.25 m and an accuracy of 0.1°C (and higher resolution). The data acquisition system allows measurements at up to 7 s intervals allowing the determination of equilibrium temperatures and also observation of temperature transients over long time periods. For ODP Site 889.

4. Controlled- source EM (CSEM: transmitter TX and two 1-5 km long receiver RX arrays, operated 24hr/month). Detects crustal resistivities and their time variations. Insulating hydrate or free gas displace conductive pore water, allowing the hydrate deposit and underlying "plumbing" to be monitored. At Bullseye vent. This equipment requires intermittent high power for the transmitter. For Bullseye and Nootka.

5. 4-Component (4C) Ocean Bottom Seismo-Acoustic Array. Will provide acoustic images of the sediment structure and time variations. Using both P- and S-waves, it will be possible to estimate the velocity-depth profile and calculate hydrate concentrations. Can also provide information about seismo-acoustic interface waves (Scholte waves) to estimate the S-wave velocity profile. For Bullseye and Nootka.

6. Compliance package (Differential Pressure Gauge DPG and Gravimeter). Time-series data of pressure induced by surface gravity waves and the associated deformation of the seafloor can be inverted for shear modulus depth profiles. The shear modulus is a sensitive indicator of the skeletal strength of underlying sediments, and by inference the amount of hydrate that is cementing the grains. The time evolution of hydrate content as a function of depth will be monitored over the Bullseye vent. The high-resolution gravimeter also will allow monitoring of density changes in the underlying sedimentary prism, especially from earthquake shaking. For Bullseye and Nootka.

7. Measurement of temperature versus time in the water, at the sea floor and at shallow depths in the sediment. The temperature probes will be where there has been evidence of active gas seepage at Bullseye vent. Each sediment probe with an array of temperature sensors is about 1 m long. It is deployed in the sediment to measure the temperature profile in the water and into the sediment. Bullseye and Nootka

8. Digital still photos of the seafloor environment. Cameras are designed to take digital photos at specific bearings during a 360° sweep of the seafloor environment. These data provide a time history of the biological communities and the effect on hydrate outcrops. Bullseye and Nootka.

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7. *Proposed Data Management Plan* (Maximum 3,000 characters)

In language appropriate for a multidisciplinary committee address the following:

- **outline the data management plan;**
- **explain how the proposed plan will support the scientific program; and,**
- **identify potential challenges and areas of concern.**

The sites proposed here will produce a variety of different kinds of data that will be acquired at different time scales. Information from the various bore-hole instruments need to be linked with the instruments deployed on the seafloor.We plan in the initial stage (FY 2005/2006) of this proposal to develop a data management plan to coordinate (a) the frequency of data acquisition from the various sensors, (b) placing of the individual experiments at each site to prevent interference, and (c) data archiving and presentation for potential end-users.

The borehole components of this proposal mainly represent passive experiments, where a constant stream of data (e.g. temperature, pressure) needs to be regularly captured at an appropriate interval (e.g. once every 10 minutes). An exception is the active cross-hole experiment at the A-CORK Site.

Data acquisition using the acoustic array requires a special cruise to revisit the site and shoot airguns, which is planned typically once a year. The seismic data recorded with the seafloor array will be retrieved over the NEPTUNE cable network, converted onshore into the standard industry SEGY-format, and subsequently archived and provided to the end-user. Constant passive noise-monitoring may also be possible but is currently not planned.

CSEM system will be operated at least monthly for a period of 24 hours at 1 kHz. Data will be pre-processed prior to uploading to DMAS. Time synchronization of source TX with local RX array and power to run TX are required. Most communications to be from instruments to network but some control signals required from lab to instruments. Concerns include interference from cable system and other instruments and corrosion of TX electrodes in long term deployment.

Compliance data consist of 1 Hz time series of acceleration and pressure. Calibration and uploading to DMAS will be straightforward.

Potentially fairly high data rates during special seismic experiments may represent a challenge.

8. *Training of Highly Qualified Personnel (HQP)* (Maximum 1 500 characters)

The proposed research will support the training of HQP by imparting (check all that apply):

X 1. the basic skills and expertise required to undertake research activities;
X 2. an appropriate set of skills and expertise needed in areas of importance to Canada; and,
X 3. a broad range of high-level skills and expertise in areas of importance to Canada.

Using the space below address all of the following aspects:

- **how the proposed research will create a stimulating and enriched training environment for HQP;**
- **current HQP training at the institution(s); and,**
- **future plans for HQP training to be carried out.**

Include the current number and level (undergraduate and graduate students, postdoctoral fellows, technicians, technologists, or other trainees/students) of HQP trained as well as the number and level of HQP to be trained as a result of the proposed research.

This proposal gives high priority to training of highly qualified personnel, with a minimum of one Postdoctoral fellow (or Research Associate), and at least one PhD student. Candidates for the postdoctoral fellow position and for the PhD student for this project have now been identified. Additional graduate students and one or more undergraduate COOP students will be employed if there are suitable candidates and adequate funds. The N. Cascadia natural gas hydrate team has an excellent record for involvement of graduate students and postdoctoral fellows. Hyndman currently supervises 6 PhD students/postdoctoral fellows. The EM and compliance components follow shipborne instrumentation developed by Edwards and a series of graduate students/PDFs. Spence currently supervises or co-supervises 5 graduate students and one PDF. Chapman currently supervises 7 graduate students and 1 postdoctoral fellow.

Michael Riedel was a PhD student, then a NSERC government laboratory postdoctoral fellow, both supervised by Hyndman, working on marine gas hydrate. Willoughby was a PhD student supervised by Edwards working on seafloor hydrate, and is now a NSERC government laboratory postdoctoral fellow supervised by Hyndman, working on compliance and EM measurements of seafloor hydrate.

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9. *Schedule, Part I* (Maximum 3,000 characters)

Use the space below to summarize the schedule for the duration of the project. In accordance with the complexity of the project, the schedule should describe how the project will be managed, utilization monitored, and user priorities established. On the following page, describe the tasks required to achieve the objectives for each year of the proposal by listing milestones. Indicate the start and end dates for the activities leading to the milestones as well as the major results expected.

Several aspects of this proposal are linked to the IODP expedition 553. Installation of the initial borehole monitoring instruments will be in August-October 2005. A second IODP leg is requested that may be about the time of installation of the NEPTUNE cable network in 2008/2009.

Although the borehole instruments (CORKs, DTS etc.) all have been deployed succesfully in various geological environments and their design and specification are known, they have yet to be linked to an underwater network. Originally they were designed to be visited by ROV and are outfitted with underwater connectors for data and sample retrieval.

Therefore, pre-deployment (2005 – 2007) we will develop and test the interfaces between the borehole instruments and the NEPTUNE cable. This will be carried out in close collaboration with IODP. The interface may be build as a hard-wire plug-in or using wireless bluetooth technology. During 2005–2007 we will produce a detailed map for each experiment site. Careful consideration will be made of placement of instruments and the potential for interference (for the CSEM system in particular), and to ensure optimal coupling for the seismo-acoustic array. This requires high-resolution (decimenter vertical accuray) bathymetric maps including backscatter data. Also we will define data acquisition time-schemes for each sensor (especially borehole components) and to develop an archiving and data-interpretation, processing, and distribution policy.

In close collaboration with the HYDRATES-I proposal we plan a test phase on VENUS for the deployment of a simplified acoustic array (single receiver). The seismic data acquired on the ocean-bottom array need to be carefully linked with the active seismic shooting (exact position of the airgun). We will develop a data protocol for these seismic experiments including (a) transfer of data onshore and conversion to industry standard SEGY format, (b) merging navigation data from the shooting ship with location of the array on the seafloor, and (c) accurate description of meta-data.

Both the compliance and the CSEM were designed as ship-based systems. They require reengineering for operation entirely on the seafloor using NEPTUNE power and communications. The compliance system may be reduced to borehole size, the CSEM Transmitter miniaturized and the receiver arrays redesigned for fiber opitc cable. This work should be completed quickly to meet the deployment schedule. Plans are now underway to deploy the compliance system on the MARS array.

After deployment (2008/2009), we plan to obtain data from the borehole sites regularly as defined above. Yearly seismic experiments are planned. Further servicing of the CORK instruments and DTS are planned to retrieve osmo-samplers and to replace battery packs, which are required for the period before the NEPTUNE cable can provide power to the site.

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9. *Schedule, Part II*

In the sections below, describe the tasks required to achieve the objectives for each year of the proposal by listing milestones. Indicate the start and end dates for the activities leading to the milestones as well as the major results expected.

Milestone (Maximum 70 characters)	Description of Activities (Maximum 150 characters)	Anticipated Starting Date	Anticipated Completion Date
Design, development and interfacing	Develop interface for IODP instruments. Design CSEM transmitter (contractor) and receiver array (Univ. T). Modify compliance system for MARS.	2005-06-01	2007-06-01
Development of instrument deployment strategy	Define instrument location at each Site to prevent interference; requires high-resolution bathymetric maps and backscatter	2005-06-01	2007-06-01
First VENUS tests	Test of underwater camera system; test of accoustic array and EM; development of data acquisition and processing policy; data distribution scheme	2005-06-01	2007-06-01
First MARS test	Compliance test at MARS test Site; development of data acquisition and processing policy; data distribution scheme	2006-06-01	2007-06-01
Construction of modified instruments	Construction of borehole size compliance system (Scientrex), CSEM TX (contractor) and RX (U of T). Interface to NEPTUNE. Testing on VENUS/MARS.	2006-06-01	2008-06-01
Deployment of instruments offshore	Deployment of entire instrument packages at each Site. Fieldwork will continue.	2008-06-01	2009-06-01
First repeat active experiment	First active experiment at each Site	2009-06-01	2010-06-01
Second repeat active experiment	Second active experiment at each Site	2010-06-01	2011-06-01
Third repeat active experiment	Third active experiment at each Site	2011-06-01	2012-06-01
Fourth repeat active experiment	Fourth active experiment at each Site	2012-06-01	2013-06-01

10. *Socio-economic Benefits* **(Maximum 1,500 characters)**

Select the statement that best represents the research project.

The proposed research has the potential to (check only <u>one</u>):

X **1. contribute indirectly to economic activities (e.g. economic growth, cost savings, job creation) or contribute indirectly to the improvement of society, quality of life, health, or the environment;**

X **2. improve economic activities (e.g. economic growth, cost savings, job creation) or improve society, the quality of life, health, or the environment;**

X **3. contribute to increased economic activity in strong or emerging areas of the Canadian economy or yield a major benefit in terms of society, quality of life, health, or the environment;**

X **4. contribute significantly to increased economic activity; help Canadian industry increase its global competitiveness and create new economic ventures; or lead to dramatic sustained improvements to society, quality of life, health, or the environment.**

Using the space below address all of the following aspects:

- **identify potential users of the research results (including partnerships with industry, academia, government, etc.);**
- **describe expected benefits and how these will be realized and the timeframe over which they are expected; and,**
- **where appropriate, provide plans for the development of clusters and for technology transfer, other forms of commercialization or transfer of expertise, as well as contributions to policies and practices.**

This proposal is for gas hydrate research within the accretionary prism of the Northern Cascadia Subduction zone. Gas hydrates have been the focus of intense research since several decades because it was recognized that they may represent a future energy resource (Kvenvolden, 1993). Although global estimates vary greatly, the total amount of hydrocarbon locked in gas hydrates may be much larger than all conventional known oil- and gas reservoirs together. the work in this proposal should contribute substantially to understanding the energy potential of hydrate, and how it may be produced.

Methane (the main constituent in natural hydrate) is also a strong green-house gas and may play an important role in global climate change. Natural variations in ocean temperatures, climate change and sea-level effect marine gas hydrate stability and could result in wide-spread dissociation of hydrate, which in turn would release methane and enhance global warming. Gas hydrate dissociation also represents an hazard for slope stability and generation of submarine slides, and a hazard in the offshore industry (communication networks, gas and oil pipelines, platforms, drilling operations).

In this proposal we adress all issues related to the role of gas hydrates on accretionary prisms by determining gas hydrate concentrations in the subsurface and calibrating remote sensing methods, monitoring changes in the sub-seafloor physical properties of gas-hydrate bearing and underlying sediments induced by tectonic processes (e.g. earthquakes), monitoring fluid-and gas fluxes from the base of the gas hydrate stability field at depth to the seafloor and into the water column.

Potential direct users include academics (for scientific study), industry, who would benefit from drilling hazard and seafloor stability studies as well as government, who can use the data series to develop better guidelines and safety protocols for drilling in hydrate provinces, and long-term energy policies.

11. Detailed Annual Budgets, Part I

Outline the annual expenditures and sources of support committed to ensure effective operation and maintenance of the project for the duration of the project.

Costs	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**
Personnel	$ 70,000	$ 95,000	$ 95,000	$ 115,000	$ 65,000	$ 65,000	$ 65,000	$ 65,000
Supplies	$ 50,000	$ 572,000	$ 652,000	$ 40,000	$ 0	$ 0	$ 0	$ 0
Maintenance and Repairs	$ 0	$ 0	$ 0	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000
Services	$ 0	$ 0	$ 0	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000
Other, specify below	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000
TOTAL	**$ 140,000**	**$ 687,000**	**$ 767,000**	**$ 245,000**	**$ 155,000**	**$ 155,000**	**$ 155,000**	**$ 155,000**

(Maximum 7 characters per entry)

Funding sources	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**
Institutional Contribution	$	$	$	$	$	$	$	$
Other Organizations	$	$	$	$	$	$	$	$
User fees	$	$	$	$	$	$	$	$
Other, specify below	$	$	$	$	$	$	$	$
TOTAL	**$**	**$**	**$**	**$**	**$**	**$**	**$**	**$**

(Maximum 7 characters per entry)

11. Detailed Annual Budgets, Part II

Budget Justification

Use up to five pages to provide a brief justification for the items or systems indicated in the above Costs and Funding Sources categories. Along with the item description, list the cost of individual items for each category, for example:

Costs

1. **Personnel (to include salary and benefits)**
   - a. **Students**
   - b. **Postdoctoral fellows**
   - c. **Technical/professional assistants**
   - d. **Other, specify**
2. **Supplies (to include equipment or facility)**
   - a. **Purchase or rental**
   - b. **User fees**
3. **Maintenance and Repairs**
   - a. **Maintenance**
   - b. **Operating Costs**
   - c. **Minor equipment/upgrades**
   - d. **Other, specify**
4. **Services**
5. **Other**
   - a. **Travel**
     - i. **Conferences**
     - ii. **Field work**
     - iii. **Collaboration/consultation**
   - b. **Dissemination Costs**
     - i. **Publication costs**
     - ii. **Other activities, specify**
   - c. **Technology Transfer Activities**
     - i. **Field trials**
     - ii. **Prototypes**
     - iii. **Other, specify**

Funding sources

1. **Institutional Contribution**
   - a. **Cash contributions (for both direct and indirect costs)**
   - b. **In-kind contributions (for both direct and indirect costs)**
     - i. **Salaries for scientific and technical staff**
     - ii. **Donation of equipment, software**
     - iii. **Donation of material**
     - iv. **Field work logistics**
     - v. **Provision of services**
     - vi. **Other, specify**
     - vii. **Use of organization's facilities**
     - viii. **Salaries of managerial and administrative staff**
2. **Other Organizations**
   - a. **Cash contributions (for both direct and indirect costs)**
   - b. **In-kind contributions (for both direct and indirect costs)**
     - i. **Salaries for scientific and technical staff**
     - ii. **Donation of equipment, software**
     - iii. **Donation of material**
     - iv. **Provision of technical services**
     - v. **Other, specify**
3. **User fees**
   - a. **Internal source**
   - b. **External source**
4. **Other, specify**

Text to be attached (maximum five pages)

- **Use white paper, 8 1/2 x 11 inches (21.5 cm x 28 cm), portrait format, with a single column.**
- **Set margins at 3/4 of an inch (1.9 cm) (minimum) all around.**
- **Enter your Family Name and Project Title at the top of every page, within the set margins.**
- **Number consecutively following the last page.**
- **Print on one side of the page only.**
- **Pages in excess of the number permitted will be removed.**

Budget justification for HYDRATES-II NEPTUNE proposal: Monitoring of sub-seafloor fluid and gas processes, and gas hydrate formation using IODP boreholes and seafloor geophysical imaging

(1) Equipment costs

1.1 IODP Borehole monitoring (CORKs, Temperature, Sampling) $50K

Costs are for development of interface between CORK-II, A-CORK, and DTS cable system to NEPTUNE cable and technical support.

1.2 CSEM (at 2 sites) $350K

This system is identical to what is described in the Ridge-EM proposal.
Cable & electrodes $130K; Design engineering $110K;
Transmitters $30K; Interfaces $20K; Supplies $40K;
Travel etc. $20K

1.3 Compliance & Recording Gravimeters (at 2 sites) $250K

This system is identical to what is described in the Ridge-EM proposal.
Gravimeter $100K (each); Differential Pressure gauges $10K;
Interfaces $20K; Supplies $20K

1.4 Acoustic Array (at 2 sites) $520K

This is a similar version of that described in Hydrate I
The cost of a 20 sensor package of length about 400 m is estimated as $260,000.

1.5 RTD temperature probes (at 1 site): 5 probes @ $6000 $30K

The temperature probes have been developed at Oregon State University. These probes are identical to those in the Hydrate-I proposal. The budget schedule is to acquire all the temperature units during the first year, in preparation for the test phase at the VENUS site in Saanich Inlet in year two.

1.6 Digital cameras (at 1 site): 2 cameras @ 12,000 $24K

These cameras have been developed by Dr. Ian MacDonald at Texas A&M University for specialized research at sea bed seep and hydrate sites. These cameras are also part of the Hydrate-I proposal. Interfacing to the NEPTUNE array will provide optional surveillance routines in the event of rapid change. The budget schedule for the camera system is to acquire one camera for the test phase at the VENUS site in Saanich Inlet in year two, with the remainder to follow the next year for deployment offshore. These operations will be combined with tests carried out for the Hydrate-I proposal

(2) Site specific specs for equipment

ODP 889	- Borehole monitoring		$50K
		Total	**$50K**
Bullseye Vent	- EM		$175K
	- Acoustic array		$260K
	- Compliance		$150K
	- Rotary camera		$24K
	- Temperature-probes		$30K
		Total	**$639K**
Nootka slope	- EM		$175K
	- Acoustic array (short)		$260K
	- Compliance		$150K
		Total	**$585K**
		Overall Total	**$1,224K**

(3) Schedule of equipment costs

IODP CORK-II installation	September 2005		$50K
For fiscal year 2005/2006		**Total**	**$50K**
Test of camera at VENUS	in summer 2006		$12K
Test of compliance	in summer 2006		$125K
Test of acoustic array at VENUS	in summer 2006		$260K
Test of EM at VENUS	in summer 2006		$175K
For fiscal year 2006/2007		**Total**	**$572K**
Entire equipment to be spent by 2008/2009		**Total left**	**$652K**

(4) Personnel costs

Pre-deployment (before 2008-2009):

Research Associate/Engineer 3.5 years at 50K/yr For experiment design, management, field tests, construction, etc. to develop interface for IODP components, generate maps and data policy;	$175K
Graduate Student 4 years at $20K/yr	$80K
Technical support, COOP student, etc.; 4 years at $25K/yr computing etc.,	$100K

Associated with personnel should be computer equipment (PC and software), travel costs, publication costs, consumables; rough estimate should be $20,000 per year

Post-deployment (after 2008):

Overall duration: 5 years

Grad-students ($20K/yr); 2 students,	$160K
Post-doc (50%; $25K/yr)	$100K

Total $65,000 per year

Associated with personnel should be computer equipment (PC and software), travel costs, publication costs, consumables; rough estimate should be $20,000 per year for new and existing staff

(5) Service costs

Repeated cruises starting in 2008-2009

$50,000 per year for one cruise; Ship time costs not included

Costs for contractors, rental of equipment, travel, mob-demob, repairs and spares of airgun system, winches

(6) Maintenance and repairs post-deployment

(Starting in fiscal year 2008-2009)

Roughly $20,000 per year not including ship and field costs	$100K

Data processing and archiving costs are not included

(7) Miscellaneous

Travel, computing, general supplies, etc.	$20K/yr	$80K
