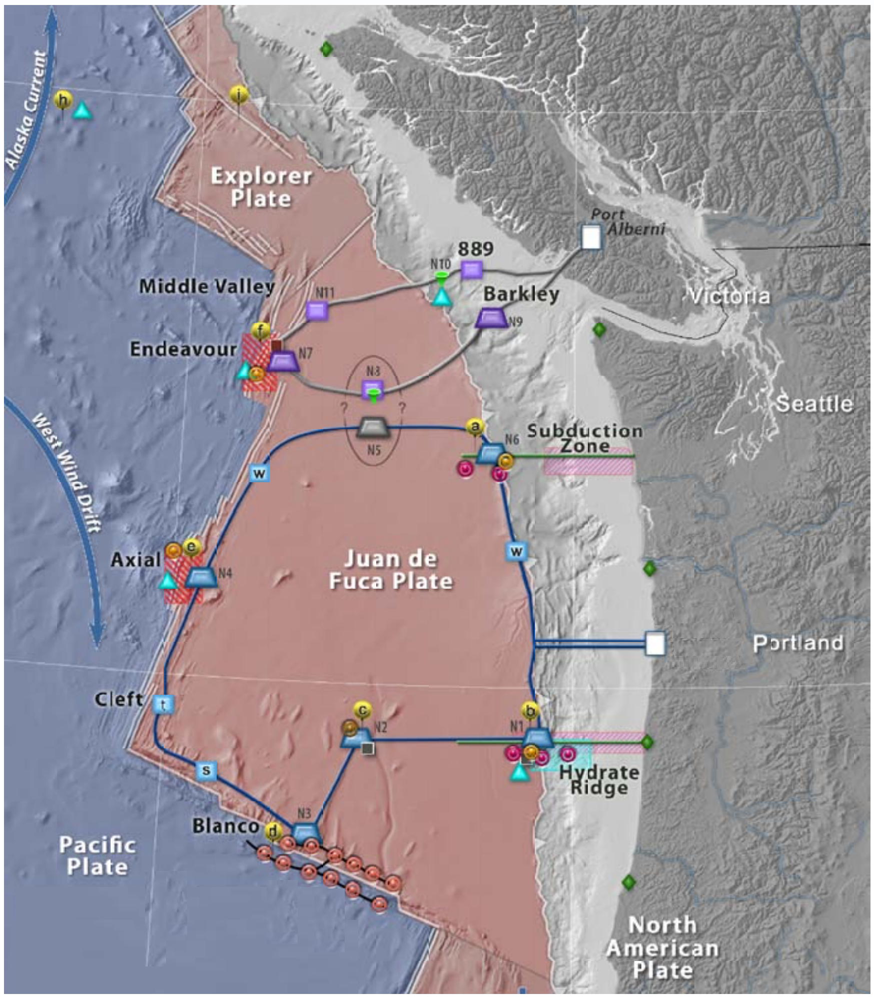
DRAFT 2.0

Regional Cabled Conceptual Network Design for ORION's Ocean Observatories Initiative (OOI)



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Joint Oceanographic Institutions
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CORE

Draft 2.0 Regional Conceptual Network Design
19 JUNE 2006

This draft Regional Conceptual Network Design was constructed by the efforts of members of the following ORION committees and the ORION Program Office

ORION Science and Technical Advisory Committee

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Janice McDonnell (Rutgers)
Carrie McDougall (NOAA)
Mike Wright (DLESE)
Karen Young (Freelance writer)

ORION Program Office

Kendra Daly, Program Director (USF)*
Stu Williams, OOI Project Director
Peter Milne, Director, Ocean Observing

ORION Engineering Committee

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Oscar Schofield (Rutgers)
Robert Weller (WHOI)

Key to Sub-Committees:
CSO: Coastal Scale Observatory
RCO: Regional Cabled Observatory
GSO: Global Scale Observatory
**D&I Workshop Organizing Committee*

ORION REGIONAL CABLED OBSERVATORY CONCEPTUAL DESIGN

DOCUMENT CONTROL SHEET

Contact for Revisions: Deborah S. Kelley, University of Washington; Keith Raybould; MBARI; William Wilcock, University of Washington

RECORD OF ISSUE

Issue	Date	Document Status
DRAFT 1.0	15 March 2006	Initial draft based on RFA's, ORION RCO subcommittee recommendations, iterative PI, RCO and Engineering Subcommittee discussions
DRAFT 2.0	19 June 2006	Second draft revisions based on community recommendations from ORION Design and Implementation Workshop March 27, 2006; STAC meeting May 1-3, 2006; operations and Maintenance Meeting, April 26-27, 2006; STAC Engineering subcommittee meeting May 3-4, 2006

REVISIONS

Date	Nature of Change
March 2006	Draft 1.0 Changed >> $150M design from 2,000 km backbone cable, 12 primary nodes, 12 vertical profilers, connection to Stage 1, and significant secondary infrastructure to 1,750 km backbone cable, 5 primary nodes, 6 branching units, 7 vertical profiling moorings, 2 buoyed profiling moorings, and limited secondary infrastructure.
March 18, 2006	Reformatted ORION Program Office
May 2006	Draft 2.0 1750 km backbone cable reduced to 1,490 km backbone. 6 branching units to 3 branching units. 7 cabled vertical profiling moorings to 6. Reduced scope of secondary infrastructure. Added $2M in core instruments.
	Changed surface layed cable cost only
	Removed ship and ROV costs to install secondary infrastructure
	Node 2 copper connectors added
	Node 6, Subduction Zone, eastern benthic node removed and associated cable
	Node 7, Endeavour site 50% reduced in cost and infrastructure
	Profiler mornings provided $125K ea core instrumentation
	Core seismometers, pressure sensor and hydrophone added to Nodes 1-4 and Node 6 ($1M)
	Middle Valley infrastructure removed

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CONCEPTUAL NETWORK DESIGN FRAMWORK FOR THE REGIONAL CABLE OBSERVATORY

1.0 Introduction

Oceans are central to global, regional, and local human habitats and ecological systems. Indeed, processes within the world's ocean basins are a critical determinant for the quality of life on Earth. The oceans modulate short- and long-term climate, influence food production on continents, and generate hazards such as storms, earthquakes, and tsunamis. The US benefits tremendously because of its access to the oceans. Within the US, contributions from ocean- and coastal-related activities and coastal watershed counties amount to ">$4.5 trillion annually, fully half of the nations' gross domestic product, accounting for some 60 million jobs"[1].

Because of the importance of our oceans world wide, as the world's human population continues to increase, one key to our survival will be improvement of our ability to detect, understand, and forecast changes in the complex and extensive interactions among the atmosphere, the oceans, and the underlying seafloor. New technologies, reliable data, and powerful new modeling and visualization techniques that allow integration and interpretation of vast and diverse data sets are required to meet the global challenges that will soon be faced within the oceans.

The Regional Cabled Observatory (RCO) component of the National Science Foundation's Ocean Observatories Initiative (OOI) provides an unprecedented step toward meeting these challenges. The RCO is a plate scale experiment of unparalleled scope that is focused on integrated investigations spanning the subseafloor biosphere to the hydrosphere, the entire ocean water column, and the sea surface-atmosphere interface (Fig. 1). Spatially associated with the Juan de Fuca tectonic plate, the RCO will enable in-depth study and decadal time–series observations of globally significant oceanographic processes expressed regionally -- including biogeochemical cycles, fisheries and climate forcing, tsunamis, ocean dynamics, life in extreme environments, and plate tectonic processes. Dense spatial and temporal sampling, coupled with interactive capabilities will allow the Ocean Science community for the first time to make fundamental measurements and exciting discoveries about processes that occur over centimeter to 100's of kilometer distances, and at seconds to decade time scales.

This thirty-year experiment, which includes ~2000 km of instrumented electro-optical cable on the seafloor and thousands of meters of instrumented moorings reaching from the seafloor to the oceans surface, will forever transform the way we view and study our planet, the kinds of questions we can ask, and how we educate and interact with researchers, students and the public. The RCO is also at the forefront of a transformation in the sciences that is opening a new era of discovery on our planet. Traditionally, the oceans and seafloor have been studied with ships, satellites, and instrumented moorings. Ships, however, can only be in one place at one time, and satellites mostly provide information about the shallow-most portions of the ocean. Autonomous instruments are limited by battery life and power requirements. Yet many of the most powerful and fascinating processes in the oceans take place in episodic or intermittent fashion: massive storms, erupting submarine volcanoes, giant earthquakes, marine mammal feeding and hunting patterns, phytoplankton blooms in the upper ocean, and releases of microbes that live in the rocks beneath the seafloor and thrive on a diet of volcanic gas.

[1] *US Commissions on Ocean Policy "An Ocean Blueprint for the 21st Century", http://www.oceancommission.gov/*

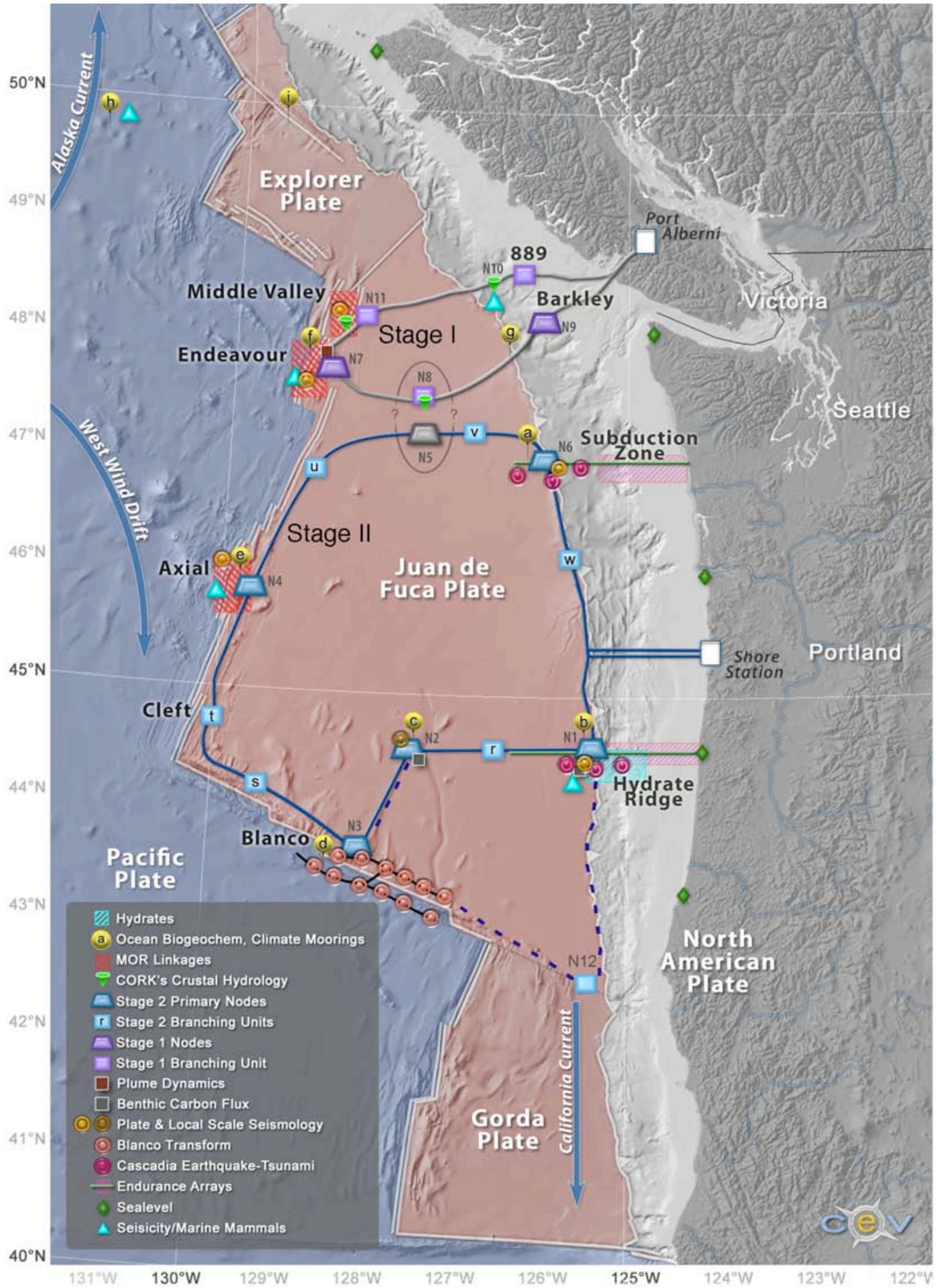


Figure 1. Regional cabled observatory integrated experimental design. This plate scale experiment, which allows integration of global, regional and coastal observations, is of unparalleled scope: it will forever transform the way that we view and study our planet, the kinds of questions we can address, and how we educate and interact with researchers, students and the public. This design, which includes 5 primary nodes, 6 branching units for future expansion and 9 full water column moorings, will provide unprecedented access to our oceans in real-time by the global community through the internet. Future expansion may also include a southern node or branching unit at the southern end of the plate (N12) to accommodate additional seismic and water column experiments.

We have not studied these processes or events well because the tools at hand are not well suited to the task. Understanding and prediction depend upon being present throughout the ocean, all the time, with the capacity to detect, measure, sample and respond to these rapidly evolving, energetic events. The RCO will enable this type of remote, real-time, long-term interactive presence in the oceans and it offers a four-dimensional approach -- the three spatial dimensions plus time -- to the study of earth and ocean processes. Sensor networks, seafloor cameras, and interactive experiments will be easily accessible in real-time via the Internet to researchers, educators, students, policy makers, and the public around the globe. Such unprecedented access will make the last frontier on Earth--the oceans--accessible to the global community. Public access to science will be transformed by enabling cyber-participation in the journey of scientific exploration and discovery, promoting a strong sense of stewardship for our planet.

1.1 Linking the RCO, Global and Coastal Components of the OOI and EarthScope

The RCO has been in the planning stage for nearly a decade including >10 workshops and meetings, which have defined many of the scientific and technical elements that can be pursued with this type of observatory (Appendix 1). In October 2003, an NSF-supported RECONN workshop identified the Northeast Pacific as the location of the first Regional Cabled Ocean Observatory (www.orionprogram.org/documents.default.html). As a consequence, over the coming decade, the North Pacific is the primary area where opportunities exist to develop integration among all three components of the OOI - global, regional, and coastal. For example, Station PAPA (50°N, 145°W)(Fig. 2) in the N.E. Pacific is one of five highest priority acoustically-linked buoy sites for the global component of the OOI. PAPA is designed to study global circulation, biogeochemistry, air-sea flux, and geophysical processes at high latitudes. In addition to Station PAPA, the HOT site (Hawaii Ocean Time-Series Station ALOHA; 23.45'N, 158°W)(Fig. 2) has been targeted as an important RCO-Global connection for enabling acoustic investigations. The Pacific Northwest Endurance Arrays at two locations along the Washington-Oregon margin are high priority coastal sites key to studying linkages among chemical and biological processes, carbon flux from the coast to the deep sea, and climate-change (Figs. 1 & 2). One of the coastal arrays will be cabled allowing fundamental transport and biogeochemical measurements to be made from a shallow coastal environment, across the continental slope, to the mid plate. Nowhere else in the world does this capability exist. In concert, PAPA, HOT, the RCO, and the Pacific Northwest coastal arrays will allow for the first time investigation of processes operative at an ocean basin to coastal scale.

Coupling of the RCO and the NSF's EarthScope (http://www.earthscope.org/) geophysical observatory will significantly extend the capabilities of both these programs to understand active processes associated with formation and destruction of the Earth's lithosphere (Fig. 3). This recently funded continental geophysical observatory is designed to investigate the structure and evolution of the North American continent and the processes controlling earthquakes and volcanic eruptions. Networks of geophysical instruments will be distributed along the west coast, stopping at the "high tide mark". The RCO will extend this geophysical array westward across the subduction zone and Juan de Fuca Plate to where some of the youngest, hottest rocks on our planet are formed, the Juan de Fuca Ridge. In concert, these two NSF-funded observatories will allow scientists for the first time to examine outstanding questions concerning the linkages between continental and oceanic earthquakes and possible plate-wide perturbations in the subsurface hydrology of the oceanic crust and accretionary margins, the impact that these events

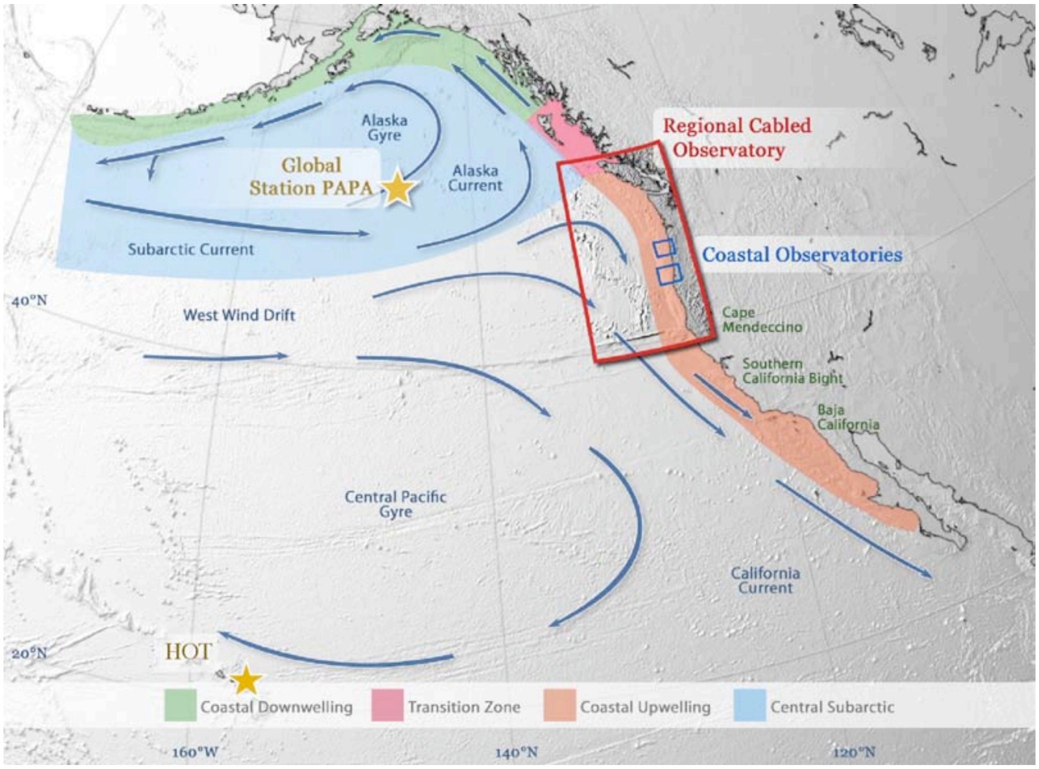


Figure 2. Spatially associated with the Juan de Fuca Plate, the RCO will enable in-depth study and decadal time-series observations of globally significant oceanographic processes that are expressed regionally. It is the primary area where opportunities exist to develop integration of all three components of the OOI - global, regional, and coastal observatories. In concert, the global Stations PAPA and HOT and the Pacific Northwest coastal arrays will allow unprecedented investigation of oceanic physical and biogeochemical processes. In concert, these three systems will contribute to all of the grand challenges identified in the NSF's Ocean Sciences at the New Millennium Report.

have on degassing of methane from gas hydrates and slope destabilization, and the connections between seismic events, nutrient outflow, and microbial productivity.

1.2 Significant Leveraging Opportunities Significant national and international leveraging opportunities are expected for the RCO and OOI in general. An excellent example is provided by the University of Victoria, Canada, which has partnered with the NSF for the implementation of the RCO in two stages. In 2003, the Canadian Foundation for Innovation and British Columbia Knowledge Development Fund announced CAN $62.4 million in funding to the University of Victoria for NEPTUNE Canada (http://www.neptunecanada.ca/) to establish a northern loop (Stage 1) of the RCO (Fig. 4). In 2005, the University of Victoria requested an additional CAN $20.0 million from funding agencies to achieve the full scope of the observatory. Additional funding would allow the cabled array to have up to six *instrumented* nodes, rather than the two instrumented nodes and two unpopulated node bases that are now funded (Fig. 4). In the US, the W.M. Keck Foundation provided $5M support for development of sensors key to studying submarine seismic and hydrothermal processes and implementation of two proto-NEPTUNE observatories on the Juan de Fuca Plate (http://www.neptune.washington.edu/research/); this year they also provided funds for 10 seafloor seismometers ($1M) that are the centerpiece of an

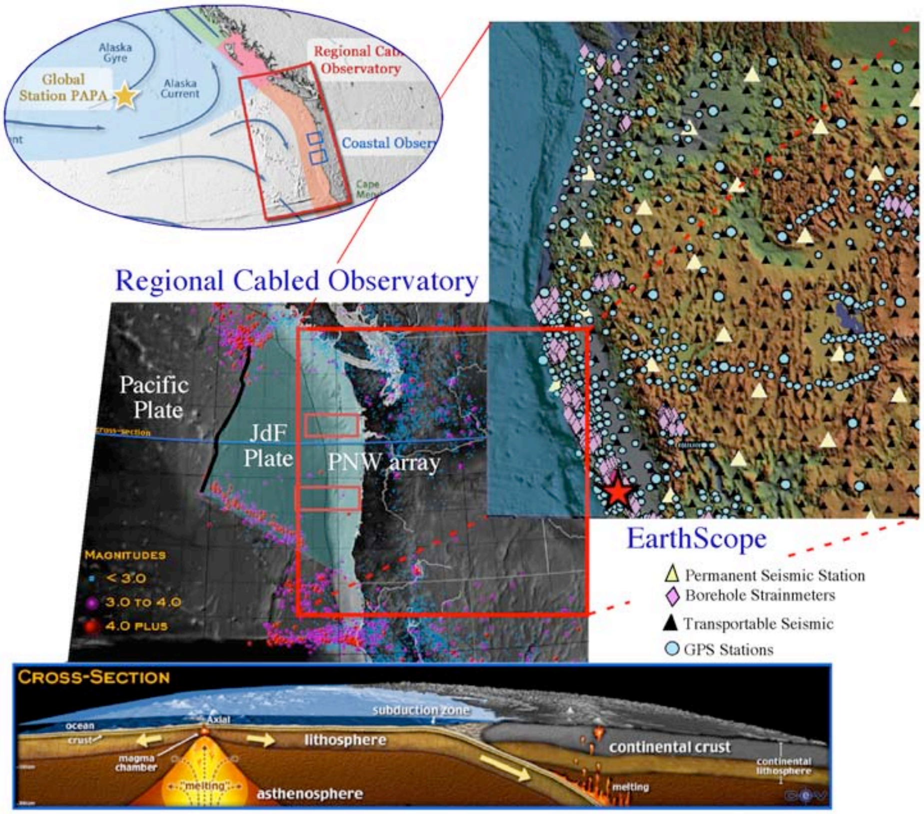


Figure 3. The movement and interaction of tectonic plates gives rise to many of the Earth's most dramatic and hazardous geologic features. In the Pacific Northwest, the processes accompanying the creation of the oceanic Juan de Fuca plate and its eventual subduction beneath North America result in mountain building, damaging earthquakes. tsunamis, and explosive volcanism. Seismology is one of the principal tools for understanding the causes of such geologic hazards, as well as the processes responsible for the formation, evolution, interaction, and destruction of tectonic plates. Coupling EarthScope and the RCO will allow unprecedented studies to be completed on a remarkable array of plate tectonic features, including all major types of oceanic plate boundary and a continent-ocean convergent margin capable of destructive earthquakes.

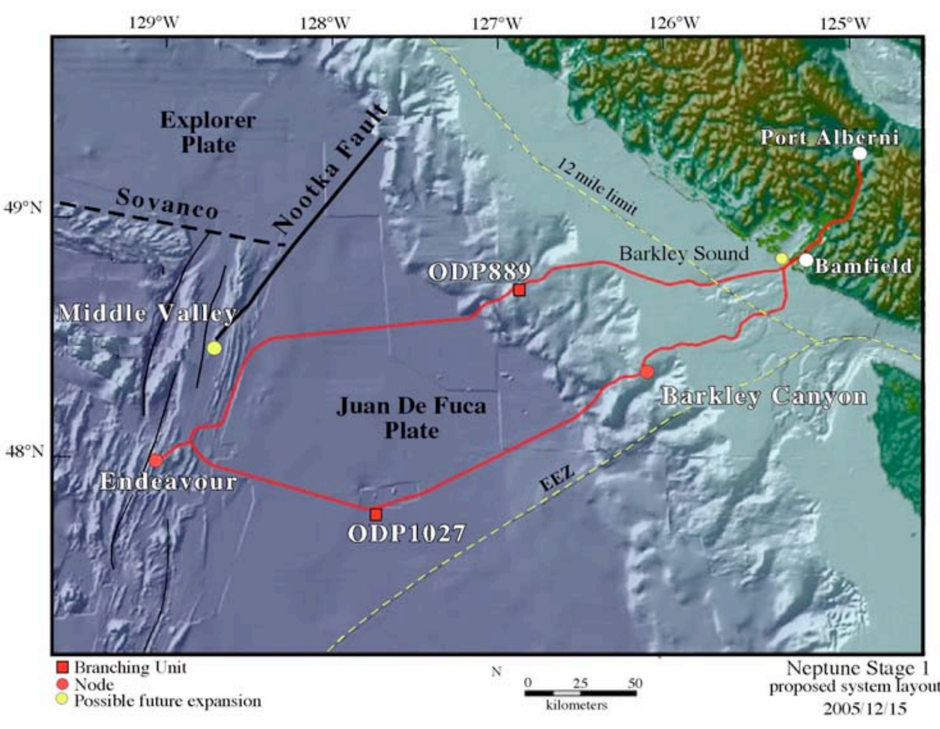


Figure 4. Proposed cable route and observatory sites for Neptune Canada. The Endeavour, Barkley Canyon and Barkley Sound sites will be instrumented in 2007-2008. Unpopulated nodes will be deployed near Ocean Drilling Program Sites 1027 (ODP1027) and 889 (ODP889), allowing for nodes and instruments to be installed without disruption as funds become available. The University of Victoria is currently seeking additional funds to instrument the nodes at the ODP sites, and to place additional nodes at Middle Valley and Folger Passage near Bamfield. Figure courtesy of Neptune Canada.

RCO experiment proposed for the Blanco Fracture Zone. In addition to these significant funding efforts, there is also the potential to integrate the RCO with several of the west coast components of the Integrated Ocean Observing System [for example, the Northwest Association of Network Ocean Observing Systems (www.nanoos.org)]. This document (DRAFT 2.0) lays out plans for Stage II of the RCO.

1.3 History of the RCO Conceptual Network Design

In response to the NSF Request for Conceptual Science RFA's, sixteen proposals that included > 175 participants were submitted in May 2005 focusing on the RCO and closely related studies (Appendix's 1&2; also see http://www.orionprogram.org/RFA/default.html). In late September 2005 an NSF-appointed panel indicated that 9 of these proposals were ready to go forward, 2 as needing some additional development, and 5 as preliminary. In October 2005, a subcommittee of the Science and Technical Advisory Committee (STAC) was formed at an ORION meeting in Washington D.C. to summarize the proposals in terms of their location and science and technological requirements, and to prioritize the experiments based on a target of $90M allocated to the RCO efforts. Subcommittee members include:

Deborah Kelley	Co-Chair	University of Washington
Kevin Brown		Scripps Institution of Oceanography
Keir Becker		University of Miami
John Horne		Applied Physics Lab, University of Washington
Charlie Paull		Monterey Bay Aquarium Research Institute
William Wilcock	Co-Chair	University of Washington

Keith Raybould (MBARI) played a central role in the engineering design efforts and costing out the infrastructure. At the October 2005 meeting, all 16 proposals were assigned a "watch dog" member of the RCO subcommittee, and a liaison from the Sensor and Engineering committees (Appendix 2). Working with the PI's and Sensor and Engineering Committee liaisons, preliminary Science User Requirement summaries (SUR's) were completed in January 2006 for all proposals recommend as ready to go forward by the NSF panel. The SUR's are included in DRAFT 1 of the RCO CND online at http://www.orionprogram.org/di_workshop.html/. Based on these documents, two *preliminary* integrated network designs for Stage II were drafted that included $150M and $107.4M infrastructure options. In March 2006, a representative subset of PI's from the RFA's and engineers met to finalize the second preliminary design. This $107.4M design (DRAFT 1.0) was presented at the Design & Implementation community workshop in Salt Lake City April 2006 (http://www.orionprogram.org/di_workshop.html). Key recommendations from the community were considered for implementation into DRAFT 2.0 (e.g. extension of the backbone cable south to the Gorda Plate). In April 2006, representatives from the National Deep Submergence Facility, Monterey Bay Aquarium Research Institute, and the Canadian Scientific Submersible Facility met with a subset of proponents to define Operations and Management (O&M) costs for the RCO. O&M costs were refined over the next 2 months. At a meeting of the STAC in May 2006, the RCO design was again modified in an effort to approach the $90M target budget for the RCO. The ORION Engineering Committee met for an additional two days to obtain consistent infrastructure language and costs across all 3 components of the OOI. This document (DRAFT 2.0) provides science drivers for an ambitious design should additional funds be available (Section 2; Fig. 1) and a design that meets the

~$90M budgeting target for the RCO infrastructure based on science mission requirements, associated costs, and priorities based on science (Sections 3-7; Fig. 8). This design is under continuing review and modification by the STAC, the ORION Observatory Steering Committee, and the ORION Project Office.

2.0 A Regional Plate Scale Experiment Science Drivers

2.1 Oceanic Physical and Biogeochemical Processes

The location of the first RCO, spanning the boundary between subpolar and subtropical gyres at the eastern edge of the North Pacific (Fig. 2), provides an unprecedented opportunity to measure a broad continuum of temporal and spatial interactions among oceanic physical and biogeochemical processes. Full water column measurements have been proposed to contribute to three of the grand challenges identified in the NSF's Ocean Sciences at the New Millennium Report (2001) (http://www.joss.ucar.edu/joss_psg/publications/decadal/): ocean turbulence and dynamics, the role of the ocean in global climate, and non-equilibrium ecosystem dynamics. With a vertical dimension provided by a network of instrumented cabled moorings at nine initial sites, the RCO will enable interdisciplinary observations of water-column processes offshore of the continental margin in a region strongly forced by air-sea interaction, by shelf-slope interactions with the deep sea, and by coupled atmospheric/oceanic phenomena acting to produce variations in North Pacific circulation over gyre scales.

Moored profiling capability throughout the water column at each site, coupled with acoustic tomography measurements between sites, are vital to advancing knowledge of ocean turbulence, ocean dynamics and climate studies, and to assessing their impacts on embedded marine communities. Long-term simultaneous measurements of physical, chemical, and biological parameters are crucial if we are to advance from co-relational observations towards an understanding of the mechanisms that lead to ecosystem change and the role of biological feedbacks. Many of the principal sensors (e.g., acoustic and optical imaging systems) needed to investigate key science questions require the high power, high bandwidth, and precision timing that the RCO will provide. Near real-time data and two-way communication will permit adaptive sampling of episodic events and provide data for assimilation into operational biophysical models. Spatially distributed and long-term sustained time-series will resolve variability and trends in multidisciplinary processes extending from the air-sea interface through the water column to the sea floor. The RCO will provide the data necessary to increase our understanding of dynamic physical/biogeochemical systems, allowing models to improve the predictive skills that will be essential in a changing climate.

2.2 Biogeochemical Cycles and the Benthic Community

The deep sea (depths >1000 m) represents the largest portion of the earth's surface. However, our knowledge of biogeochemical cycling in the ocean generally decreases with increasing depth. There have been many attempts to compare the sinking flux of particulate matter in the water column with processes in the sediments on a variety of time scales. However, given the high variability and low resolution of measurements of biogeochemical processes on a variety of spatial and temporal scales, it has been difficult to interpret the coupling between a pelagically-derived food source and its utilization by the benthic community. This coupling is an integral part of the biological pump, which encompasses the export of phytoplankton production (i.e. carbon fixation) to the deep sea and, ultimately, storage in deep-sea sediments. However, the biological pump is a complex process, mediated by decomposition, consumption, and particle dynamics in the water column and at the sea floor. The biological pump, although seasonal in temperate and polar regions, is notoriously episodic due to phytoplankton blooms impacted by upper ocean physical and chemical processes. Long time series studies with high temporal resolution are essential in examining this pump, especially the coupling of pelagic and benthic processes. The commitment of energy, resources and time to such long-term measurements is great and continuity in sampling is essential to avoid missing crucial events required to interpret the time-series data in conjunction with climate and upper ocean changes. Observatories deployed in strategic locations will enable a better understanding of the complex interplay between physics, chemistry, and biology during episodic events extending from the atmosphere, through the water column, and to the sea floor. The proposed installation of a cabled network in the NE Pacific across the continental margin will provide unparalleled opportunities to concurrently study the relationships between temporally-varying particulate fluxes and benthic community processes on relevant time scales from slope to abyssal depths in real time. The pelagic and benthic monitoring network on the RCO will provide real-time, interactive capability to assess pelagic/benthic coupling across the continental margin with sampling frequencies from hours to years for correlation with regional surface remote sensing and climate indices.

2.3 Pelagic Marine Ecosystems

Macroscopic biomass in pelagic marine ecosystems is composed of mammal, fish, and invertebrate aggregations. Describing and understanding distributions, abundances, fluxes, community structure, and energy transfer of biological aggregations are critical to biological research and for resource management. High-density aggregations are biologically important because animals may be concentrating to forage, spawn, or to avoid predators.

Potential transforming biological science opportunities can be addressed by the RCO. With the exception of mesopelagic fishes and squid, the majority of macroscopic biota is found on the continental shelf and slope. Continuous power, control, and data offload capabilities provided by the RCO and coupled Pacific Northwest Coastal Array will facilitate distribution and density observations of aquatic organisms over a broad range of temporal scales, and biological responses to physical episodic events and longer-term trends. Active acoustic sensors will enable tracking of fish and invertebrate fluxes as a function of time, stationary assessment of biological resources, species-specific habitat preferences, biological responses to physical events (e.g. upwelling, tidal fluxes), and temporally scale-dependent distribution patterns.

The flux of biomass has not been traditionally quantified over large spatial and temporal scales. Yet, long-term sensor deployments are central to investigations into the kinematic processes of migration, dispersal, and the coupling of biomass flux to environmental gradients. The RCO provides a fundamental change from conventional biological surveys and stationary observing systems because of its potential for wide-area spatial and long-term temporal sampling by networked sensor arrays in real time. In concert, these arrays offer a unique opportunity to concurrently examine linkages among ecosystem processes that range from physical oceanography (wind stress, currents, mixing), through primary and secondary production, to feeding ecology of top predators.

2.4 Seismic Activity and Stress Propagation

The RCO presents an exceptional opportunity to observe seismogenic failure throughout a tectonic plate with known boundary conditions (Fig. 3), specifically for understanding inter-linked and temporally variable processes across the plate. RCO data will constrain temporal and spatial variations in stress propagation, the styles and causes of intra-plate deformation and its relation to plate boundary failure, and ultimately the coupling of forces across plate boundaries that controls site-specific phenomena as well as regional-scale tectonics. By monitoring radiated energy over the full seismic spectrum we will also discover previously unknown signals, much in the same way that land-based networks have recently discovered episodic-tremor-and-slip phenomena along the megathrusts in Japan and Cascadia. A plate-scale seismic array will also accelerate studies of the structure and evolution of the lithosphere-asthenosphere system by providing new opportunities to image the deep and shallow structure that accompanies plate formation, evolution and subduction. The key design criterion is to have plate-scale coverage with a relatively even distribution of sites.

2.5 Crustal Hydrology-Geobiology-Plate Scale Strain

The oceanic crust is the largest fractured aquifer system on the planet, and it potentially harbors a biosphere that rivals that on the continents. Thermally driven fluid circulation through the oceanic lithosphere profoundly influences the physical, chemical, and biological evolution of the crust and ocean. Although much work over the last 30 years has focused on hot springs along mid-ocean ridges, global advective heat loss from crust older than 1 million years is more than three times that at the axes. Ridge-flank circulation generates enormous solute fluxes, profoundly alters basement rocks, supports a potentially vast subseafloor biosphere and continues throughout the crust to the trench, influencing the thermal, mechanical, and chemical state of subducting plates. Borehole experiments provide the only means to directly study physical, chemical, and biological processes active in the subsurface. The RCO offers an unparalleled opportunity to examine the hydrological connectivity of the oceanic crust and crust strain at a plate scale. The Jaun de Fuca Plate hosts the highest density of Ocean Drilling Program (ODP) and Integrated Ocean Drilling Program (IODP) sites of any place within the world's oceans: a high number of CORK (www.joilearning.org/schoolofrock/PDFs/CORK_review.2005.PDF) hydrogeological observatories are already in place and more are planned. Observations form existing CORK's on the Juan de Fuca Ridge measured pressure transients resulting from seismic and non-seismic tectonic strain events from up to ~ 100 km away from the CORK's. The combination of access to the sub-seafloor via sealed boreholes and a cable offers an unprecedented opportunity to study many fundamental questions about the dynamics of the oceanic lithosphere and the subseafloor hydrosphere.

2.6 Crustal Formation and Life

Scientific studies of mid-ocean ridges are motivated by three overarching goals of understanding: (1) the geological processes that form and age the oceanic lithosphere; (2) the role of mid-ocean ridge volcanoes in fostering diverse and productive biological communities above and below the seafloor; and (3) the fluxes of heat, chemicals, and biomass across the seafloor and their effect on the overlying ocean. Investigations that address these goals are inherently multidisciplinary, because they aim to unravel the complex interaction of numerous physical, chemical and biological processes. Further advances in mid-ocean ridge studies are increasingly dependent on our ability to collect long-term, high frequency observations using diverse networks of sensors and samplers. The major volcanic and tectonic events that create the oceanic crust and modulate the fluxes across the seafloor and biological communities are inherently episodic on decadal timescales and are also short-lived. The only way to capture these events is to maintain a long-term monitoring capability at a number of sites with high probability for tectonic or magmatic activity. It is also becoming increasingly apparent that the effects of magmatic and tectonic events are not only limited to the near field. Stress changes induced by fault motions and the passage of seismic waves from distant earthquakes may trigger earthquakes and perhaps even volcanic eruptions. These punctuated events have been shown to perturb hydrothermal systems. Seafloor observatories are equally important for understanding the progressive changes in hydrothermal systems and the biological communities that occur between major events. Seafloor observatories can be used to examine shorter-term hydrothermal perturbations such as those arising from tides. A high-power, high-bandwidth cabled observatory will facilitate controlled experiments such as the introduction and monitoring of tracer chemicals to deduce paths of subsurface hydrothermal flow or biological experiments to understand the factors controlling biological succession, community evolution and activity.

2.7 Heat and Chemical Fluxes

Knowledge of the volume and heat flux from hydrothermal vents can yield important information about the evolution of hydrothermal systems and their contribution to the chemical and thermal budgets of the oceans. The objective of the integrated acoustic imaging and scintillation experiment at the Endeavour Segment is to monitor hydrothermal plume properties (volume and heat fluxes, bending, entrainment, particle distribution, turbulence) and partitioning between plume and diffuse flow on time scales ranging from hours to years. These studies will advance our understanding of the linkages between hydrothermal flow to oceanographic tides and currents, geological-geophysical processes (earthquakes, faulting, igneous intrusive-extrusive activity), and biological (micro- and macro- blooms and dispersion) events. Initially the experiment will be on the scale of an individual vent cluster, but this can be expanded to an entire field with the addition of acoustic tomography.

2.8 Ridge-Transform Interactions: The Blanco Transform Fault

Tectonic plates are the fundamental building blocks of our planet, with boundaries defined by subduction zones, mid-ocean ridges, and transform faults. The Blanco Transform fault observatory will be the first to provide long-term measurements of seismicity, deformation, and possibly fault-zone fluid discharge over multiple earthquake cycles along this important plate boundary. This will allow us to separate the effects of geological heterogeneity from stress-state, a fundamental tradeoff that limits studies of continental faults with longer recurrence intervals. Moreover, owing to the well-characterized plate tectonic boundary conditions and compositional uniformity of oceanic lithosphere, the seismogenic properties of the Blanco Transform can be directly compared to realistic geodynamic models of fault thermal structure and seismogenesis.

The Blanco Ridge segment has ruptured repeatedly in magnitude (M) 6.1–6.5 earthquakes (5 events since 1967), suggesting a recurrence time of about 10 years! Thus over the 30 year life span of the RCO, we expect multiple M6 earthquakes to be recorded. Such a dataset would be unprecedented in the earthquake science community. Large earthquakes on oceanic transform faults, and specifically the Blanco, are usually preceded by foreshock sequences in the last few hours before the mainshock at rates that are an order of magnitude higher than in continental settings. We hope to determine the pre-earthquake process, most likely fluid flow or aseismic fault slip, which triggers the incredibly abundant foreshock activity on oceanic transform faults. This will also be the southernmost site in the plate-scale seismology network, the Cabled Water Column Moorings, and possibly the acoustic arrays described in the introduction.

A spectacular example of the linkages among seismic activity on the Blanco and hydrothermal activity on the Juan de Fuca Ridge was an 18ºC drop in high temperature vent fluids on the Cleft Segment following the June 2000 M 6 earthquake, which took place on the westernmost segment of the Blanco. This earthquake was preceded by a ~16 hour long foreshock sequence that probably reflected fluid migration within the fault-zone. Additionally, the first ever documentation of an active high-T vent field and biological community within a transform fault zone was located here. Thus, the interactions between the transform fault and the Cleft Ridge segment and hydrothermal/biological sites are expected to be a significant target of study during the lifetime of the RCO. We do not yet know how far the impact of such large earthquake events are "felt" along the Juan de Fuca Ridge system.

2.9 Subduction Zone Seismic Events and Tsunamis

The Cascadia subduction zone has a well-documented history of large tsunamigenic earthquakes. Historical and geologic data indicate that the Cascadia megathrust last ruptured in AD 1700 and experiences large earthquakes at intervals that vary from about 200 to 1200 years: large events are to be expected in the future. Several lines of current research on subduction zones worldwide are leading to new hypotheses about how strain accumulates and is released along subduction zone thrust faults in response to plate tectonic forces. Among interesting new observations are tremor-like seismic events that correlate with aseismic slow slip events that appear as sudden displacements in continuous GPS data. These have been well documented onshore in Cascadia; the slow slip events have been interpreted to represent slip on the plate boundary that occurs down dip from the locked zone that is storing strain prior to the next big earthquake, and the seismic tremor is thought to reflect motion of fluids. Correlations between forearc basin structure and co-seismic rupture areas in other subduction zones with historic activity suggest strong geologic controls on which parts of the megathrust accomodate plate motion through large, infrequent events and which are characterized by fault creep and microseismicity. Similar geologic variations are observed in Cascadia; if these correlations can be confirmed, they may provide a basis for developing future early warning systems. Offshore instrumentation is also needed to determine the updip extent of the seismogenic zone, information that cannot be resolved from onshore stations but which is critical for understanding tsunamigenic potential. A network of offshore seismic and geodetic stations to monitor strain accumulation and release along the Cascadia subduction zone has the potential to provide critical new data for resolving the extent of the locked zone, the rate of strain accumulation and the physical mechanisms controlling stress accumulation (locking) and strain release in this and similar systems.

2.10 Gas Hydrate Formation: Hydrate Ridge

A significant amount of the methane near the surface of the Earth is locked into gas hydrates in the shallow sediments on continental margins. The hydrates may act as a capacitor in the carbon cycle by slowly storing methane that can be suddenly released into the ocean and atmosphere. Hydrate Ridge, in the central Cascadia accretionary complex, is one of the best-studied gas hydrate deposits. Vigorous seafloor venting and formation of gas rich hydrate deposits near the seafloor have been documented here through ODP drilling during Legs 146 and 204 and through a series of seafloor studies using submersibles and ROV's. These studies have provided a good understanding of how gas hydrate is distributed in marine sediments and the processes that lead to heterogeneity in this distribution. The subsurface has been imaged with 3D seismic data, which define a focused plumbing system that provides a clear target for observatory instruments to define the temporal evolution of this system, determine material fluxes from the earth into the ocean and understand biogeochemical coupling associated with gas hydrate formation and destruction.

The stratigraphically-controlled plumbing system at Hydrate Ridge contrasts with the gas hydrate system explored on the northern Cascadia margin (Site 889) during ODP Leg 146 and IODP Expedition 311. Here, fluid flow appears to be controlled by structures that cut across stratigraphic horizons. The central and northern Cascadia margins also provide a strong contrast in lithology, with much greater abundance of coarse-grained sediments in the north, which affects the nature of gas hydrate deposition. Establishment of observatories at both sites should, therefore, lead to a comprehensive understanding of gas hydrate processes as a function of lithology, stratigraphy and structure.

3.0 Cost Estimates Used for the RCO

This section describes the processes used during the February and May 2006 ORION Engineering meetings to determine the preliminary cost estimates for developing the RCO. A combination of engineering estimates and actual costing data for different RCO components were gathered from NEPTUNE Canada (http://www.neptunecanada.ca/), MARS (http://www.mbari.org/mars/), VENUS (http://www.venus.uvic.ca/) and other programs. In the following sections, the components that make up the RCO are defined, as are their associated costs. Capabilities and costs are summarized in Table 1.

3.1 Ship and Remotely Operated Vehicle (ROV) Installed Cable

The backbone and primary benthic nodes will be installed with a ship. The cable may include repeaters. Estimated costs are $20k/km installed. Ships may also be used to lay long extension cables (>15 km armored cable) at a cost of $17k/km. For short run cables and in areas where high precision lays are needed, an ROV will be used. Costs for these runs are $10k/km.

3.2 Primary Backbone Node $2.5M ea (cost uncertainty ±10%)

An RCO Primary Node provides the connection between the backbone cable, secondary nodes (medium voltage = MV), and the RCO instruments (Fig. 5). Its function is to provide a source of regulated energy to power instruments and a connectivity that enables the instruments to receive instructions from the shore based controller and transmit data back to the rest of the system. The node consists of a rugged trawl-resistant frame that houses pressure cases, bulkhead connectors and an integral electronics package. A set of wet-mateable bulkhead connectors is included to handle the routing of extension cables between the node and the different instrumentation packages. Under the current design, each of the Stage II nodes would have the following characteristics:

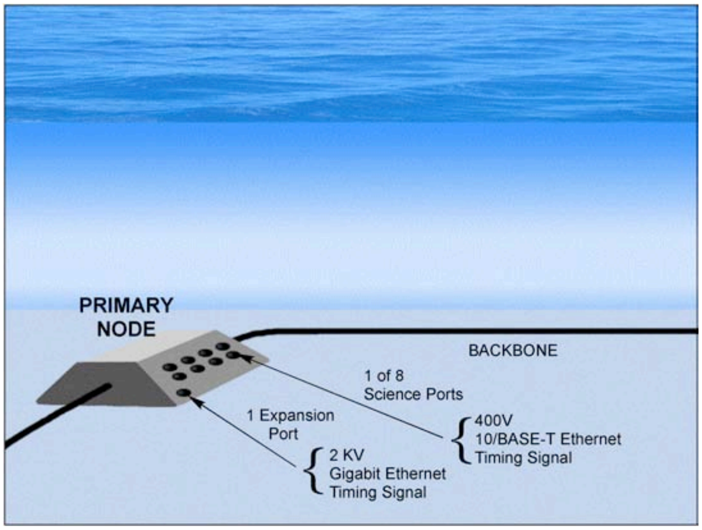


Figure 5. Primary Node Characteristics

A) Up to 10kW, UW mateable connector to extension cable surface laid
B) 2 kV-10kV (only 2 kV needed, actual V depends on power converter design in backbone node power system).
C) Single termination from main cable
D) 8-10 ports, 400V, 48V, precision timing signal
E) Secondary nodes could be daisy chained

3.3 Medium Voltage Benthic Node (MV) $1.5M (cost uncertainty ±30%)

Medium voltage nodes in this document are also referred to as secondary nodes (Fig. 6). They are connected to the backbone via the primary node and an extension cable that can be up to 100 km in length. They are a simpler version of the primary backbone node. Depending on where they are located they may not need to be trawl resistant (i.e. >~1500 m water depth). Under the current design, each of the MV nodes would have the following characteristics:

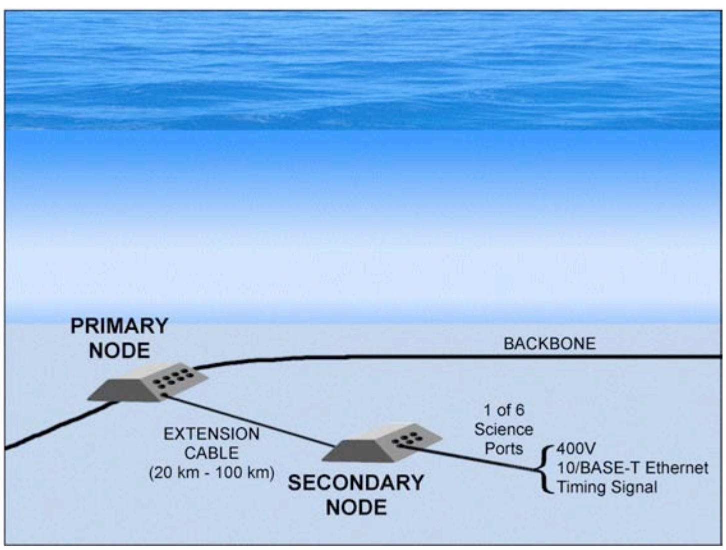


Figure 6. Secondary Node Characteristics

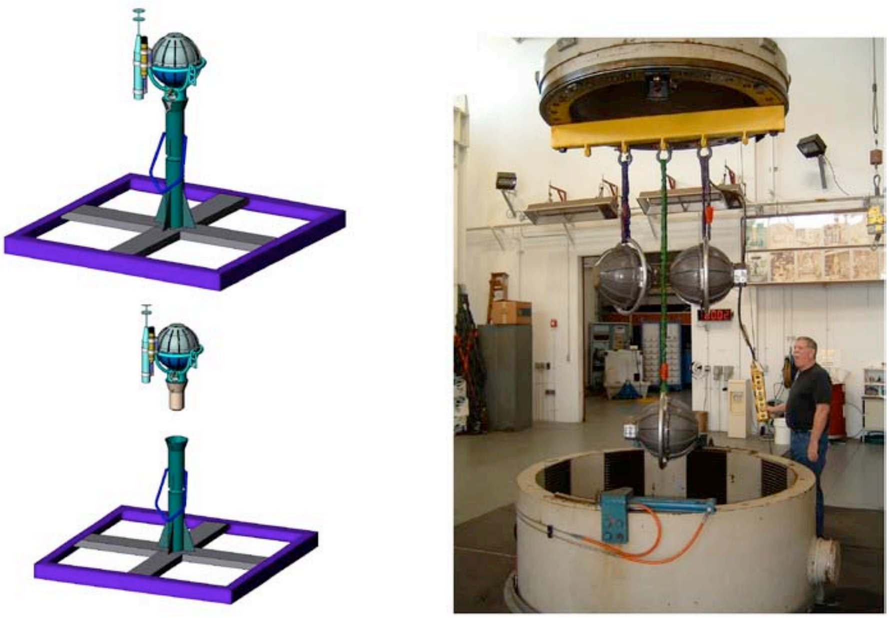
A) Maximum of 10 kW Regulated output power per Node
B) Time accurate to 1 microsecond corrected for latency & jitter
C) Up to 10 Science Ports each with the following:
    a. 1 Wet-mateable electrical connector
    b. 1 10/100 BaseT Ethernet connection
    c. 1 400 VDC Power Output line
    d. 1 48 VDC Power Output line
    e. 1 Timing signal
D) One Expansion Port with the following:
    a. 1 Wet-mateable fiber optic/ electrical connector
    b. 1 Gigabit 10/1000BaseF Ethernet connection
    c. 1 400 VDC Power Output line
    d. 1 Dual line 2 KVDC power output connection
    e. 1 Timing signal

3.4 Branching Unit $500K ea (cost uncertainty ±30%)

The Branching Unit (BU) is a relatively inexpensive subsystem that acts as an "empty" node. A BU may be installed in the backbone cable in areas that have high expectations of becoming full-up primary nodes in the near future. The unit consists of an outer trawl-resistant framework, along with the bulkhead connectors, mounting hardware and the minimal electronics needed to make the BU transparent to the rest of the system. It will appear as a passive feed-through to the RCO not disturbing either the power or the communication signals passing through the cable. The BU design will enable it to be easily upgraded to full primary node status without requiring the services of a cable laying ship. This node has yet to be engineered.

3.5 Low Voltage Benthic Node (LV): $161k (cost uncertainty ±20 %)

Low voltage benthic nodes provide a cost efficient means to plug in an array of instruments that are in close proximity to each other, and they allow for easy recovery and redeployment of suites of instruments (Fig. 7). Under the current design, each of the LV nodes would have the following characteristics:



A) ROV laid cable from secondary node, or backbone node, to the BN to power small cluster of instruments
B) Low voltage 400V (close to backbone node or secondary node: 5 km of cable, deploy using academic ROV if cable not armored; armored cable needs commercial ROV, 2000 lb load and limitation of 2 km of armored cable)
C) 2 underwater (UW) mateable copper connectors (limitation of 100 m cable lengths)
D) Most instruments connected to controller housing via deck mateable connectors
E) Easily retrieved to bring back to shore to service instruments

Figure 7. Low voltage benthic nodes.

3.6 Timing Requirements

Timing requirements for the nodes are predominantly driven by geodetic and acoustic measurements. Timing for broadband seismometers require 0.1 msec timing accuracy. Reciprocal tomography experiments, which measure the difference in travel time between nodes to determine absolute water velocity, require 10 μsecond or better absolute timing. These signals are 10 or 100 μseconds to a few milliseconds.

3.7 Costing

A summary of estimated costs for each of the main components on Stage II and component capabilities are shown in Table 1. These are used to calculate overall costs for each of the five Stage II nodes and for costs associated with augmentation of Stage I. The primary node cost and backbone cable costs were derived from the NEPTUNE Canada Stage I estimates, MARS and Venus. The vertical profiler cost was taken from the Aloha Mooring sensor network project (see http://alohamooring.apl.washington.edu/project/project.html). These estimates, while certainly not final, represent the best effort estimates for costs of the RCO infrastructure at this time.

In addition to the above infrastructure costs, we anticipate that there will be non-recurring engineering costs to develop items that have not been designed and/or are considered outside the scope of responsibility of the RCO commercial cable-laying subcontractor. For example, items such as Branching Units, Desktop Simulators, the Observatory Control System, and SIIMS need to be designed and prototyped before they can be fabricated in quantity.

Table 1. Summary of RCO Stage II Infrastructure Costs

Infrastructure	Cost	Description and Capabilities
		Cable
Backbone Cable (lay and vessel)	$20k/km	Includes repeaters (if needed) for RCO backbone cable (not including the following: mobilization, post lay inspection, cable burial, shore end work and marine survey); Costs may be high but may cover node installation costs
Extension cable, ship surface lay	$17k/km	>15 km armored lifetime >2yrs; $17k/km (not including: survey, set-up, or mobilization if separate from main cable lay)
Extension cable, Laid with a robotic vehicle (ROV)	$10k/km	<15 km, 400V, light weight protected cable; Cable lay at 0.25kt with cable reel, $50k per day ship time, factor 1.5 for preparation optical connector $52k Ship time for 1-5 km ROV cable laying & plug in; Ship cost $35k/day ROV cost $15k/day
		Benthic Nodes
Backbone Node	$2.5M	Includes installation cost; high reliability (needs defining); 10kv to 400V;10kW converters ;LV converters to power internal loads and science ports;10Gb; 3,500 m depth rated; 4-10 science ports; precision timing signal; galvanic isolation ports; ground fault detection; protections overcurrent
Medium Voltage (MV) also called Secondary Node	$1.5M	Simpler version of backbone node; does not necessarily need to be trawl resistant frame; cost reductions; lower FIT rate than backbone node (needs defining); 2kV-10 kv to 400 V; 10kW converters; 3,500 m depth rated; 4-10 science ports; precision timing signal; galvanic isolation ports; ground fault detection; protections overcurrent; single cable termination; 1Gb
Low Voltage	$161k	Small housing able to be retrieved by ROV; Power converters, 400V to instrument V; 10/100baseT; NTP timing signal; 4,000 m depth rated; Node controller; Copper penetrations for 4-8 instrument; connections; overcurrent protection, galvanic isolation ports; 1 optical penetrator for fiber connection to BN1

4.0 Regional Cabled Observatory Integrated Experimental Design

The RCO CND presented in this document is the third version (Fig. 8). This evolution was based on an iterative process reflecting community input, refinement of science priorities, and changes in costing estimates. Significant changes in the various scenarios are summarized in Table 2 to provide a historical perspective of the revisions. An important philosophy behind all versions of the CND is the recognition that this experiment is a 30-year sustained effort and that installation of initial infrastructure that allows optimal flexibility and lowest cost for future instrumentation and expansion of experiments is the critical first step. Based on the initial success in leveraging funds for the RCO, an assumption is made that additional secondary infrastructure and instrumentation costs will be much easier to attain than large, one-time costs associated with installation of the backbone and primary and secondary nodes. This implementation design (Fig. 8) and the more ambitious plan shown in Figure 1 most closely meet the spirit and intent of the MREFC to support "the acquisition, construction and commissioning of a facility…that represents the possibility of transformative knowledge and the potential to shift existing programs in scientific understanding, engineering processes, and/or infrastructure technology".

Therefore, we have not included substantial costs for core instruments, minor extension cables or connectors. Looking towards the future, we have prioritized 5 backbone nodes, and 3 branching units that allow future expansion (Fig. 8). The name, location, and depth of the primary nodes are included in Tables 3 and 4 and shown in Figures 1 and 8 along with the branching units. This cost also assumes that the University of Victoria will be successful in obtaining additional funding to install nodes at ODP889 and ODP1027, and to install a branching unit, spur cable and node into Middle Valley.

Table 2: Evolution of RCO Conceptual Network Design

Version	Cost	Description	Comments
Scenario 1 January 2006	>>$150M	2,000 km of backbone cable, 12 primary nodes, 12 vertical profilers on backbone; a physical connection to Stage 1; extensive secondary infrastructure and long extension cables; significant augmentation to Stage 1; no core instruments	First costing effort based on all RFA's and engineering costs defined at January 2006 STAC meeting
Draft 1.0 March 2006	$107.46M	1,750 km of backbone cable, 5 primary nodes; a physical connection to Stage 1; 6 branching units; 7 vertical profilers on backbone; 2 buoyed vertical profilers; limited secondary infrastructure; significant augmentation to Stage 1; no core instruments	Developed by subset of representative PI's, the RCO STAC subcommittee and STAC engineers. Scenario 2 was presented at the D&I workshop.
Final Design for Review May 2006 Draft 2.0	$91.88M	1,490 km of backbone cable; 5 primary nodes; 3 branching units; funds to explore physical connection to Stage 1; 6 vertical profilers on backbone; 2 buoyed vertical profilers; limited secondary infrastructure; reduced augmentation to Stage 1; limited core instrumentation	Iteratively developed at and subsequent to the May STAC meeting. Minimal design to achieve science requirements

The final design (DRAFT 2.0) presented in this document and summarized in Figure 8 and Tables 3 and 4 is a minimal design that meets many of the science requirements outlined in the RFA's. This design includes $29.8M for the cable backbone (including installation), $12.5M for backbone primary nodes, $1.5M backbone branching units, $8.6M for moorings (installed) necessary for water column studies, $24.5M for additional secondary infrastructure that would access locations of scientific interest on and beneath the seafloor, $8M for engineering, and $5M for ship mobilization and demobilization. In addition, $2.5M is reserved as minimal funds to engineer, purchase hardware and construct the connection between Stages 1 and 2 if appropriate.

Several major factors must be decided before the total system cost can be determined. The first factor is what system architecture will be selected for Stage II of the RCO. There are two types of infrastructure that have been studied for the project. The first is the "baseline" system on which the MARS design is based. One of the requirements for this type of infrastructure is that a primary node must be placed approximately every 150 km along the cable to provide appropriate signal amplification. Because the proposed cable length is 1490 km, at least 10 primary nodes would be required for this purpose.

The second proposed system called the "alternate" is a derivative of a global telecom type of submarine cable that has optical repeaters built into the cable (the "alternate" type was selected for Stage I based on a competitive process). If this alternate system is chosen, Stage II could be built without any minimum number of primary nodes. Each of the two system architectures has technical and reliability advantages and disadvantages. For this estimation of infrastructure budget, we have tried to generalize the costing by not introducing any requirements that would preclude one of the proposed architectures from being selected in the future. Thus, for the purposes of this budgeting exercise and because of prioritization considerations, 5 primary backbone nodes (N1-N4; N6) have been included with a series of 3 high priority branching units (t,s,w) (Fig. 8) on Stage II. N5 is shown only as a visual "place holder" to indicate that funds are reserved for connectivity between Stage 1 and II should this be optimal for the design based on final engineering requirements. If additional funds become available, a full suite of 6 primary nodes (N1-N4; N6; N12-Gorda), 6 branching units (r-w), and 9 full water column moorings should be considered for installation (Fig. 1).

Table 3. Location of Primary Nodes and Branching Units

Type	Name	Designation	Stage	Latitude	Longitude	Depth (m)
Shore Station	Nedonna Beach	S1*	Stage II	45°39.00'N	123°56.1'W	0
Node	Hydrate Ridge	N1*	Stage II	44°34.00'N	125°26.0'W	3000
Branching Unit	Mid-Newport Line	r	Stage II	44°34.00'N	126°25.0'W	3000
Node	Newport Line West	N2*	Stage II	44°34.0'N	127°40.0'W	2500
Node	Blanco Fracture Zone	N3*	Stage II	43°50.0'N	128°00.0'W	3000
Branching Unit	Western Blanco	s*	Stage II	44°21.0'N	129°36.0W	2400
Branching Unit	Cleft Segment	t*	Stage II	44°39.0'N	130°08.0'W	2700
Node	Axial Volcano	N4*	Stage II	45°50.0'N	129°40.0'W	2800
Branching Unit	N Symmetrical Ridge	u	Stage II	46°45.0'N	129°00.0'W	2700
Holder	Mid Plate N	N5	Stage II	47°02.0'N	127°44.0W	2700
Branching Unit	East Plate N	v	Stage II	46°54.0N	126°42.0'W	2600
Node	Subduction Zone	N6*	Stage II	47°00.0'N	125°54.0W	2700
Branching Unit	Astoria Canyon	w*	Stage II	46°03.0'N	125°39.0W	2400
Node	Endeavour	N7*	Stage I	47°55.7'N	129°04.6'W	2200
Branching Unit	ODP 1027	N8*	Stage I†	47°45.6'N	127°45.6'W	2600
Node	Barkley Canyon	N9	Stage I	48°21.3'N	126°05.9'W	200
Branching Unit	ODP 889	N10*	Stage I†	48°42.00'N	127°10.0'W	2500
Branching Unit	Middle Valley	N11	Stage I†	48°26.5'N	128°42.6'W	2500

**Highest priority experimental sites; other sites should be considered should funding become available. Locations of high priority sites are shown in Figure 1, and Figure 8, a less aggressive design.. †Proposed pending funding from Canadian Foundation for Innovation. Note that primary nodes and branching units are described in detail in Section 3.0. At the D&I workshop an additional primary node was requested for incorporation onto Stage II of the RCO. This node, Node 12 is located at the far southeast corner of the Juan de Fuca plate at the triple junction boundary between the subduction zone, Blanco Fracture Zone, and Gorda Plate (Fig. 1)*

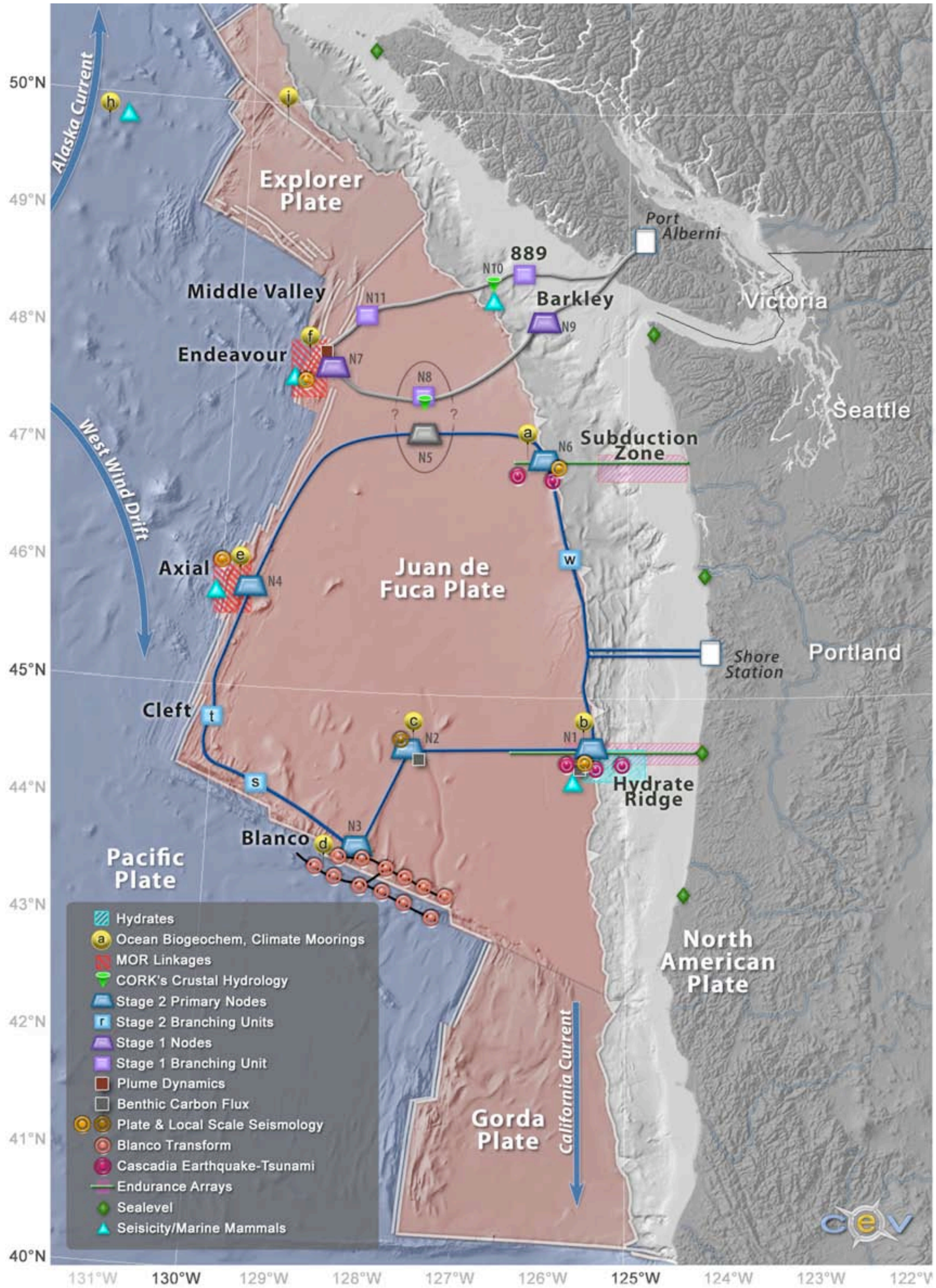


Figure 8. Minimal Regional Cabled Observatory integrated experimental design that meets the $90M target for the OOI. This design allows many of the science objectives to be achieved that are important to the community and some capabilities for future expansion. This design must be reevaluated as engineering-technology issues are addressed (e.g. connection between Stage 1 and Stage 2, ability to augment Stage 1). Infrastructure on Stage 1 should not be incorporated at the expense of accommodating all 6 branching units (shown in Figure 1).

Table 4: Regional Cabled Observatory Integrated Experimental Design Infrastructure & Costs

Location Primary RFA's	Science	Requirements	#	Cost $
NODE 1 (N1) **Hydrate Ridge** 2,4,5,7,12,14,15	Understand dynamic processes that control methane transport and hydrate formation, biogechemical processes, large-scale coastal gradients in productivity and community structure, megathrust events and tsunamis, plate scale hydrology and seismicity global carbon cycles, mammals, California current	MV benthic node NP1	1	1,500,000
		MV benthic node NP2	1	1,500,000
		MV benthic node NP3	1	1,500,000
		Extn cable N1-NP1 km	30	459,000
		Extn cable N1-NP2 km	15	271,500
		Extn cable N1-NP3 km	25	396,500
		Optical conn. NP1	2	34,000
		Optical conn. NP2	2	34,000
		Optical conn. NP3	1	17,000
Total				**$5,712,000**
NODE 2 (N2) **Newport Line West** 5,7,13,14	Understanding fluid-sediment transport coast to mid plate, long-period climate ecosystem dynamics, large-scale along coast gradients in productivity and community structure, seismicity, cross margin flux, carbon cycle, migration, north south fluctuations in WWD	LV benthic node	1	161,000
		Extn cable N2–LV benthic node	1	94,000
		Cu conn benthic node to vertical profiling mooring	2	14,000
Total				**$269,000**
NODE 3 (N3) **Blanco Fracture Zone** 5,8,14	Understanding physics of earthquakes along major plate boundaries, linkages between earthquakes, fluid flow, chemical and biological processes, plate scale hydrology, climate change and biogeochemistry, tracking marine mammals, ocean turbulence and dynamics	LV benthic nodes	12	1,932,000
		Extn cables km	145	1,812,500
		Double armored cable km	12	360,000
		Cu conn benthic node to instruments	24	168,000
Total				**$4,272,500**
NODE 4 (N4) **Axial Seamount** 5,7,12,14,16	Understanding crustal accretion at large active volcanoes, hydrothermal flow, seismic tremor and linkages to plate scale sesimicity and hydrology, ocean carbon cycles, biogeochemical processes across a plate, topographic forcing of currents; larval transport; subseafloor biosphere, tracking marine mammals	MV benthic node(east)	1	1,500,000
		MV benthic node(west)	1	1,500,000
		Extn cable N4-east MV benthic node km	20	334,000
		Extn cable east MV benthic node-west MV km	15	271,500
		LV benthic node Castle	1	161,000
		Extn cable & opt connectors Castle	3	114,000
		Geodetic Array LV benthic nodes	8	1,288,000
		Surface cable lay km	50	625,000
		LV benthic node Ashes	1	161,000
		Extn. cable & optical conn. Ashes	6	144,000
Total				**$6,098,500**
Connection (N5) **Stage 1-2** 14,15	Minimal holder for engineering, hardware and ship time to provide connection between Phase 1 and Phase 2 if appropriate			
Total				**$2,500,000**

Location Primary RFA's	Science	Requirements	#	Cost $
NODE 6 (N6) **Subduction Zone** 2,4,5,12,14,15	Understanding factors that control seafloor deformation and slides, monitor elastic strain accumulation along subduction zone, plate scale hydrology and seismicity, large-scale along coast gradients in productivity and community structure, hypoxia, carbon dynamics and cross-margin flux	MV benthic node Extn cable km Extn cable km	1 40	1,500,000 584,000 84,000
Total				**$2,168,000**
NODE 7 (N7) **Endeavour** **Stage 1 node** 5,11,12,14,16	Understanding crustal accretion, seismicity and hydrothermal flow in vigorously venting system, linkages to plate scale seismicity and hydrology, ocean carbon cycle, biogeochemical processes across a plate, subseafloor biosphere, carbon cycle, heat flux, tracking marine mammals	Cable from N7 to GT LV BN km	4	124,000
		Geodetic transponder LV benthic node (GT LV BN)	4	644,000
		Cable for geodetic transponders km	8	100,000
		Sasquatch LV benthic node	1	161,000
		Cable from GT LV BN to Sasquatch LV BN km	4	124,000
Total				**$1,153,000**
Node 8 (N8) **ODP 1027** **Stage 1 node** 3,14,16	Understanding crustal hydrology, seismicity and hydrothermal flow in vigorous off-axis system, in sediment-covered permeable basement, related biogeochemical and microbiological processes, heat flux	ROV laid extn cable (6 off) 2 km each	6	624,000
		MV benthic node	1	1,500,000
Total				**$2,124,000**
NODE 9 (N9) **Barkley Canyon** **Stage 1 node**	Understanding hydrate formation in very different geologic setting than Hydrate Ridge, comparison of onshelf/slope/offshelf processes and fluxes at locations of different upwelling and mean current regimes.	Mooring Removed		
Total				**---**
NODE 10 (N10) **Cascadia Margin** **SITE 889** **Stage 1 node** 3,4,12,14,15	Understanding hydrate formation, seismicity, hydrological connectivity at a plate scale, subseafloor biosphere, biogeochemical cycles, carbon budget, tsunamis, megathrust events	Exten cable to 889 Exten cable to second CORK site		94,000 94,000
Total				**$188,000**
NODE 11 (N11) **Middle Valley** **Stage 1 node** 3,7,9,14,16	Understanding crustal hydrology, seismicity and hydrothermal flow in vigorously venting sedimented system, biogeochemical processes, heat flux, vent macrofauna	Removed		
Total				**---**

COST Summary			
Backbone cable	(includes installation)	1490	**29,800,000**
Backbone nodes	(includes installation)	5	**12,500,000**
Backbone B'outs		3	**1,500,000**
Mode/demobe	Mobilization of equipment in port and demobilization of cable laying and instrument deployment gear		**5,000,000**
Node 1	Extension cables, benthic nodes		**5,712,200**
Node 2	Extension cables, benthic nodes		**269,000**
Node 3	Extension cables, benthic nodes		**4,272,500**
Node 4	Extension cables, benthic nodes		**6,098,500**
Node 5 ($holder)	Connection Phase 1 to Phase 2		**2,500,000**
Node 6	Extension cables, benthic nodes		**2,168,000**
Node 7	Extension cables, benthic nodes		**1,153,000**
Node 8	Extension cables, benthic nodes		**2,124,000**
Node 9	Extension cables, benthic nodes		**--**
Node 10	Extension cables, benthic nodes		**188,000**
Node 11	Extension cables, benthic nodes		
Node 12	Extension cables, benthic nodes		
NRE	Engineering		**4,000,000**
NRE	OCS, DMAS, SIIM, engineering		**4,000,000**
Mooring NRE	(builds on Aloha moorings)		**2,000,000**
Moorings		8	**5,984,000**
Mooring	Deployments	8	**608,000**
Moorings	Core Instruments for moorings	8	**1,000,000**
Core Instrumts.	Broadbands, pressure, temperature sensors ea Node (Excluding moorings)		**1,000,000**
RCO Total			**$91,877,200**

RFA's: 1 = Ocean Noise Monitoring for ORION; 2 = A Multi-Scale Ocean Observatory for Ocean Dynamics and Ecosystem Response along the Northeast Pacific Continental Margin; 3 = Regional arrays of borehole observatories for sustained time-series observations of (a) subseafloor hydrogeological processes and (b) formation pressure as a proxy for plate-scale strain; 4 = A Northeast Pacific Hydrate Observatory System (NEPHOS) at South Hydrate Ridge; 5 = An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from basin to Regional Scales; 6 = Fluxes of Pelagic Nekton: Using Temporally Indexed Movements of Fish and Marine Mammals to Understand Ecosystem Processes; 7 = Distributed pH Observatory: Assessing the Effects of the Anticipated Shift in the Upper ocean on the Oceanic Energy and Carbon Cycle; 8 = An Earthquake, Physics, and Fault Mechanics Observatory on the Blanco transform Fault; 9 = Long Term Observations of the Ocean Acoustic Environment and Its Impact On Marine Mammals; 10 = Three-Dimensional Optical Imaging and Classification of Marine Species with Length Scales of Microns to One Meter; 11 = VIA (Vent Integrated Acoustics) Cabled Experiment: Main Endeavour Field, Juan de Fuca Ridge; 12 = Regional Ocean Hydrophone Array Observatory (ROHAO); 13 The Coupling of Pelagic Particulate Matter Fluxes and Benthic Community Processes Across the NE Pacific Continental Margin: Long Time-Series Monitoring With Real-Time Data Acquisition and Control; 14 A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific; 15 = Seismic and Geodetic Observations of the Cascadia Continental Margin: Towards an Effective Real-Time earthquake and Tsunami Warning System; 16 = A Cabled Observatory on the Juan de Fuca Ridge

4.1 Core Instrumentation

At the Salt Lake City D&I workshop, there was nearly unanimous agreement among the ~100 participants of the RCO breakout group that little if any MREFC funds should be used for core sensors. This was revisited at the May 2006 STAC meeting and a decision was made to include ~$2M for high priority core instrumentation. A suite of broadband seismometers, and pressure and hydrophone sensors at the 5 primary nodes ($1M) was chosen because real-time data from the seismometers in concert with EarthScope geophysical data will allow early investigation of seismicity, magmatism and deformation at a scale never before possible-across the North American Continent, Cascadia Subduction Zone and the Juan de Fuca Plate (Table 5).

The core seismic monitoring package includes a three-component broadband seismometer, a seafloor hydrophone and a high-resolution pressure sensor, for a tsunami early warning system and tidal measurements required for interpretation of the seismic data. To reduce environmental noise the broadband seismometers must be installed below the seafloor or placed in boreholes at ~ 200 m depth and be located at least 20 m away from other instrumentation. Power, timing and communications requirements are shown in Table 5. The cost of the core seismic monitoring package is approximately $80,000; one day of on-bottom ROV time is required to install each seismic monitoring package. Installation costs are included in the $1M for core seismic sensors; costs for calibration of instruments and data processing are not included.

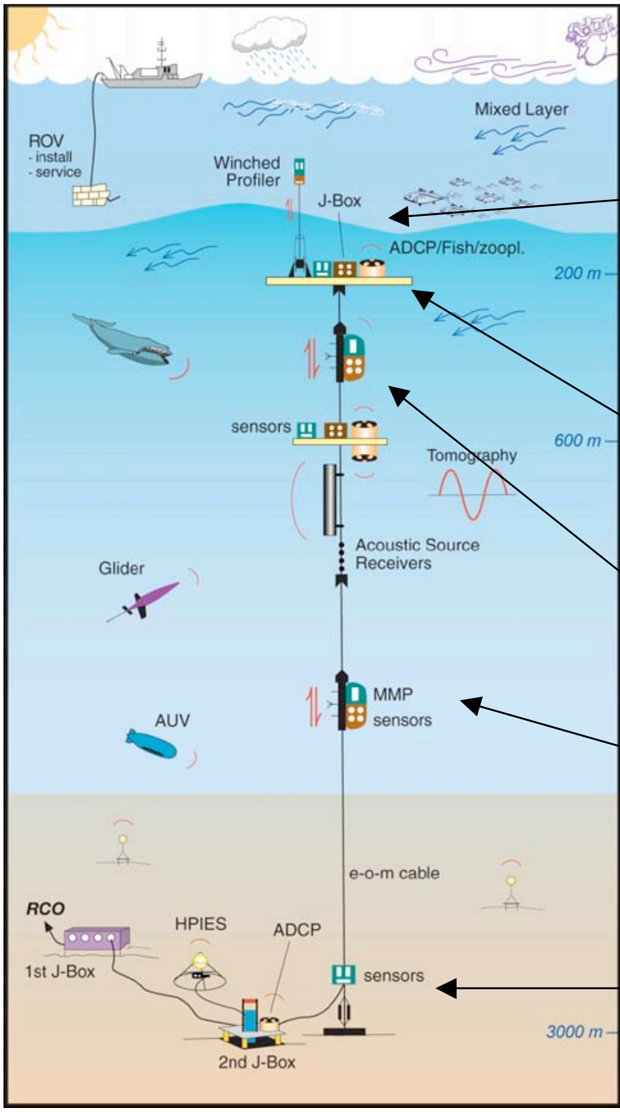
All seismic data will be freely available with protocols similar to those that have been developed for IRIS. Data processing will involve automatic detection, location and evaluation of transient events such as earthquakes, volcanic eruption signals, and submarine landslides. Results can be made available through electronic means (e-mail, FTP, web pages). A dedicated network operator and data analyst are required to ensure that basic data processing and dissemination occur. This could be done through the Pacific Northwest Seismograph Network. Data archiving would follow procedures adopted by the IRIS Data Management System in Seattle, which is already set up to provide long term archiving and distribution of seismic data.

Table 5: Core Seismic Suite of Instruments

Instrument	Data Rate/Data Storage	Communications	Timing/Power	Comments
Broad-band seismometer (500 sec to 50 Hz)	Rechargable battery pack, onboard data storage capability (hard disk or Flashcard) 300 sps	Internet Protocol	0.1 msec timing accuracy 2.5 W & power to write data to the onboard storage	All three instruments can be attached to a single data logger 6 x 24 bit A/D channels.
Hydrophone	100 sps	Internet Protocol	250 mW	
Pressure sensor	100 sps	Internet Protocol	250 mW	4 differential 16 bit, 1 Hz, A/D channels

In addition to inclusion of this geophysical array, a second array of sensors for chemical and physical measurements in the full water column is included on each of the profiling moorings ($1M). An illustration of instruments that may be included on the moorings is shown in Figure 9.

These instruments are off-the-shelf and will not require development. However, similar to the seismic array, there will be a facility need for standardization, calibration and maintenance of these instruments. In the current Operations and Management plan (Section 5), these instruments would be installed at the same time as the cabled profiling moorings and buoys so that the entire network can be tested. It may be that a management and protocol system similar to IRIS will need to be implemented, but this awaits additional discussion and planning that also integrates with CI efforts. In addition to core instrumentation to be purchased under the OOI, a diverse array of high priority multidisciplinary sensors currently exists that can be rapidly and cheaply transitioned onto the cable when it is installed (Table 6). These instruments are either now installed on the seafloor or are in laboratories awaiting installation.



	Core	Cost	Additional	Cost
Surface layer profiling package	C-T-D-O_2 PAR FL-Tr NO_3 ADV	\$12K \$10K \$5K \$25K \$10K	pCO_2/pH SIPPER camera	\$20K \$60K
200 m float	150KHz ADCP (up-looking) hydrophone	\$38K \$10K	TAPS (up-looking multiple frequency acoustics)	\$100K
200-600 m profiler	C-T-D-O_2 FL-Tr NO_3 ADV	\$12K \$5K \$25K \$20K		
600 m float	NO_3 Tr	\$25K \$4K	Tomography transducer	\$250K
600 m-bottom profiler	C-T-D-O_2 Tr ADV	\$12K \$4K \$10K		
bottom package	PIES Tr	\$30K \$4K	ADV 75KHz (up-looking) ADCP	\$10K \$50K
Total		\$251K		\$490K

CTD = conductivity, temperature, depth, DO = dissolved oxygen, PAR = Photosynthetically Active Radiation, FL = fluorescence, Tr = optical backscatter, NO_3 = nitrate sensor, ADCP = Acoustic Doppler Current Profiler, ADV = acoustic doppler velocimeter, PIES = current meter/pressure sensor/inverted echo sounders.

Figure 9. A subset of this instrument suite could be incorporated on the RCO profiling moorings as core instruments. Specific instrumentation will require additional input from the user community.

In total over $9M of instrument leveraging is available currently. Examples of instruments that PI's indicated could be incorporated immediately into the RCO efforts are shown in Table 6.

Table 6. Representative Instruments to be Leveraged on RCO Early Installation

Instrument	#	Measurement	Cost ea
*Broadband seismometers	13	seismicity, melt intrusion beneath seafloor	$80K; three deployment sites already available; $100K savings each site, $1M Blanco BB
*Short-period seismometers	10	Seismicity, cracking	$20K; installed in drill holes in volcanic rocks; 7 sites; $50K savings each site for installation
Pressure Sensor	1	Tidal and storm influence on sesmicity and hydrothermal flow	$30K
*Microbial Incubators	3	Environmental conditions within chimney walls, co-registered microbe-temperature-fluid sampling	$70K; installed in drill holes in black smoker walls; 4-5 sites currently drilled; $20K savings each site for installation
*Temperature-Resistivity-H_2	5	Temperature-"chlorinity" and dissolved hydrogen in high temperature vent fluids	$40K
*Fluid-particulate DNA	3	Time-series sampling of diffusely venting fluids and microbial DNA	$40K
Gravity meter	1	Gravity field	$100K
CORKS	7	Hydrological parameters subseafloor environments, sampling of fluids, DNA, temperature; pressure pulses associated with earthquakes, diking events	~$1M; Juan de Fuca plate hosts highest density of CORKED observatories within the oceans, and most long-lived continuous records; drilled with the JOIDES Resolution ($50K/day); installed with wireline; serviced with Alvin or ROV, several million $$ savings.

**Funding from Neptune Canada is now in place to transition a subset of these instruments onto Stage 1.*

In concert, these suites of instruments offer unprecedented opportunities for early integration of physical, seismic, and biogeochemical information at global, regional and coastal scales.

4.2 Node and Infrastructure Prioritization

There was a strong consensus at the D&I workshop that the plate-scale primary infrastructure of Stage II was critical for achieving many of the scientific objectives of the RFA responses, and that nodes N1, N2, N3, N4 and N6, should receive the highest priority for funding (Table 4; Fig. 8). Nodes N1 and N4 might be considered by some as the very highest priority because they serve the highest number of RFA responses. Node N5 was inserted as a place-holder for funds that might be necessary for a connection to Stage 1. This may be desirable from the point of view of network reliability, but the site is not a high priority for scientific experiments. Node N12 [Gorda (Fig. 1)], is a new node at the southeast corner of the Juan de Fuca plate. It was promoted at the D&I workshop for studies of plate scale and transform seismicity, the subduction zone, and water column processes. Node N12 has a lower priority than Nodes N1-4 and N6 because of its additional cost, but it should be included as an option in the bidding process for cable installation.

The primary cable route for Stage II includes six branching units, which can be considered as 'empty' primary nodes that allow easy future expansion of the system (Figs. 1 and 8). Branching units t and s at Cleft and Blanco have the highest priority because they are directly linked to RFA responses for ridge and transform studies. Branching unit w should have the next priority because it will allow an additional site at the margin. Branching units v, u, and r should be included in the bidding process because they are critical to future expansion, but are lower priorities.

The secondary infrastructure and the uncabled profiling moorings are lower priority than Nodes N1-4 and N6. Removal of any of these nodes would result in a very significant loss in science that could otherwise have been addressed by the RCO. The addition of Node N12 (or a branching unit) should not be funded entirely at the expense of the budget for secondary infrastructure and profiling moorings. Of the secondary infrastructure, the easternmost secondary node on N6 and the infrastructure at Node 11 Middle Valley are the lowest priority. The secondary node at N6 was considered as a lower priority because it was the second site along the margin where a full geophysical-geodetic experiment was to be instrumented. A full seismic-tsunami-related observatory is accommodated at N1 (Hydrate Ridge) and infrastructure remains at N6 to meet some of the goals of the seismic studies at this site.

Initially, it was argued that the western secondary node on Axial Seamount (N4) should be given lower priority. However, this was a very high priority site for numerous RFA's and in the current budgetary model, it is the only spreading center-hydrothermal observatory where a full geodetic experiment can be accommodated. Similar to Axial Seamount, Hydrate Ridge is a very high priority site with three secondary nodes (NP1-NP3). Hydrate Ridge should have priority for additional secondary nodes because these will facilitate connection to the coastal experiments of the West Coast Endurance Array (see Section 4.4, Fig. 10; Section 7.1, Fig. 12).

Of the profiling moorings, the mooring connected by an extension cable to N9 (Fig. 1), Barclay Canyon, is the lowest priority because of its expense ($4M if installed subsequent to Stage I). The two northern acoustic moorings are critical for water column experiments to examine the Alaska current and should be considered equal priority to other moorings on the RCO. The water column community may, however, choose to eliminate one or more additional moorings and use the funds to augment their core instrument packages.

4.3 Augmentation to Stage I Considerations

Very significant issues for planning, costing considerations, and design implementation for Stage II of the RCO concern the relationships between the design, installation schedule, and technological and cyber-infrastructure requirements for Stages 1 and II. In costing out the $90M scenario presented in this document, significant funds (~$4.4M) are provided for augmentation of infrastructure on Stage I. Although there are strong science drivers for supplementing Stage I, there are numerous difficult-to-answer engineering and phasing questions that must be addressed before a final decision is made on whether the US should provide secondary infrastructure to Stage I out of US MREFC funds. One challenge is whether it is technically feasible to connect Stage I and Stage II for power and communications redundancy. If a connection is feasible, cost-risk analyses must be completed, and a clear understanding needs to be had on what this design may or may not impose on Stage II requirements. A second major challenge is whether the timing between installation of Stage I and fund availability from the MREFC will be such that it will not be feasible for augmentation of Stage I. In the current Neptune Canada design there are not enough connectors on Stage I primary and secondary nodes to accommodate the experiments outlined in this document. There is significant hesitancy by NEPTUNE Canada to add US-funded infrastructure to Stage I subsequent to the main installation because it may require powering down of the entire cabled network, pulling up nodes, and installing the additional infrastructure at significant costs and possible high risk. Because of these issues, the final decision on funding of infrastructure for Stage I at the expense of Stage II will need to be revisited.

In general, secondary infrastructure on Stage 1 should have a *lower* priority than that on Stage II because the Stage 1 sites will already have some development by NEPTUNE Canada. It is more important to facilitate the initial development of experimental components on Stage II, than to enhance experimental components on Stage 1. If adopted, this plan would allow incorporation of all branching units on Stage II. The exception to this relative prioritization of Stage 1 and II infrastructure is the minimal augmentation of N8 (ODP 1027) and N10 (Cascadia 889) to connect the ODP-IODP 'CORK'ed" borehole observatories to NEPTUNE Canada. If necessary secondary infrastructure for N8 and N10 is not funded by NEPTUNE Canada, it should be considered for a higher prioritization.

The more aggressive RCO scenario depicted in Figure 1 includes support for a secondary node at Middle Valley (N11) for instrumentation around the CORKed borehole, and significant funding for augmentation of infrastructure at Endeavour (N7). To reduce RCO Stage II costs to the $90M target, the Middle Valley site is a lower priority because it may be accommodated through funding from Canada, and the initial funds to Endeavour were reduced by 50% (Table 4) because this site already includes both secondary infrastructure and instrumentation through NEPTUNE Canada.

4.4 Interface with the Pacific Northwest Coastal Array

The Pacific Northwest coastal Endurance lines (PNW) will include 1) a series of five cabled moorings on the shelf and slope east of Node 1 at Hydrate Ridge that will be linked to the backbone of the RCO and 2) a second set of uncabled moorings on the shelf and slope east of Node N6 (47°N) (Figs. 10 & 12). This design fulfills a major objective of Observatory efforts: to create an ocean observatory that extends from shore to the deep sea. This area is of importance to understanding local physical and biogeochemical oceanographic problems, but is also globally important in understanding the impacts of eastern boundary currents in general, and ocean basin forcing functions on the regional climate.

The northern portion of the Juan de Fuca Plate is dominated by the boundary between the sub-tropical and sub-arctic gyres (Fig. 2). The two gyres are fundamentally different physically, biologically, and biogeochemically. The sub-tropical gyre is characterized by wind-forced downwelling, and the sub-arctic by upwelling. The current separating the gyres, commonly known as the West Wind Drift (Fig. 2) flows eastward, meets the eastern boundary, and bifurcates into northward- and southward flowing branches. The southward branch provides the source water for the California Current, while the northward branch feeds the Alaska Current. These currents interact with flows of the shelf/slope region through upwelling and mesoscale processes. This Pacific Northwest coastal area is strongly influenced also by local wind and buoyancy-driven interannual variability originating in the tropical Pacific, and variations in large-scale North Pacific circulation.

The physical setting within the Pacific Northwest region offers contrasts for comparative studies that include examination of narrow versus wide continental shelves, smooth versus highly variable coastline bottom topography, and various degrees of freshwater forcing from two major sources—the Strait of Juan de Fuca and Columbia River outflow. Important opportunities in this area exist for making significant progress on questions concerning the large-scale transport of water and biogeochemical properties, large-scale along-coast gradients in productivity and community structure, mesoscale ecosystem response in regions contrasted by strong, flow-topography interaction (central Oregon) and strong river-influenced dynamics (central Washington), hypoxia and harmful algal blooms, and carbon dynamics and cross-margin to interior plate flux. Based on the important science that could be achieved in this area and maturity of the experimental design presented in the RFA "A Multi-Scale Ocean Observatory for Ocean Dynamics and Ecosystem Response along the Northeast Pacific Continental Margin", this area is one of three sites marked as highest priority for the Coastal component of the OOI.

The N1 array maintains the historical record provided by the Newport line and allows integration of science proposed for the RCO. In this design, a full water column profiling mooring will be at 2900 m near N1, with secondary nodes at 700 and 500 m (see also Fig. 12).

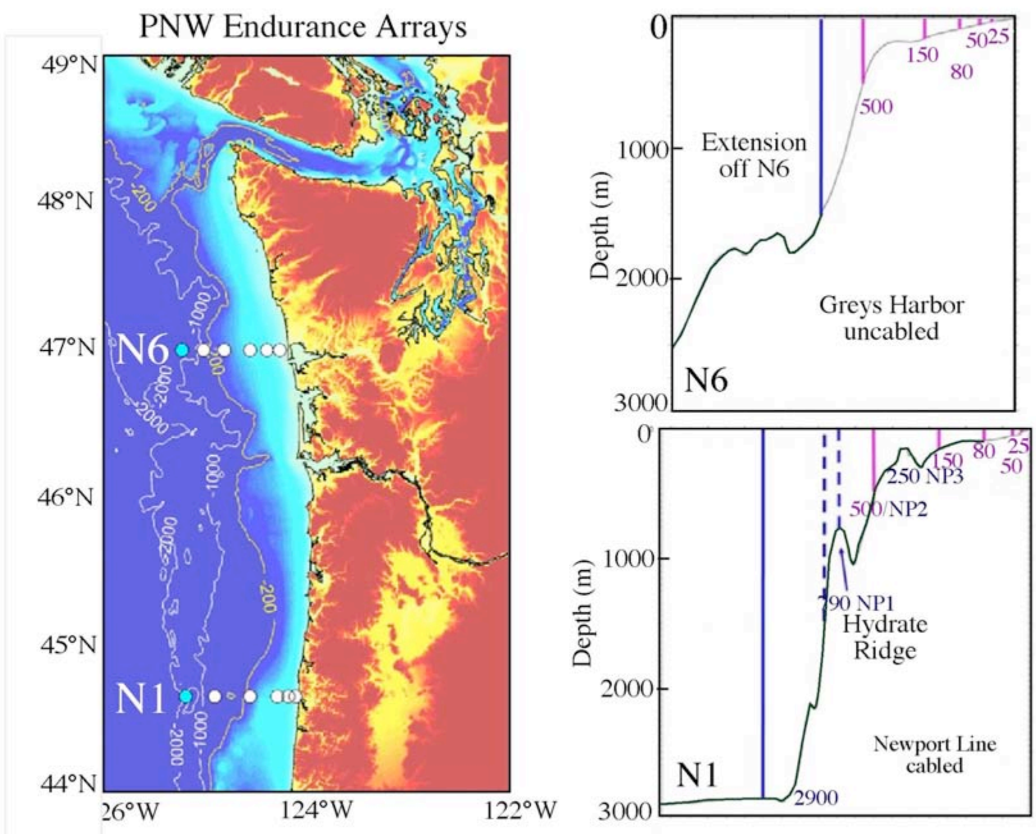


Figure 10. Integration of the Pacific Northwest (PNW) Coastal Observatory and the RCO. N1 will include an extension cable from 2900 m (N1), through a major experimental site at Hydrate Ridge, to a water depth of at least 80 m (green line). This line will include a full water column RCO mooring, and three of the five cabled PNW moorings. The Endurance experiment west of Greys Harbor (47°N) will also include a deep, full water column RCO mooring connected by an extension cable to N6, and five shallow water PNW moorings at 500, 150, 80, 50, and 25 m water depth.

5.0 Operations and Maintenance (O&M):
Required ship and ROV days for installation of secondary infrastructure, as well as maintenance days, were examined in detail for each of the nodes. Many of the installation and maintenance estimates were completed at an O&M meeting at the University of Washington in April 2006. This meeting included a subset of members from the RCO and Engineering STAC committees and ROV operators from MBARI, the National Deep Submergence Facility, and the Canadian Scientific Submersible Facility. Table 7 provides a preliminary estimate of the operation days required to install the infrastructure at each node, and annual maintenance days. Total days required to install the secondary infrastructure is 280. Assuming a ship/ROV day rate of $50k, installation of the secondary infrastructure totals $14M. Although the backbone cable and primary nodes will be installed during a single cruise, it is likely that the secondary infrastructure will be phased in over a period of ~ 4 years. This is based on the assumption that mature science proposals will be funded early on, while others may take longer to develop.

Table 7. Estimated Operations and Maintenance for the RCO

	Ship with ROV		Ship Only	
Site	Initial Installation	Annual Estimates	Initial Installation	Annual Estimates
Node 1 Hydrate Ridge	31	14		
Node 2 Newport Line West	2	0		
Node 3 Blanco Fracture Zone	28	9		
Node 4 Axial Seamount	61	33		
Node 6 Subduction Zone	31	14		
Node 7 Endeavour Segment	27	13		
Node 8 ODP 1027	8	4		
Node 9 Barkley Canyon	0	0		
Node 10 ODP 889	3	3		
Node 11 Middle Valley	0	0		
Vertical Profiling Moorings	64	45	56	12
Transit and Port Mobe	20	20		
Total Ship/ROV estimate (d)	280	158	56	12

Note: excludes backbone cable/backbone node/MV benthic node ship time

Operations and maintenance costs for the RCO are difficult to estimate but in general will include the following items:

a) Infrastructure between the backbone nodes and the instruments. Funding for the medium and low voltage benthic nodes, surface laid extension cables, ROV laid extension cables and SIIM's (science instrument interface modules) are included in the MRE capital costs. It is assumed that ship time to install this equipment, and instrument and mooring deployments, will be covered under O&M. The installation will be timed to coincide with deployment of the science experiments at that site. Installation of the secondary support hardware should not be completed until the science experiments are funded. Installation of these systems is estimated require 280 days of ship time, which will be spread over the first 4 years of operation (i.e. 70 days per year).
b) Hardware replacement. It is assumed that 5% of the backbone nodes will need to be replaced annually and that 15% of the MV and LV benthic nodes and extension cables will be replaced annually. The reason for the shorter lifetime for the secondary nodes and

extension cables is that they are sited in more hostile environments than the backbone infrastructure. Mooring hardware, on average, will need to be replaced every 5 years.

c) <u>The project office</u> will be staffed with one manager, at least one half time project scientist, three engineers and 5 technicians and one administrator. The project scientist will be a liaison between scientists and engineers. The engineers will be responsible for operating the system, managing and quality controlling the data streams, designing the SIIMs, supporting PI's, and testing systems prior to installation. The technicians will be responsible for preparing instruments, benthic nodes, preparing the cables and connectors for deployments, preparing deployment systems and will support the cruise deployments. They will also be responsible for managing instrument calibration.
d) We have assumed that on average instruments will need to be recovered and redeployed every two years, either for repairs, maintenance or for calibration, and that ROV laid cable will need replacing at 2 yearly intervals. To support this maintenance, 160 days of ship/ROV time and 12 days of ship time for mooring work will be needed each year. The breakdown of ship and ROV time for each node is shown in Table 6.
e) A contract will be placed with a cable vessel to be on call to make cable repairs or perform backbone node repairs as needed.
f) Shore station costs, rights of way, permit condition compliance, and backhaul fees are estimated to be $1m
g) Contingency of 10% has been added to cover the many items that are as yet unidentified.

5.1 Operations and Maintenance Example: Axial Seamount

The Axial Seamount observatory is one of the most complicated experimental sites to be proposed for the RCO (Fig. 11). It provides a good example of the level of detail that went into calculating the ship/ROV installation and maintenance requirements for the RCO infrastructure. Table 8 provides estimates for installation and maintenance of N4 (Axial Seamount). Total

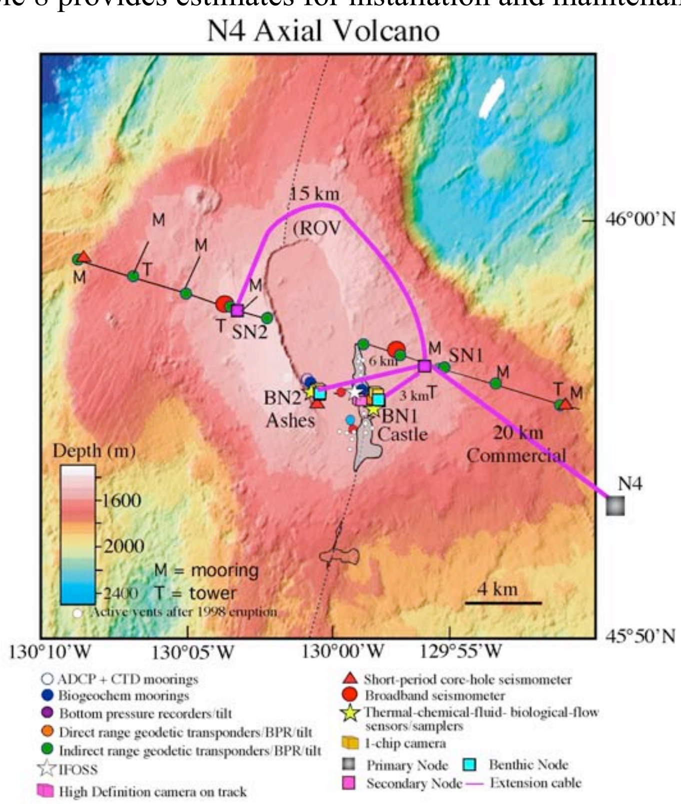


Figure 11. Axial Volcano is the largest volcano on the Juan de Fuca Ridge and hosts three robustly venting hydrothermal sites [Ashes, Castle, and Chasm (not shown)] within its summit caldera. It has been a buoyed NOAA observatory for several years. It has the longest co-registered time-series analyses of fluid and microbial community evolution following a volcanic eruption within the ocean basins. This area was the focus of five RFA's, and because of its importance in addressing the linkages among volcanism, crustal accretion, hydrothermal flow, and biological processes, extensive secondary infrastructure is planned for this site. Because this could be a hazardous environment, a 20 km extension cable is planned from the primary backbone cable. Multiple shorter cables will be laid with an ROV to provide power for an extensive array of sensors.

installation for ship and ROV days is 61, with 33 days required annually for maintenance.

Table 8. Estimated Installation and Annual Maintenance Days for Axial Seamount Node 4

Site	Commercial or ROV	Days	Comments
	Main cable lays		
Connect Backbone cable N4 to SN1	Commercial	1	Connect with ROV
SN1 cable to SN2 15 km 1/4 knt	ROV	4	Seabed reel, too difficult with ship
Install SN1 and connect	ROV	1	
Install SN2 and connect	ROV	1	
Contingency		1	
Total DAYS		**8**	
	Castle Hydrothermal Field		
Lower frame and put BN1 in place		1	Assuming 10 individual instruments
Lay cable SN1 to BN1 (C4), connect	ROV	1	3 km armored cable
Deploy instruments	ROV	2	Instruments go down on frame-pallet load
Seismometer and incubator drilled	ROV	1	Require boreholes in basalt and sulfide
Contingency	ROV	2	
Recover, redeploy instruments, check	ROV	3	Assume instruments fail 1st deployment
Total DAYS		**10**	
	Ashes Hydrothermal Field		
Same as for Castle but add 1 day	ROV	11	11 days because SN1 to BN2 is 6 km
Ashes static water column mooring		3	
Total DAYS		**14**	
Water sampling each site		**6**	3 days vent fluid sampling each field
	Geodetic Arrays		
Lower 2 towers		2	Direct path acoustic towers-include
One tower at SN2	ROV	1	Tilt meter, bottom pressure sensor
Lay cable from towers to SN2 (T)	ROV	1	
Install short-periods and cable	ROV	3	4 short-period seismometers east and west
Transponders on 100 m moorings (M)	ROV	3	Install 6 and connect
Contingency days		2	
Total DAYS		**12**	
Total DAYS for both sides		**24**	
TOTAL AXIAL INSTALLATION		**61**	
	Annual Maintenance		
Maintenance at each site	ROV	4	
Sampling at each site	ROV	4	
50% cable-connector failure	ROV	25	
TOTAL MAINTENANCE		**33**	

SN = secondary node; BN1 = low voltage benthic node.

6.0 Future Considerations

In prior versions of this document, a few key elements were not included because of time constraints. These include sections on required site characterization, sample recovery that is critical for calibrating many seafloor sensors, and upcoming technological developments that are likely to play a major role in RCO science and success over its 30-year history. The following section provides a brief summary of some of these topics.

6.1 Site Characterization

To optimally study observatory sites and develop cable and instrument deployment strategies, nested sets of bathymetric, side-scan, and sub-bottom profiling data are required. Lessons learned from Stage 1 and NSF-funded Ridge Integrated Study sites show that early mapping is critical to the optimal and efficient development of long-term experimental sites. Perhaps the highest, first order priority for Stage II is very early mapping of the node sites at multiple resolutions, and mapping of cable routes for planning and environmental assessment activities. Margin cable route sites should be mapped at least at 30-50 m resolution (EM300 or better) with coregistered chirp surveys. It is likely that environmental assessment studies will require video imagery of particularly sensitive areas. All of the main instrumentation sites will require mapping at least to a resolution of 5 m or better, and extensive video imagery to define bottom topography and roughness, to delineate fault scarps and fissures, and to avoid areas of venting or other environmentally sensitive and hazardous areas. This level of detailed mapping is best achieved with autonomous underwater vehicles (AUV's); ROV's can be used, but they are much less efficient for sonar-based mapping. It is likely that some sites, such as Axial Seamount and Blanco, will require ~several weeks each of mapping. It is absolutely critical that the mapping/environmental characterization studies be completed as early as possible.

Mapping is also important to help define scientific investigation of the sites. Most process-oriented studies of plate boundaries start with mapping. Addressing key questions concerning tectonic processes associated with the formation of oceanic lithosphere and active margins requires high-resolution bathymetric information that most present generation maps lack. Although mapping is commonly thought of as a one-time activity, the face of the seafloor is a dynamic one with new faults and seafloor eruptions occurring at less than decadal scales. Having tools to quantify these spatial changes in the time domain represents a central part of the approach to understand the mid-ocean ridge, transform, and margin environments.

6.2 Sample Return

Many of the geochemical sensors planned for installation on the RCO require calibration through sampling and analyses of fluids and gases when the instruments are installed and recovered. In the O&M section a few days at each site are included for these purposes. In addition to calibration of samples, however, many sites will also require sampling of rocks, fluids, and biota to examine linkages among geological, chemical and biological processes that will be well placed within the environmental context provided by the RCO sensors. Because of the dynamic, ever changing nature of active seafloor systems it will be important to have autonomous sampling capabilities in opportune sites (e.g. vents and seeps) that allow samples to be rapidly recovered from the seafloor. For example, there are dramatic, very short-lived changes in fluid and gas chemistry and biota during eruptive events. One recommendation has been to develop technologies that would allow release of sample modules to the surface and have them recovered by drones, which could rapidly return them to shore-based analytical facilities. While this may seem futuristic, the technology is now available to conduct such operations and these capabilities will certainly be viable during the 30 years that the RCO observatory is in operation.

6.3 Important Opportunities in Ecogenomics

The new field of ecogenomic sensors takes advantage of technology developed in the Human Genome Project, such as DNA and protein micro-arrays and large-scale DNA sequencing to discover microbial and animal community structure, metabolic activity, and how organisms respond to events in the ocean environment (e.g. earthquakes, volcanoes, toxic algae blooms, and changes in carbon, pH, and temperature).

Ecogenomic measurements are not currently possible in the oceans over long periods of time and space. However, the RCO will provide both high power and bandwidth on the seafloor and in situ analyzers are now under development (e.g. MBARI's Environmental Sample Processor that has "DNA on-a-chip" analytical capabilities). It is reasonable to assume that future RCO technologies will include robotically controlled distributed sensor networks that can adaptively survey and sample dynamically changing volumes of the ocean. These sensor robots, outfitted with physical, chemical, and ecogenomic sensors, will be capable of moving under remote control, in a 3D geometric formation through precisely controlled volumes of seawater to record spatial and temporal variations in aquatic environmental parameters, and monitor and respond to changes near volcanic or seismic activity. Development of new ecogenomic sensors that will enable this next generation type of science, are currently under development.

The long-term benefits of ecogenomic sensors include the discovery of new microbes, an understanding of the significance and role of these microbes in the oceans, and also the potential for discovery of new enzymes for pharmaceuticals and industrial applications. In the next 5 to 10 years, with the development of the RCO and new ecogenomic sensors we will know who is there and what they do for a better understanding of the immense diversity of the oceans and ocean processes and how they are interrelated to processes on land.

7.0 Experiment Descriptions For Individual Nodes

The following sections provide descriptions of experiments proposed at each node. The layouts are best efforts that attempt to integrate experiments described in disparate RFA's. Future science-based meetings will be required, which include interested scientists and engineers, and vehicle operators to further refine the experimental layouts and to accommodate new participants. The costs associated with most instrumentation are estimated based on current costs. In some cases they are very well known, in others the instruments are still in early developmental stages. Sections 7.1 – 7.12 provide guidance in planning efforts and minimum requirements for power, connectors, etc. Clearly some of these instrumental layouts are extremely complex. Because of this, as the RCO matures it will be critical to have "real estate" management of the sites.

7. 1 Node 1 Hydrate Ridge-California Current Transect
Location: 44°39.0'N 125°25.0'W
Overlapping RFA's at this Node:

- A Multi-Scale Ocean Observatory for Ocean Dynamics and Ecosystem Response along the Northeast Pacific Continental Margin
- A Northeast Pacific Hydrate Observatory System (NEPHOS) at South Hydrate Ridge
- An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from basin to Regional Scales
- The Coupling of Pelagic Particulate Matter Fluxes and Benthic Community Processes Across the NE Pacific Continental Margin: Long Time-Series Monitoring With Real-Time Data Acquisition and ControlSeismic and Geodetic Observations of the Cascadia Continental Margin: Towards an Effective Real-Time earthquake and Tsunami Warning SystemA Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific

Node 1 is located on the abyssal plain seaward of the central Cascadia deformation front along the Newport transect (Figs. 8 & 10). This transect serves a variety of interdisciplinary objectives, including integrated hydrologic, geophysical, and biogeochemical studies of gas hydrates, geophysical studies of subduction earthquake behavior, and regional and coastal water column studies. An extension cable with three sub nodes is planned for the summit of Hydrate Ridge and the adjacent subduction zone forearc.

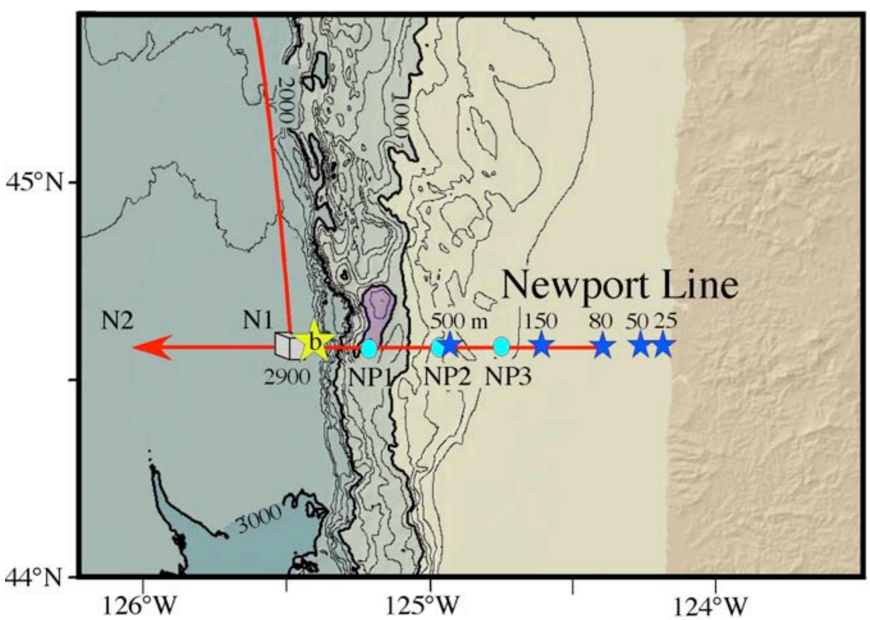


Figure 12. Map showing location of the primary and secondary nodes along the Newport Line. Gas hydrate related studies are primarily focused at secondary NP1 on the southern summit of Hydrate Ridge (light purple shading). Subduction zone related objectives are addressed by instrumentation placed at each of the three proposed secondary (NP1 - NP3). Benthic studies, physical oceanographic, biogeo-chemical, and carbon flux studies will be addressed at a series of 6 moorings. Five of these are outlined in the Coastal OOI CND (blue stars). The sixth mooring is a full water column vertical profiling mooring that will be placed on the backbone of the RCO (yellow star).

The primary node will support a seismic/geodetic station and a water column mooring, as well as a 70-km-long extension cable that extends across the accretionary complex almost to the shelf break. The cable forms the western component of the Coastal cabled observatory at this site.

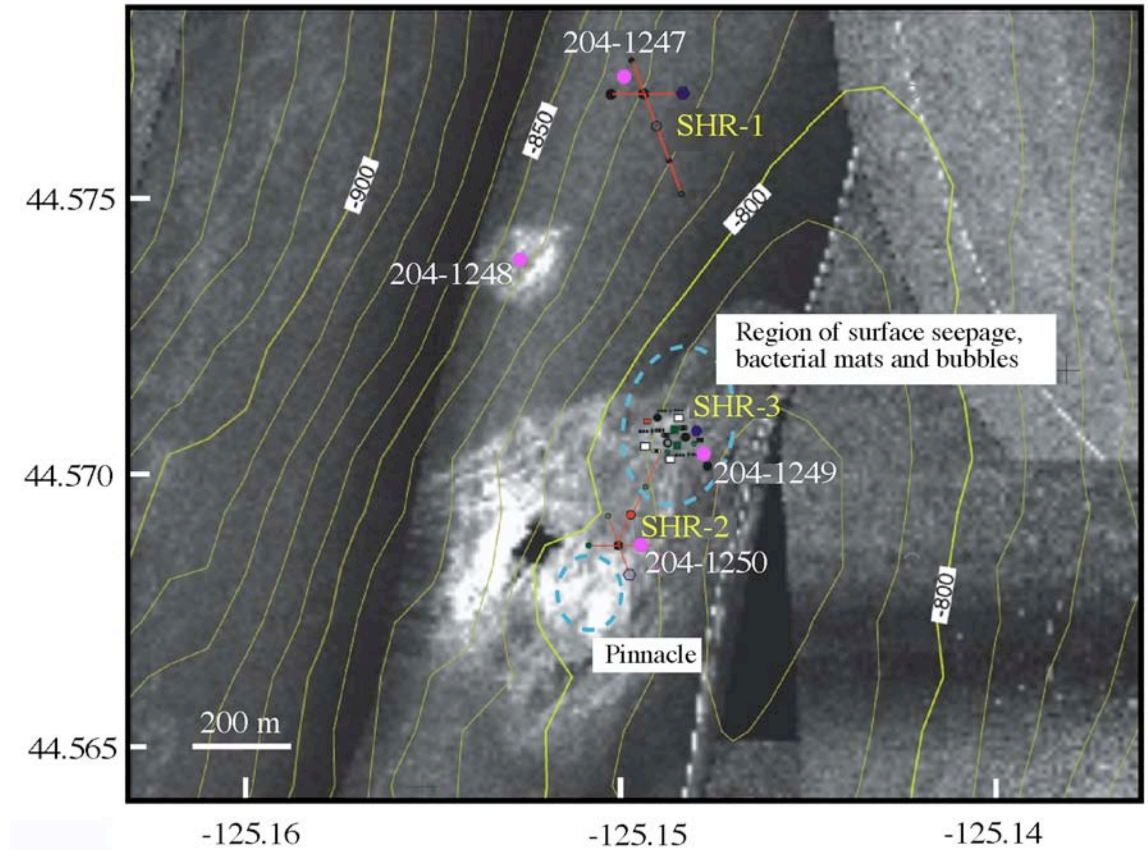
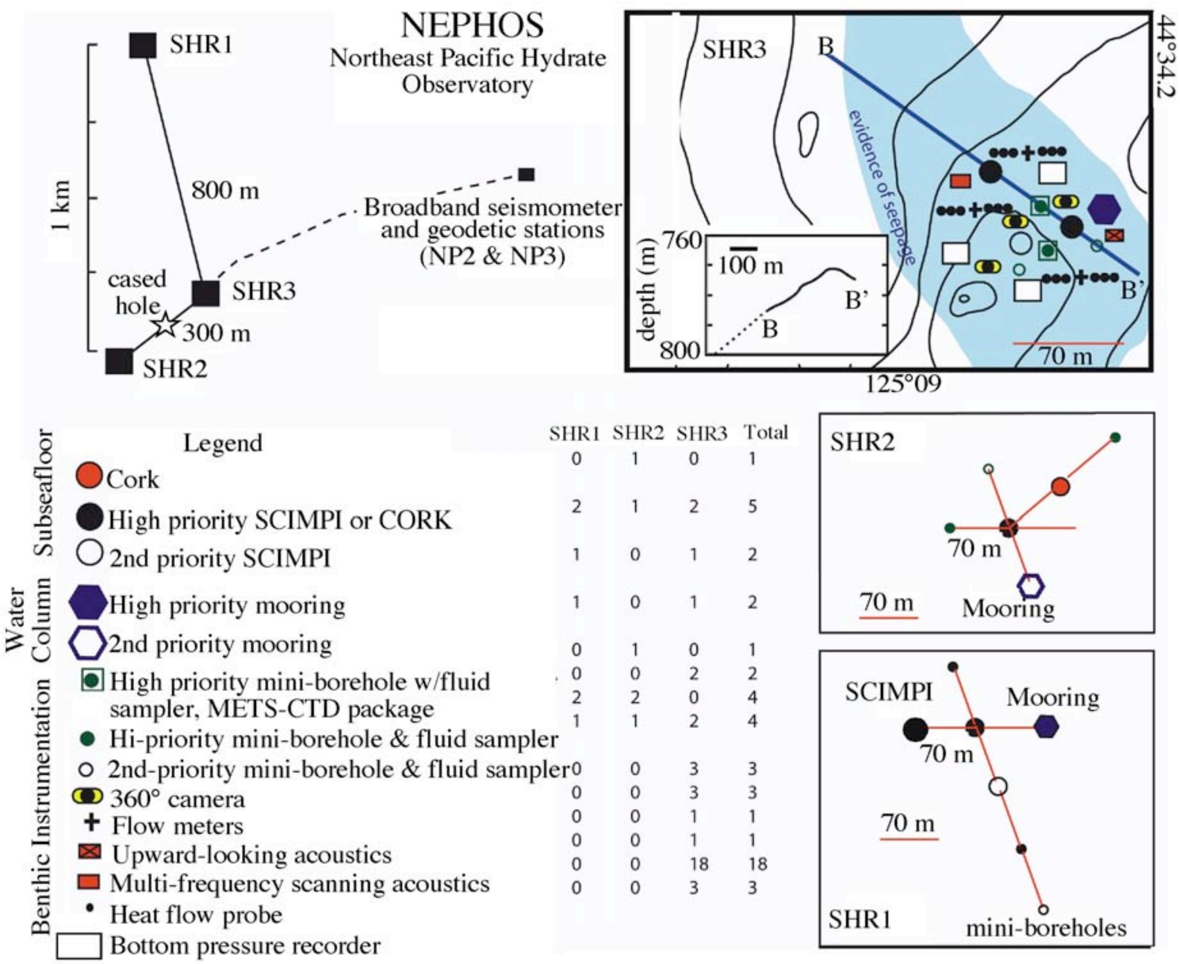


Figure 13. Map showing seafloor topography (yellow contours) and reflectivity (grey-scale image) at the southern summit of Hydrate Ridge. The conceptual instrumentation array (shown in detail in Figure 14) is.also shown, as are the locations of sites drilled during ODP Leg 204 (pink). The region characterized by seafloor seeps and bubble vents is outlined as is a carbonate pinnacle, which represents the only major authigenic carbonate structure on the southern summit. Except for the pinnacle, the seafloor topography is smooth. The vent region is characterized by mounds covered by bacterial mats within intervening hollows. Away from the mounds, the seafloor is covered with sediment, included (note: The reflectivity grid is shifted by ~150 m NW relative to the topographic grid. The source of this mismatch is under investigation. These maps should not be used for detailed planning.)

Secondary Node NP1 will be located on Hydrate Ridge, a large anticlinal structure near the toe of the Cascadia subduction zone. Up-dip flow of methane-rich pore water and free gas have led to the development of a focused region of shallow methane hydrate formation and local methane gas release to the overlying water column at the southern crest of the ridge. Abundant evidence for related, biogeochemical and hydrologic activity in the form of benthic cold seep related ecological systems is present at the ridge crest both at the benthic boundary layer in a several 10s-100m diameter region and in the subsurface across much of the crest of the ridge. Similar hydrate systems are common along this continental margin. Current evidence suggests that many of the processes are temporally highly variable. Changes in flow rates and even the direction of fluid flow (in or out of the seafloor) have been documented with time scales that range from tidal to several months. However, no long-term measurements are available, and the origin and impact of these changes are poorly understood. Specific hydrate-related scientific objectives include the following:

1) Studies of carbon fluxes by tides, hydrologic processes, tectonic stress transients, subsurface gas dynamics, and bottom water temperature variations in the subsurface and at the benthic boundary layer.
2) Studies of the biogeochemical interactions between methane fluxes and the nature and composition chemosynthetic biological communities and hydrologic process throughout the sedimentary section and across the benthic boundary layer.
3) Studies of the potential impact of projected future oceanographic changes associated with global warming on both sediment hosted hydrates and related methane fluxes to the seafloor and into the water column, the nature and rates biogenic degradation of water column methane, and the potential implications of large-scale methane hydrate destabilization on atmospheric and ocean chemistry.
4) Studies of methane plume dispersal and decay (via microbial oxidation) in the water column and the net effects on ocean chemistry. For example, enhanced methane/ CO_2 release from margin settings may combine with increasing atmospheric CO_2 uptake to focus the adverse affects ocean alkalinity/pH changes within the margin. The magnitude and impact of these changes are unknown, but potentially very significant to marine ecosystems.



	SHR1	SHR2	SHR3	Total
Cork	0	1	0	1
High priority SCIMPI or CORK	2	1	2	5
2nd priority SCIMPI	1	0	1	2
High priority mooring	1	0	1	2
2nd priority mooring	0	1	0	1
High priority mini-borehole w/fluid sampler, METS-CTD package	0	0	2	2
	2	2	0	4
Hi-priority mini-borehole & fluid sampler	1	1	2	4
2nd-priority mini-borehole & fluid sampler	0	0	3	3
360° camera	0	0	3	3
Flow meters	0	0	1	1
Upward-looking acoustics	0	0	1	1
Multi-frequency scanning acoustics	0	0	18	18
Heat flow probe	0	0	3	3

Figure 14. Schematic illustration of a comprehensive conceptual gas hydrates observatory. Some elements of the observatory can be constructed and installed as soon as funding is obtained; others require various stages of development.

of subseafloor, benthic and water column instrumentation, as outlined in Figure 9-10. Perturbation experiments may also be possible to allow controlled disassociation of subsurface hydrate to assess its impact on the environment. Vertical subsurface instrumentation arrays can include borehole geophones for across-hole seismic and electromagnetic tomographic studies, formation pore pressure measurements, chemical sampling, and microbial experiments. Benthic instrumentation around the boreholes (e.g. heat flow, fluid/carbon fluxes measurements, biogeochemical studies, acoustic Doppler studies) can be used to extrapolate the borehole data in 3D. Water column instruments will track the fate of methane and other vent products released into the ocean.

Secondary nodes NP2 and NP3 will be instrumented by seismic/geodetic stations. They will also help support instrumentation planned by the Coast Oceanography group.

Infrastructure The costs of OOI funded infrastructure at this site excluding the water column mooring is

MV benthic node NP1	1,5000,000
MV benthic node NP2	1,5000,000
MV benthic node NP3	1,5000,000
Extn cable N1-NP1 30 km	459,000
Extn cable N1-NP2 15 km	271,500
Extn cable N1-NP3 25 km	396,000
Optical conn. NP1 (2)	34,000
Optical conn. NP2 (2)	34,000
Optical conn. NP3 (1)	17,000
TOTAL	**$5,712,000**

Instrumentation. The cost of instrumentation is as follows:

Seismic/geodetic station (including bottom current meter) at primary node	$579K
Vertical hydrophone array for the mooring	$50K
Instruments for secondary node NP1 at hydrate ridge that are off-the-shelf or can be fabricated based on established plans.	$1,095K
CORKs and SCIMPIs at secondary node NP1	$5,000K
Seismic/geodetic station at secondary node NP2	$579K
Seismic/geodetic station at secondary node NP2	$579K
Pelagic/Benthic Monitoring system for each site	$1,505,677
TOTAL	$9,387677

Water column instrumentation (off-the-shelf or can be fabricated using existing designs):

Instrument	Components	Development status	Sampling rate	Power	Est. cost
Water column mooring with methane and other sensors	measure water column chemistry	Same technology proposed for NEPCM RFA. Two additional units needed for SHR.	4 MBytes per day	3 W	$390 each/ 2 units proposed. $780K
Seabird CTD			3 MBytes per day	6 W	

Subsurface instrumentation (under development):

Instrument	Components	Development status	Sampling rate	Power	Est. cost
CORK	pre-perforated casing for a 200 m hole; pressure and temperature sensors; ROV-removable seal; bio-traps; broad-band fluid sampler and sensor	Some development needed to adapt broadband fluid sampler, seals and bio-traps.	5 MByte per day	<0.1 W back-ground; 2.5W intermittent 15 W peak	~$1,500K (?)
mini-CORKs	Similar to CORKs but for shallow holes	Package under development	5 MByte per day	<0.1 W background 2.5 W intermittent	$500K (?)
SCIMPI	Phase 1: monitor temperature, pressure, resistivity to constrain fluid flow and gas hydrate formation through the hydrate stability zone in and underlying fluid conduit.	Phase I proposal well reviewed but not funded. Will be resubmitted.	1 Hz for each data stream; ~15 Hz/ SCIMPI ~5 MBytes/day	NA	$320K/ SCIMPI 9 SCIMPIs = $2,880K
seisSCIMPI and/or seisCORK	Phase II: Incorporation of geophones and/or hydrophones in SCIMPI and/or CORK Option A is for microearthquakes and low resolution structural imaging. Option B is for monitoring cracking fronts, high resolution imaging, etc.	Engineering plans under development by R. Stephen	12 channels per SCIMPI Option A: 50 Hz per channel 200 MBytes/ day/SCIMPI Option 2: 2000 Hz/ channel 8 GBytes/ day/SCIMPI	10 W per SCIMPI	~$50K additional/ SCIMPI x 9 = $450K

Benthic instrumentation (off-the-shelf or can be fabricated using existing designs, except for multifrequency acoustic bubble monitor):

Instrument	Components	Development status	Sampling rate	Power	Est. cost
Bottom Cameras	Panoramic views of the seafloor. Use to monitor observatory condition as well as hydrate evolution and associated fauna.	Design completed and ready for fabrication.	1 MB/image 8.7 GB/yr if an image is recorded each hour.	<1W plus intermittent draw of 100W for strobe lights	50K for 2 cameras and command/ power node (does not include engineering)
Heat flow observatory network probes (HEFLON)	Measure temperature at the seafloor and in shallow sediments. Proxy for fine-scale spatial variation in fluid flow.	Being designed for NEPTUNE-Canada.	1 sample /mn/sensor 7 kByte/day for each probe.	<0.6 W continuous ~2 W needed	$3K each 30 units proposed = $30K

				intermittently	
Bottom pressure recorders (BPR)	Sensor records ambient absolute pressure, which changes due to tides, uplift and other processes.	Autonomous instruments exist; cable-friendly version planned. Included in several other community experiments	12 MByte per day at 15 sampling interval	10 W	$50K each 3 units proposed = $150K
Seafloor flow monitors (SFM)	Measure fluid flow rate in and out of the seafloor	Design completed, including acoustic telemetry. Minimal design needed to mate to a cable	20 sample/s/ instrument 7 MBytes/day/ instrument	0.1 W per inst.	$20K each 6 units = $120K
5-150kHz seafloor up-looking ACDP	Measure high-freq. currents coupled to estimates of the seafloor fluxes and mooring data.	Standard technology – integrate with bubble monitor or water column mooring.	12 MBytes per day	6 W	$75K one unit at SHR3
Multifrequency acoustic bubble monitor	Quantify methane flux in bubbles by measureing bubble size distribution and rise rate.	To be developed based on acoustic instrumentation developed for Endeavor node	100 MBytes per day?	30 W?	Detailed estimate awaits funding and completion of pilot study.
Seafloor chem.. sensors (SCS) CH_4 - METS, LGR/TETHYS	Measure the composition and flux of fluids exchanged with the watercolumn at core benthic study sites	METS off-the-shelf but long-term application, interfaces and longevity NOT. Mass specs under develop.	Data rate is "small" (KB/day)	Power (order Watts)	10 METS w/interface x 20K/ea = 200K
Multiple Enzyme Analyzer (MEA)	Determines activities of 4 enzymes by measuring hydrolysis rates using fluorophore tags	Designed and built for a Biocomplexity project, MEA is currently being tested	Programmable assay rate. Each enzyme assay takes 20 minutes but can be run simultaneously	32W max	$50K/MEA
Sensor Head Integrated Pump (SHIP)	Low power, multipurpose chemical/optical sensor for nitrate, turbidity, metals, color, etc.; uses solid-state chemistry	Proposed to GEO-NSF-OCE-OTIC	25 Hz	0.5-3W depending on spectral range selected	$30K/SHIP

7.2 Node 2 Newport Line West

Location: 44°39.0'N 127°40.0'W

Overlapping RFA's at this Node:

- A Multi-Scale Ocean Observatory for Ocean Dynamics and Ecosystem Response along the Northeast Pacific Continental Margin
- An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from basin to Regional Scales
- Distributed pH Observatory: Assessing the Effects of the Anticipated Shift in the Upper ocean on the Oceanic Energy and Carbon Cycle
- The Coupling of Pelagic Particulate Matter Fluxes and Benthic Community Processes Across the NE Pacific Continental Margin: Long Time-Series Monitoring With Real-Time Data Acquisition and Control
- A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific

Science:

This node is critical for three types of regional scale studies. 1) It provides one of the few mid-plate sites for plate-scale seismology and geodynamics; this is important for understanding stress propagation through the plate as well as intraplate deformation and its relation to plate boundary failure. This node also provides regional scale sampling of the sub-tropical gyre.

2) Coupled with cabled profiling moorings at Node 1 (Rb) and on the shelf along the Newport Line (through the coastal component of the OOI), the water column mooring proposed for Node 2 (Rc) allows determination of biophysical processes from the exceptionally productive upwelling zone over the shelf to the nutrient-poor, subtropical waters west of the shelf break. In addition, sustained observations at this node, in the interior of the subtropical gyre, will provide insights into climate-scale (seasonal to interannual and interdecadal time scales) impacts on regional physics and ecology when compared with those at site Rh in the subpolar gyre. The exact location of the node is controlled by completing an east-west transect across the continental margin, as well as a profile normal to the Blanco Fracture Zone in support of potential studies of deep ocean tidal mixing, should an additional site to the south of the Blanco Fracture Zone become possible in the future. This node is also a key site to examine the coupling of pelagic particulate matter fluxes and benthic community processes across the shelf.

3) Finally, this node is key to studying the relationships between temporally-varying particulate fluxes and benthic community processes on relevant time scales from slope to abyssal depths in real time. This study will require 2 locations along the Newport Line at N1 and N2 and one extension beyond Plate. Sediment accumulation sites with low relief and distant from other observatory activity are required. This transect of stations is important because it crosses the continental margin from the base of the slope (out of range of commercial fishing activity) and reaches mid-plate. The pelagic and benthic monitoring network will provide real-time, interactive capability to assess pelagic/benthic coupling across the continental margin with sampling frequencies from hours to years for correlation with regional surface remote sensing and climate indices.

Infrastructure The costs of OOI funded infrastructure at this site excluding the water column mooring is :

mooring is :	LV benthic node	$161,000
	Extn cable N2–LV benthic node	$94,000
	2 Cu connect. benthic node to vertical profiling mooring	$14,000
	TOTAL	**$269,000**

Instrumentation. The cost of instrumentation is as follows:

Core seismic monitoring package	$80,000
1-day ROV –ship time	$50,000

In addition to the above infrastructure, there is also a pelagic and benthic monitoring network proposed. Another of these networks would also be placed near Hydrate Ridge.

Pelagic and benthic monitoring network

Mobile Rover	$534,770
Stationary Benthic platform	$494,540
Stationary Pelagic platform	$476,367
3 days ROV time	$150,000
Total	$1,785,677

The long-term real-time Pelagic/Benthic Monitoring System is used to monitor the benthic boundary layer and seafloor at regional sites in the NE Pacific for periods > 5 years. Three systems are proposed for this program to be deployed along a transect spanning the NE Pacific continental margin. Two of these sites are along the Newport line. In the future, ideally a third site could be added west of the Juan de Fuca Ridge.

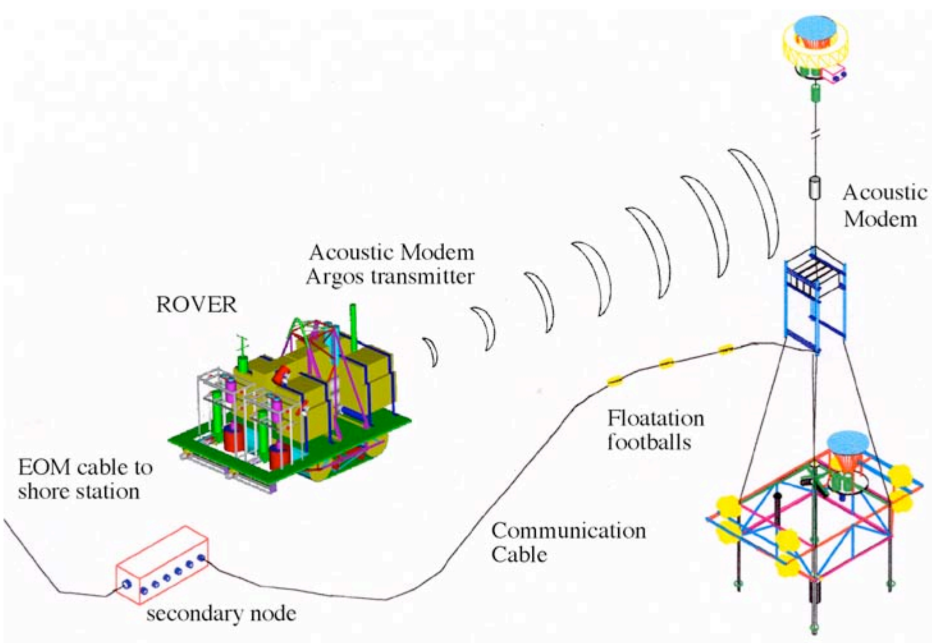


Figure 15. Pelagic/Benthic Monitoring System. Moored platform also includes cameras and sediment traps and sensors.

Conceptual Network Design for Benthic/Pelagic Monitoring System

1. Two locatios along Newport Line at Nodes 1 and 2. Sediment accumulation sites with low relief and distant from other observatory activity. Best represent a transect of stations across the continental margin from base of slope (out of range of commercial fishing activity) to abyssal depths. Pelagic ecosystem studies above sites would be beneficial. Also Station PAPA is attractive for an off-plate site.
2. Variables to be measured:
    a. Particulate matter fluxes to the sea floor (POC, PON, etc.)
    b. Sediment community oxygen consumption
    c. Bioturbation
    d. Epibenthic megafauna activity
    e. Current speed/direction
3. Extension cable of 600 m needed at each of two nodes.
4. Additional infrastructure: ROV for initial installation of arrays and for six-month servicing of mobile ROVER for battery recharging and detailed data transfer.
5. Required instrumentation/sensors
    a. Sedimentation sensors
    b. Time-lapse cameras
    c. ROVER
    d. Current meters
6. Primary infrastructure costs
    a. Initial survey of each station – 3 days shiptime/ROV time per station
    b. Servicing of ROVER with ROV every six months – 1 day per station
7. Power requirements: 5 Watts per site. Mobile Rover with autonomous rechargeable battery pack via ROV (6-month servicing).
8. Bandwidth requirements : 6.6 kilobytes per sec (66 kilobits per sec) data rate for each site.
9. Cost of fabricating three Pelagic/Benthic Monitoring Systems
    a. Mobile Rover - $534,770 each X 3 = $1,604,308.
    b. Stationary Benthic platform - $494,540 each X 3 = $1,483,620.
    c. Stationary Pelagic platform - $476,367 each X 3 = $1,429,101.
    d. Total cost of the Pelagic/Benthic Monitoring system for each site (node) would be $1,505,677.
    e. Total cost for 2 sites = $2,710,2174.

7.3 Node 3 Blanco Fracture Zone
Location: 43°45.0'N 128°00.0'W

Overlapping RFA's at this Node:

- An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from basin to Regional Scales
- Distributed pH Observatory: Assessing the Effects of the Anticipated Shift in the Upper ocean on the Oceanic Energy and Carbon Cycle
- An Earthquake, Physics, and Fault Mechanics Observatory on the Blanco transform Fault
- A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific

Science:

The Blanco node will be used for a seismic-geodetic experiment to understanding the basic physics of earthquake rupture by utilizing the short recurrence interval of magnitude 6-6.5 earthquakes on the Blanco transform fault to distinguish between the effects of geological heterogeneity and stress-state. It will contribute to the development of improved rheological models of oceanic transforms and the assessment of the implications for the geomorphology of transform fault zones and their environs and for global models linking mantle convection to plate tectonics. If a hydrothermal component is added it will contribute to characterizing the interactions between fluid flow, chemical and biological processes in the shallow lithosphere, and the thermal and geological structure of the fault zone. It is one of the sites identified for the interdisciplinary water column studies that will link ocean dynamics, climate and ecosystem response and will contribute to the plate scale seismology experiment. Figure 16 shows the segment of most interest and a network of Benthic Nodes that can cover a ~60 by 20 km wide area with a network of relatively low power instruments such as seismometers, fluid temperature sensors, and geodetic transponders. The original RFA includes additional deployments on the westernmost fault segment to study the interactions of the transform fault and the Cleft Segment of the Juan De Fuca Ridge. A branching unit is proposed for this extension.

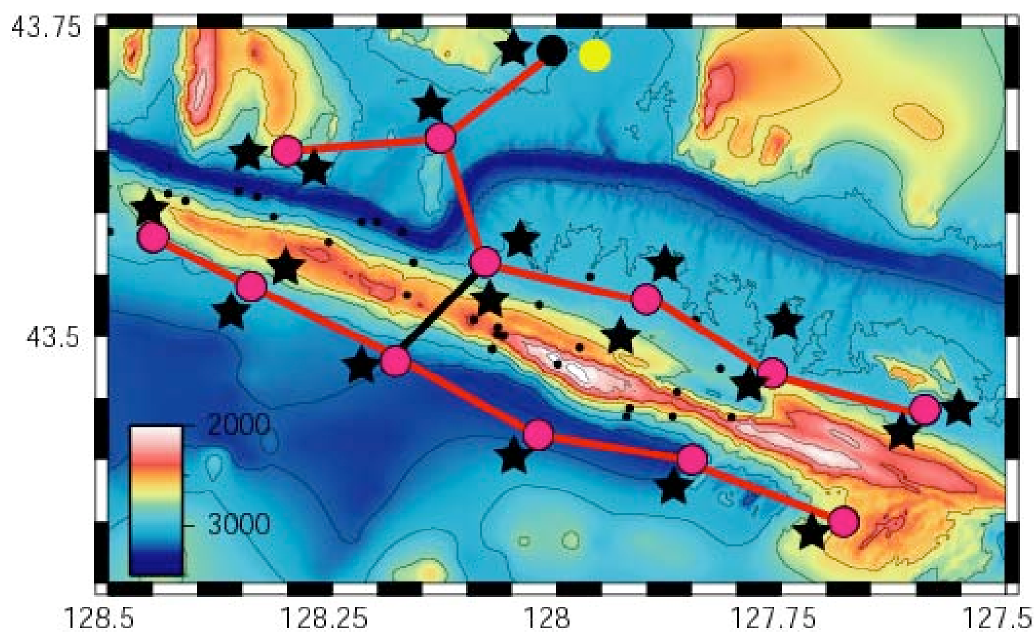


Figure 16. Map of Node 3 on the Blanco Transform Fault. The primary node (black circle), 12 Benthic Nodes (pink circles), and 18 OBS's (black stars) are shown. The 12 km cable that crosses the Blanco Ridge (black line) will need to be double armored. There will also likely be geodetic instrumentation attached to the benthic nodes. Aftershocks of the 1994 Mw 6.5 Blanco Ridge earthquake are shown as small black dots.

Infrastructure. The cost of infrastructure excluding a water column mooring is

12 LV benthic nodes	$1,932,000
145 km extension cables	$1,812,500
12 km double armored cable	$360,000
24 Cu connectors benthic node to instruments	$168,000
TOTAL	**$4,272,500**

Instrumentation. The cost of instrumentation are

18 WHOI broadband/strong motion OBS & pressure sensor @$80K*	$1440K
10 acoustic ranging geodetic stations @$40K	$400K
10 temperature sensors @$2K	$20K
TOTAL	$1860K

*10 of these instruments are already under construction and would be available for this project.

A horizontal hydrophone array comprising 3 moorings required at two sites (nominally node 3 and node 6 in the conceptual design) for the ROHAO acoustic experiment would cost $1M

7.4 Node 4 Axial Volcano
Location: 45°50'N 129°40'W
Overlapping RFA's at this Node:

- An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from basin to Regional Scales
- Distributed pH Observatory: Assessing the Effects of the Anticipated Shift in the Upper ocean on the Oceanic Energy and Carbon Cycle
- Regional Ocean Hydrophone Array Observatory (ROHAO)
- A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific
- A Cabled Observatory on the Juan de Fuca Ridge

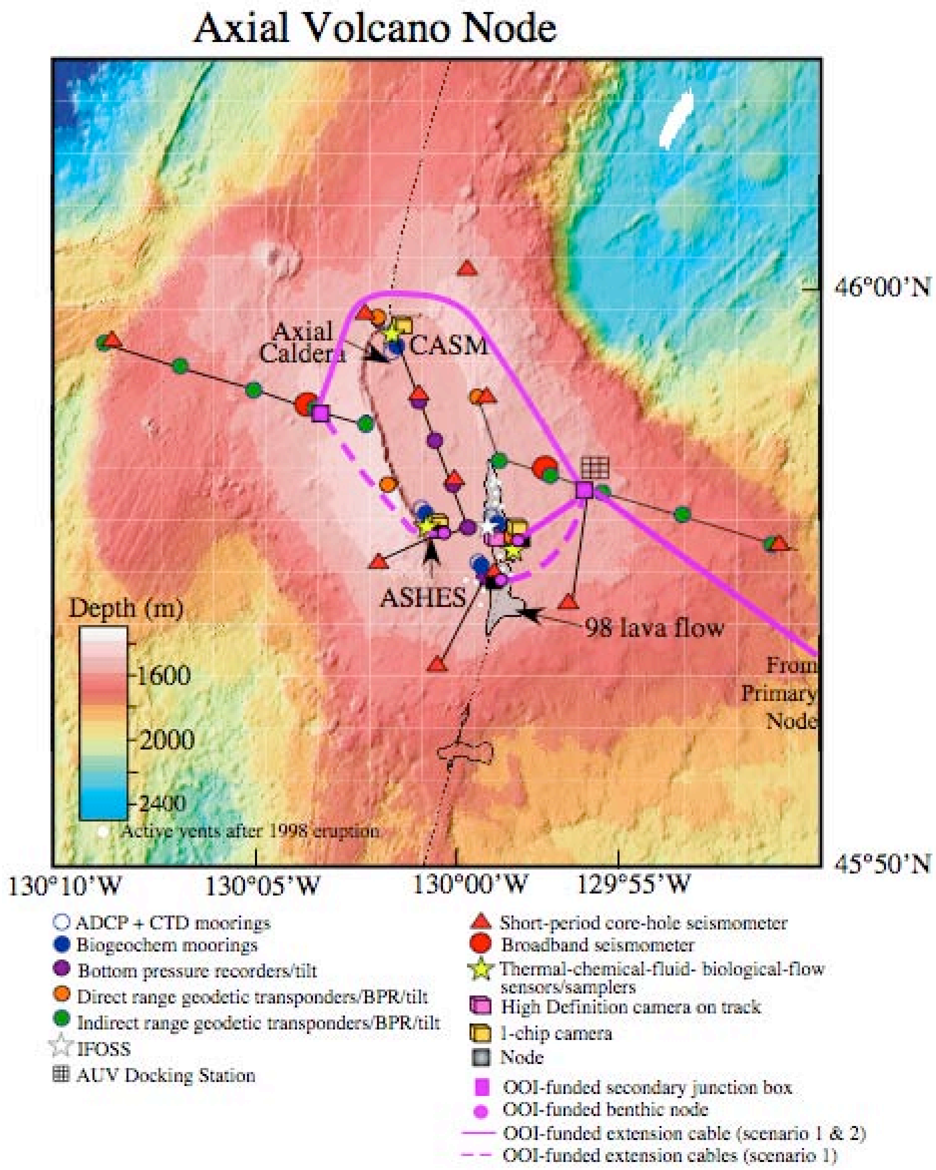


Figure 17. Map of Node 4 on Axial Volcano showing the configuration of the experiment as originally envisioned in the RFA proposal "A cabled observatory o the Juan de Fuca Ridge. Scenario 1 is what was proposed in the RFA's, Scenario 2 is the trimmed down version outlined in this document.

Science:
The Axial Volcano node is one of the sites identified for studies of the Juan de Fuca Ridge. It has the most robust magma supply on the JdF and is the site of the NOAA's New Millenium Observatory (NeMO; see http://www.pmel.noaa.gov/vents/nemo/) that documented the 1998 eruption. Given the work that has already been accomplished at this site, it presents an unparalleled opportunity for integrated long-term studies of active seafloor volcanism. It is also one of the sites identified for the deployment of a mooring that will be used interdisciplinary water column studies that will link ocean dynamics, climate and ecosystem response. The deployment of a vertical hydrophone mooring and a broadband seismometer at Cleft will maximize the area that will by covered by the hydroacoustic monitoring and plate scale seismology experiments.

Infrastructure. Two secondary nodes will be deployed on the western and eastern sides of the Caldera. A cable extends from eastern secondary node to a benthic node at the Castle vent site. The costs of the Scenario 2 infrastructure excluding a a profiling mooring is as follows:

2 MV benthic nodes (east &west)	$3,000,000
Extn cable N4-east MV benthic node 20 km	$334,000
Extn cable east MV benthic node-west MV 15 km	$271,500
LV benthic node Castle	$161,000
Extn cable & opt connectors Castle 3 km	$114,000
Geodetic Array LV benthic nodes (8)	$1,288,000
Surface cable lay 50 km	$625,000
LV benthic node Ashes	$161,000
Extn. cable & optical conn. Ashes 6 km	$144,000
TOTAL	**$6,098,500**

Instrumentation. At the primary node the instrumentation will comprise

Broadband seismometer	$60K
Vertical hydrophone array on profiling mooring	$50K
5 days ship/ROV time to install	$250K
TOTAL	$360K

An illustrative basic suite of 10 instruments for the Castle (or any other hydrothermal) vent site might comprise

Short period seismometer	$25K
Bottom pressure recorder	$50K
T-resitivity-hydrogen	$35K
Microbial incubator	$70K
Electrochemical sensor array	$20K
Thermistor array	$8K
MAV current meter	$8K
One-chip camera	$35K
Interactive fluid/particulate sampler	$150K
Gamma detector	$50K
$15k per instrument ≤100 m cable and connectors	$150K
TOTAL	$601K

The instrumentation for a seismic/geodetic array might comprise

8 Short period seismometers	$200K
2 Direct range geodetic transponders/BPR/tilt	$100K
6 Indirect range geodetic transponders/BPR/tilt	$450K
1 Interferometric fiber optic seafloor strain	$75K
TOTAL	$825K

A static water column mooring for monitoring the hydrothermal plumes would cost

Static mooring w/ hook up to benthic node	$200K
CTD	$60K
2 x Seapoint Light Backscatter Sensor	$20K
3 x Time-series Sediment/Larval Trap	$2K
2 x Water Transfer System	$60K
Laser Scattering / Transmissometry	$35K
Iron, Manganese, pH analyzer	$40K
TOTAL	$417K

7.5 Node 6 Subduction Zone
Location: 46°39.0'N 125°50.0W
Overlapping RFA's at this Node:

- A Multi-Scale Ocean Observatory for Ocean Dynamics and Ecosystem Response along the Northeast Pacific Continental Margin
- An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from basin to Regional Scales
- Distributed pH Observatory: Assessing the Effects of the Anticipated Shift in the Upper ocean on the Oceanic Energy and Carbon Cycle
- A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific
- Seismic and Geodetic Observations of the Cascadia Continental Margin: Towards an Effective Real-Time earthquake and Tsunami Warning System

Science:

Node 6 is located seaward of the Cascadia deformation front and included a cable with two subnodes to address subduction zone and water column objectives. The subduction zone objectives are summarized below; the water column objectives are discussed Sections 2.4 and 4.4. This transect is also co-located with a transect being planned by the Coastal Observatories.

The Cascadia Subduction zone is known to have generated historically enormous (Mw 9+) earthquakes and tsunamis. Recently reported correlations between forearc basin structure and the slip history of large earthquakes in other subduction zone provide a framework for designing a seismic and geodetic network that will lead to a better understanding of the subduction zone dynamics and earthquake/tsunami hazards in the Pacific Northwest. This model predicts that forearc segments characterized by lows in the gravity field and deep basins should be locked during the inter-seismic period, whereas forearc segments characterized by gravity highs should be creeping. In this model, larger earthquakes tend to nucleate at boundaries between gravity highs and low, and then propagate across the lows. This observed behavior has been associated with long-term variations in the frictional properties of the megathrust fault plane.

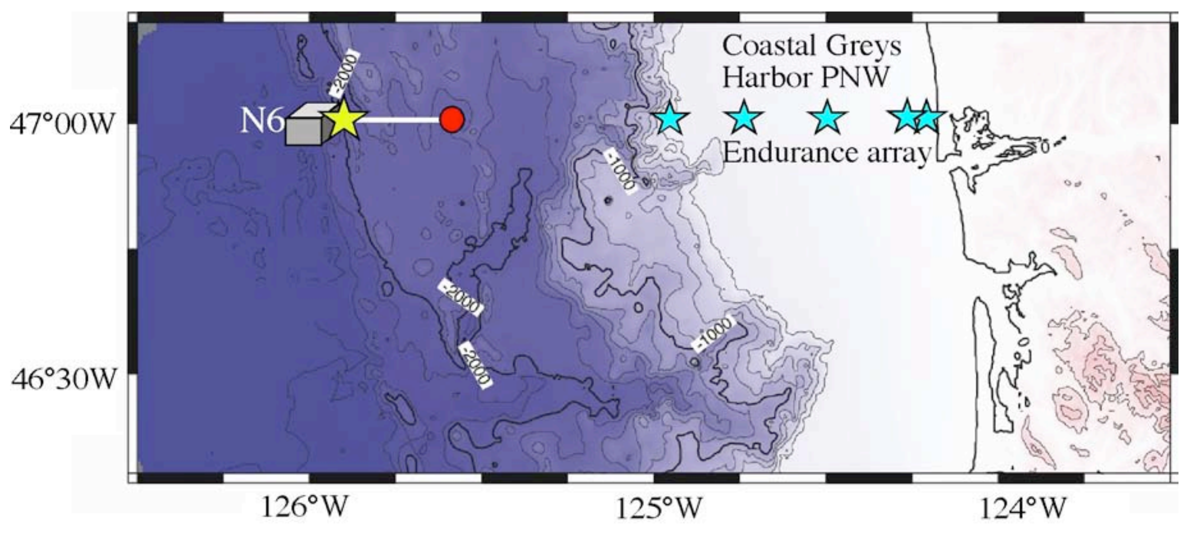


Figure 18. Topographic map of the Cascadia accretionary margin offshore central Washington showing location of Node 6, the associated seismic/geodetic transect secondary node (red dot), RCO full water column mooring (yellow star), and Coastal Endurance array of five uncabled moorings (blue stars).

With a seismic and geodetic transect originating at Node 6, which crosses the largest gravity low on the Cascadia margin, and a transect at Node 1, which crosses the gravity high at the southern end of this basin, this model can be tested. Geodetic and seismic data are also required to understand processes that determine the updip limit of the seismogenic zone. This updip limit cannot be resolved by land-based instruments and is critical for evaluating the tsunamigic potential of the next large earthquake on the Cascadia subduction zone. Finally, a number of studies indicate that oceanic transform and subduction faults may be preceded by precursory activity (see Node 4 discussion – Blanco fracture zone). Combined with recent advances based on predicting the eventual magnitude of an earthquake from the initial P waves, the planned studies of the subduction zone have the potential to lead to development of early warning strategies for large earthquakes.

The required geophysical instrumentation includes horizontal and vertical geodetic measurements as well as seismological components. 1) While marine geodetic measurements are challenging, the viability of marine GPS has been clearly demonstrated over the past several years. At present, data are restricted to measurements at infrequent intervals; a cabled or buoyed observatory would permit acquisition of continuous GPS data. The value of continuous GPS data for subduction zone studies was demonstrated by recent exciting results on episodic tremor and slip at the downdip end of the Cascadia subduction zone. 2) strainmeter measurements determine the internal deformation spanned by the station, which should have an aperture of ~1.4 times the water depth. 3) Bottom pressure measurements complement the seafloor GPS by providing information on vertical motions. 4) A broadband seismometer is planned for each station for full waveform recording (and modeling) of teleseismic and regional earthquakes. 5) An L-shaped array of short period instruments is planned for each station to provide location capabilities for small, local earthquakes and possible tremor associated with fluid motion along the thrust plane and/or within the accretionary complex. Temperature probes and a bottom current meter are included in each station to help monitor the seafloor environment and understand coupling of motion between the ocean and the seafloor.

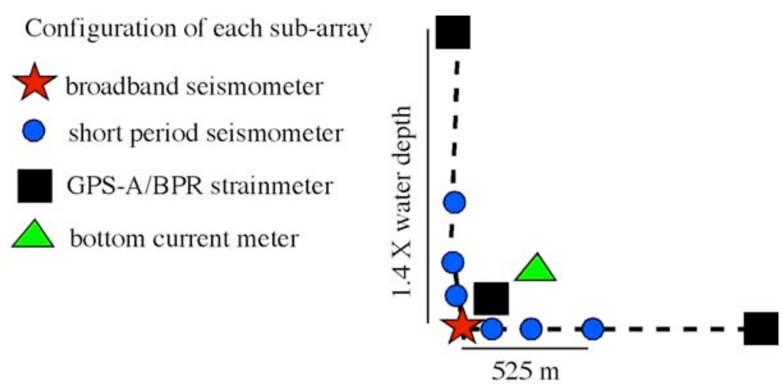


Figure 19. Schematic illustration of a seismic/geodetic station.

Estimated total cost of each seismic/geodetic station is $579K (seismometer - $80k; short-period geophones – 6 x $20k; acoutic array for strainmeter - $230k; GPS/acoustic link - $90k assuming that a water column buoy will be co-located; temperature probes – 3 x $3k; bottom current meter - $10k; cable - $40k). Figure 19 shows a schematic illustration of a seismic/geodetic station.

Infrastructure.

MV benthic node	$1,500,000
Extension cable 40 km	$584,000
Extension cable 24 km	$84,000
TOTAL	**$2,168,000**

Possible Instrumentation for a seismic/geodetic station:

Instrument	Components	Development status	Sampling rate	Power and timing	Estimated cost
Broadband seismometer	Record teleseismic, regional and local earthquakes;	Ready except for package assembly and integration to Observatory	100 samples/s 3x24 bits/sample	2.5 W and 0.5 ms timing accuracy	$70k
Strong motion seismometer	Record strong motion.	Ready except for package assembly and integration to Observatory	500 samples/s	2.5 W and 0.1 ms timing accuracy	$10
Short period seismic array	L-shaped array of 6 sensors to record local earthquakes and tremor related to fluid flow	Ready except for package assembly and integration to Observatory	100 samples/s /channel. 18 channels.	5 W and 0.5 ms timing accuracy	$20K each
Strain meter	L-shaped array of precision acoustic interrogators on the seafloor with aperature 1.4 x water depth.	Ready except for integration to Observatory.			$230k (4x$20k + 3x$50k)
Bottom pressure recorders (BPR)	Sensor records ambient absolute pressure, which changes due to tides, uplift and other processes.	Autonomous instruments exist; cable-friendly version planned. Included in several other community experiments	12 MByte per day at 15 sampling interval	10 W	$50K each 3 units proposed = $150K
Heat flow observatory network probes (HEFLON)	Seafloor and shallow subseafloor temperature at center and ends of L-shaped array.	Being designed for NEPTUNE-Canada.	1 sample /mn/sensor 7 kByte/day for each probe.	<0.6 W continuous ~2 W needed intermittent-ly	3 x $3K
GPS/acoustic	Submarine GPS measurements to determine displacement of station relative to GPS stations on land	Ready except for adaptation to observatory. Have been running offshore Cascadia and Peru.			$90k (assuming availability of oceanograph ic mooring nearby)

A horizontal hydrophone array comprising 3 moorings required at two sites (nominally node 3 and node 6 in the conceptual design) for the ROHAO acoustic experiment would cost $1m.

7.6 Node 7 Endeavour Segment
Location: 47°56.5N 129°04.0'W
Overlapping RFA's at this Node:

- An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from basin to Regional Scales
- Distributed pH Observatory: Assessing the Effects of the Anticipated Shift in the Upper ocean on the Oceanic Energy and Carbon Cycle
- VIA (Vent Integrated Acoustics) Cabled Experiment: Main Endeavour Field, Juan de Fuca Ridge
- Regional Ocean Hydrophone Array Observatory (ROHAO)
- A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific
- A Cabled Observatory on the Juan de Fuca Ridge

Science:

The Endeavour node is part of the NEPTUNE Canada cabled observatory and serves as one of the key sites identified in the RFA proposal "A Cabled Observatory on the Juan de Fuca Ridge". The Endeavour is seismically active and hosts at least five high-temperature vent fields spaced approximately 2 km apart with abundant areas of diffuse flow, both nearby and distal to the high temperature fields. It also hosts the highest temperature organism known, which grows at 121°C. It is the ideal site to study the dynamic linkages between seismicity and hydrothermal processes. It is also an optimal site to study processes and fluxes in hydrothermal plumes.

The RFA proposal "Vent Integrated Acoustics (VIA) at the Main Endeavour Field, Juan de Fuca Ridge" integrates two complementary acoustic methods comprising acoustic imaging and acoustic scintillation. A third method, acoustic tomography, is planned for a future phase on the project and will measure water temperature and flow rates on a field-wide scale. The objective of the integrated acoustic imaging and scintillation is to monitor hydrothermal plume properties (volume and heat fluxes, bending, entrainment, particle distribution, turbulence) and partitioning between plume and diffuse flow on time scales ranging from hours to years to advance understanding of linkages of hydrothermal flow to oceanographic (tides), geological (earthquakes, faulting, igneous intrusive-extrusive activity), and biologic (micro- and macro-blooms and dispersion) events, initially on the scale of a vent cluster (Hulk or equivalent vent cluster), and eventually on the scale of the entire MEF with the addition of acoustic tomography.

Endeavour is one of the sites identified for the interdisciplinary water column studies that will link ocean dynamics, climate and ecosystem response. The deployment of a vertical hydrophone mooring a will maximize the area that will by covered by the hydroacoustic monitoring.

It is assumed that NEPTUNE Canada will deploy cables and nodes that will extend to the Main and Mothra vent fields, a broadband seismometer site on the western side of the axial volcanic high, and moorings to the north of the Main Field and just to the south of Mothra. In this design, a benthic node will be deployed to the east of the axial volcanic high at the latitude of High Rise and will connect Sasquatch and to a cable that links branching nodes and instruments on a geodetic profile that crosses the axial valley. Future augmentation should include a 15 km long cable and secondary node in the axial valley south of the primary node to allow an additional mooring for water column experiments.

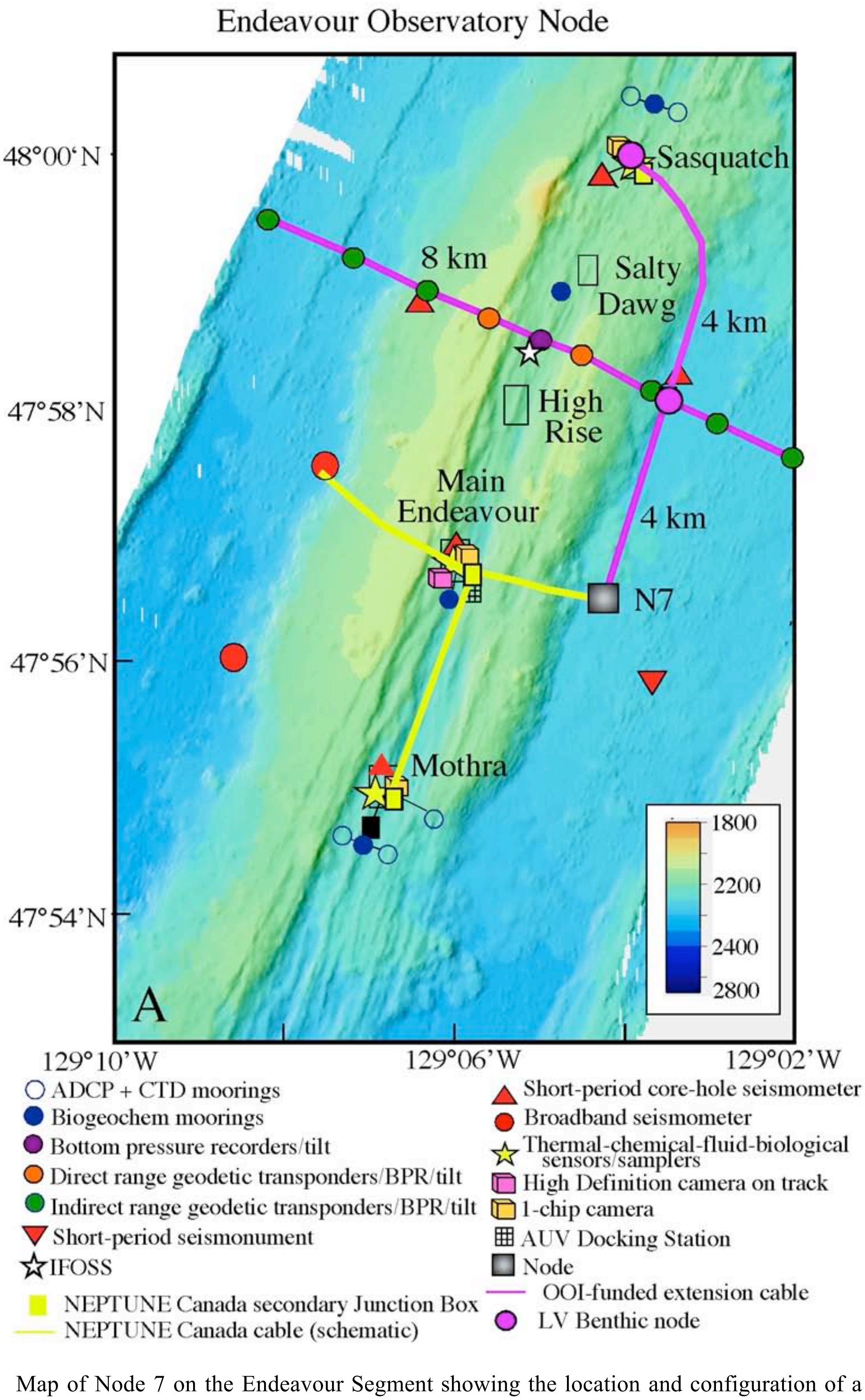


Figure 20. Map of Node 7 on the Endeavour Segment showing the location and configuration of a less extensive experiment than what was originally envisioned in the RFA proposal "A cabled observatory on the Juan de Fuca Ridge", Depending on the costs of Stage II, some of this infrastructure will need to be removed so that Stage II is not compromised. .

Infrastructure. The costs of the infrastructure shown in Figure 20 is as follows:

Cable from N7 to GT LV BN 4 km	$124,000
Geodetic transponder LV benthic node (GT LV BN)(4)	$644,000
Cable for geodetic transponders 8 km	100,000
Sasquatch LV benthic node	161,000
Cable from GT LV BN to Sasquatch LV BN 4 km	124,000
TOTAL	**$1,153,000**

Additional Infrastructure. Additional infrastructure envisioned in the initial RFA is as follows

3 km cable to High Rise	$80,000
Benthic node at High Rise	$161,000
Benthic node to accommodate mooring south of Mothra	$1,5000,000
Cable from N7 to moorng benthic node (15 km)	$271,000
TOTAL	**$2,012,000**

The vent integrated acoustics experiment requires the following infrastructure

Secondary junction box near sulfide structure Hulk (provided by NEPTUNE Canada)
3 or 4 extension cables with ROV mateable connections to sonar moorings

Instrumentation. At the primary node the instrumentation will comprise

Broadband seismometer	$60K
Vertical hydrophone array on profiling mooring	$50K
TOTAL	**$110K**

The vent integrated acoustics experiment requires the following instrumentation

2 acoustic imaging sonars	$200K
Connection to NEPTUNE Canada	$50K
Two-way reciprocal scintillation system	$175K
or one-scintillation system @ $100k	
Connection to NEPTUNE Canada	$50K
TOTAL	**$475K**

A static water column mooring for monitoring the hydrothermal plumes at the southern secondary node would cost

Static mooring w/ hook up to benthic node	$200K
CTD	$60K
2 x Seapoint Light Backscatter Sensor	$20K
3 x Time-series Sediment/Larval Trap	$2K
2 x Water Transfer System	$60K
Laser Scattering / Transmissometry	$35K
Iron, Manganese, pH analyzer	$40K
TOTAL	**$417K**

At each of the four instrumented vent fields, an illustrative suite of 10 instruments might comprise

Short period seismometer	$25K
Bottom pressure recorder	$50K
T-resitivity-hydrogen	$35K
Microbial incubator	$70K
Electrochemical sensor array	$20K
Thermistor array	$8K
MAV current meter	$8K
One-chip camera	$35K
Interactive fluid/particulate sampler	$150K
Gamma detector	$50K
TOTAL	**$451K**

The instrumentation for a geodetic profile might comprise

3 Short period seismometers	$100K
2 Direct range geodetic transponders/BPR/tilt	$100K
6 Indirect range geodetic transponders/BPR/tilt	$450K
1 bottom pressure recorder/tilt	$50K
TOTAL	**$700K**

7.7 Node 8 ODP1027
Location: 47°45.6'N 129°04.0'W
Overlapping RFA's at this Node:

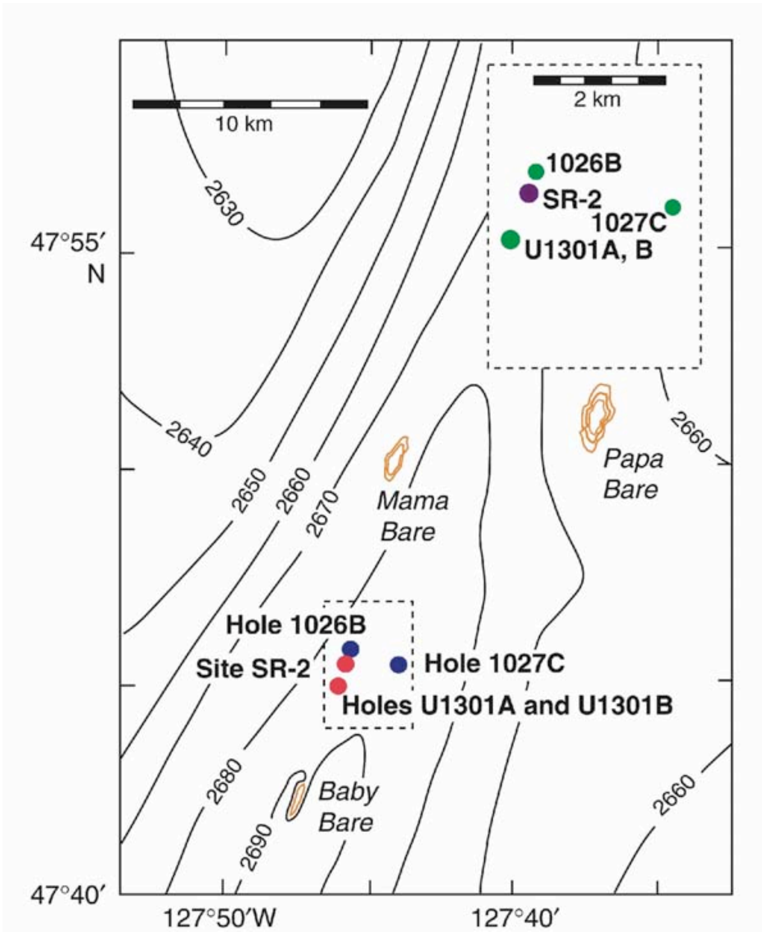
- Regional arrays of borehole observatories for sustained time-series observations of (a) subseafloor hydrogeological processes and (b) formation pressure as a proxy for plate-scale strain
- Distributed pH Observatory: Assessing the Effects of the Anticipated Shift in the Upper ocean on the Oceanic Energy and Carbon Cycle
- A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific
- A Cabled Observatory on the Juan de Fuca Ridge

Science:

The oceanic crust is the largest fractured aquifer on the planet and may harbor a subseafloor biosphere that rivals that of the continents. However, relatively little is known about the actual flow pathways within the crust and overlying sediments and many inferences about the subsurface distribution of properties remain untested. Hydrogeologic systems in the ocean crust and sediments play key roles in influencing rock alteration, mineral formation, and hydrocarbon migration. Mass, heat, and chemical exchange between oceans and the subseafloor influence the properties of the rocks and the microbial populations we now know inhabit them. Hydrologic processes and their consequences are highly linked. For example, earthquakes change the regional state of stress that in turn influence permeability, fluid pressure, fluid flow, which in turn influences such things as mineralization and nutrient supply to microbes. Feedback among these processes is ubiquitous: mineralization, rock alteration, and gas hydrates generated by fluid flow change the mechanical and hydrologic properties, commonly to the point of seismogenic failure.

Borehole experiments provide the only means to study directly processes active in the subsurface. The borehole observatory approach was initiated in 1991 as part of the Ocean Drilling Program, with two sealed and instrumented CORK (circulation obviation retrofit kit) installations in the active hydrothermal "reservoir" in Middle Valley, northern JdFR. Since that date, CORKs have been deployed in eighteen holes in various tectonic settings including six on the eastern flank of the Endeavour Segment of the Juan de Fuca Ridge. Example of specific questions that can be addressed with an array of regional borehole observatories include:

- What is the magnitude, nature and variability of permeability and storage properties as a function of fluid pressure and spatial and temporal scale?
- What are the relationships between permeability, fluid chemistry, microecology, and seismic properties?
- What is the magnitude of global fluxes, size or reservoirs, residence times, and response to transient forcing?
- What is the response of the biosphere to the variability of fluid flow?
- What is the relationship of these hydrologic processes with lithospheric cycling, magmatism, seismicity, and gas hydrate formation?
- How does an entire tectonic plate respond to transient seismic-hydrogeological events?



1026B	CORK	~25W, 50 MB/yr
1027C	CORK	<1 W, 2 MB/yr
1301A	CORK	<1 W, 2 MB/yr
1301B	CORK	~25W, 50 MB/yr
SR2-A (2008)	SeisCORK	~120W,0.13MBs
SR2-8 (2008)	CORK	~25W, 50 MB/yr

Figure 21. Experimental layout for instrumented borehole observatories east of the Juan de Fuca Ridge. Hole 1027C is planned as a branch point for NEPTUNE Canada. From that branch point, a cable array would need to be deployed to 5-6 borehole observatories with power and data needs as shown above.

Borehole Prioritization. In choosing priority sites, emphasis was placed on science that could be achieved by taking full advantage of planned cable routes for NEPTUNE Canada: this would allow for the highest payoffs at the lowest costs. NEPTUNE Canada has indicated that their cable route will include a node at the Vancouver margin hydrates area (Site 889) and that Middle Valley and Site 1027 in the mid plate will be priorities for at least incorporating branch points (Figs. 2-4). This gives a de facto prioritization of sites ODP/IODP Site 857 at Middle Valley (H-1), Mid-Flank Sites 1026, 1027, SR-2; 1301A/B) And Baby bare Outcrop (H-5), and Vancouver Margin Cascadia Site 889 (H-8).

While it's a de facto prioritization, there is also very strong scientific justification for the three sites in question, and they are the three sites that may have the best justification for utilizing the NEPTUNE capabilities.

Site H-5 corresponds to the ODP/IODP Second Ridge (SR) area in ~3.5 Ma crust on the eastern flank. There are currently 4 working CORKs within 3 km. These include three (1026B, 1301A, 1301B) with the latest multi-zone model with downhole osmosamplers for fluids and microbiology, situated on the buried basement high that has been demonstrated to produce ~60C crustal fluids and is therefore a prime candidate for deep biosphere studies. There is one original CORK at an underpressured site ~2 km farther off-axis than 1026B, which continues to record good pressures with signals of tectonic events. IODP is now scheduled to return in summer of 2008 to (a) deepen and reinstrument 1027C with a multi-zone CORK, and (b) establish and instrument a new site (SR-2) ~mid-way among the others as a source well for true hole-to-hole hydrological studies in three dimensions. It is also being proposed that IODP install a prototype SeisCORK at this site during the 2008 revisit.

Infrastructure.

ROV laid extn cable (6 off) 2 km each; 6 km total	$624,000
MV benthic node	$1,500,000
TOTAL	**2,124,000**

Instrumentation. Downhole CORK instrumentation would be funded through IODP.

7.8 Node 9 Barkley Canyon
Location: 48°21.30'N 126°05.9'W
Overlapping RFA's at this Node:

- An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from basin to Regional Scales
- A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific

Science:
This is a funded instrumented node on Stage 1 and is of interest predominantly because it has significant methane hydrate deposits at a water depth of ~ 850 m. As currently planned, it will be instrumented by Neptune Canada in 2007 (source for information bellow is the December, 2005 Neptune Canada Newsletter). Sensors include: in situ temperature probes to depths of 1 m or more, three rotary cameras deployed on known mounds, and a crawler developed by the International University of Bremen. The crawler will carry a CTD, methane sensor, Schlieren optical system, a webcam to control the vehicles movements, a video system to quantify gas bubbles. A water column profiler will be installed at a water depth of ~ 400 m on the continental slope equipped with a CTD, oxygen sensor, fluorometer, transmissometer, nitrate sensor, carbon dioxide sensor, a multi-frequency acoustics package, and an upwelling/downwelling radiometer. Bottom-mounted instruments will consist of an upward-looking 150 kHz ADCP and a pressure sensor. The bottom-mounted instruments will be deployed in 2007, with a profiler added in 2008. A benthic ecology experiment at this site will include four instrumented areas that included acoustic current meters, sediment traps, rotary sonar systems, plankton pumps, video cameras, and high resolution still cameras. Also included is a CTD with a fluorometer, microbial metablic sensor package and a laser optical plankton counter.

This node is critical to water column investigations to examine the biophysical variability in the WWD as it is advected towards the coast. A full water-depth mooring at this site (Rg) will also delineate the variability of mass and biogenic fluxes in the N/S divergence. It is also important in comparing onshelf/slope/offshelf processes and fluxes at locations of different upwelling and mean current regimes. It is located in a highy dynamic and ecologically diverse region of the NE Pacific and will provide insights into climate-scale (seasonal-to-interannual and interdecadal time scales) impacts on regional physics and ecology.

This mooring, although of high priority to water column studies was removed from costing Stage II in this document. The cost with the mooring was ~ $4M. This cost was high because it includes a 40 km cable from the Stage 1 node, downslope to the site of interest for this experiment. If a node were added on to Stage 1 during its initial installation, the cost for this experiment would be significantly less. This will need explored further once the relationship between Stage I and II becomes more mature.

7.9 Node 10 ODP889
Location: 48°42.00'N 127°10.0'W
Overlapping RFA's at this Node:

- Regional arrays of borehole observatories for sustained time-series observations of (a) subseafloor hydrogeological processes and (b) formation pressure as a proxy for plate-scale strain
- Regional Ocean Hydrophone Array Observatory (ROHAO)
- Seismic and Geodetic Observations of the Cascadia Continental Margin: Towards an Effective Real-Time earthquake and Tsunami Warning System

Science:

Site H-8 corresponds to ODP hydrate Site 889. IODP just returned to this area for highly successful hydrates coring and logging on the Vancouver Margin. That expedition included a subset of the work proposed to IODP, deferring to a future expedition re-instrumenting 889 and another site as hydrate-specific CORKs. Returning to complete the program remains a high priority for IODP; it hasn't been scheduled yet, but could occur as early as 2010. These CORKs would likely include hydrate, fluid and microbiological aspects that would be prime candidates for real-time power, control and communication via the NEPTUNE capabilities. This site provides an instrumented methane hydrate observatory that allows investigation of a very different tectonic environment than Hydrate Ridge.

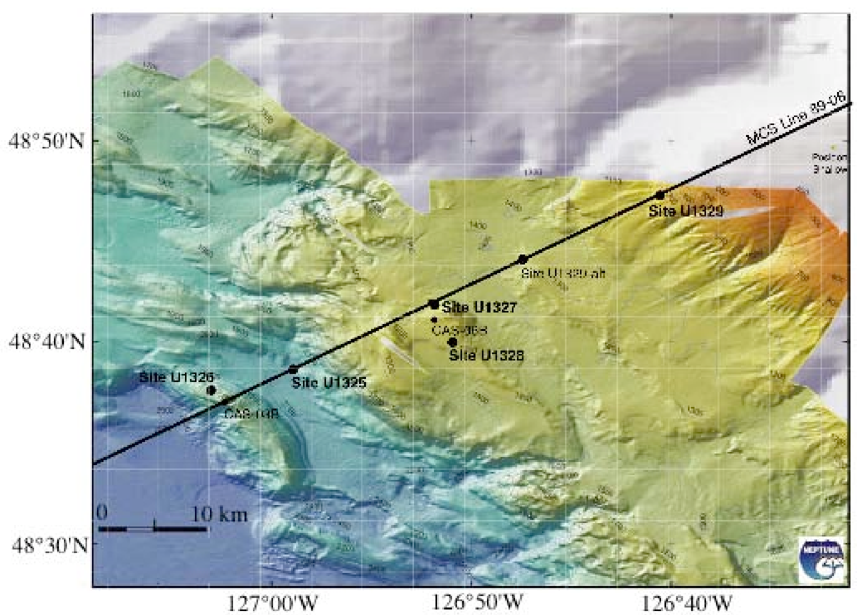


Figure 22. Node 10 at ODP site 889.

Infrastructure. The OOI is funding an extension cable to the CORK'ed observatory site and connections to the borehole. Infrastructure includes:

Extension cable to 889	$94,000
Extension cable to second CORK site	$94,000
TOTAL	**$188,000**

7.10 Branching Unit/Node 11 Middle Valley
Location: 48°26.5'N 128°42.6'W
Overlapping RFA's at this Node:

- Regional arrays of borehole observatories for sustained time-series observations of (a) subseafloor hydrogeological processes and (b) formation pressure as a proxy for plate-scale strain
- Distributed pH Observatory: Assessing the Effects of the Anticipated Shift in the Upper ocean on the Oceanic Energy and Carbon Cycle
- A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific
- A Cabled Observatory on the Juan de Fuca Ridge

Science:

Valley forms one leg of a Ridge–Transform–Transform unstable triple junction with the Sovanco Fracture Zone and the Nootka fault. It is a sediment-filled rift that, until recently, was the primary axis of spreading at the northern end of the JdFR. This young (<400,000 years) rift valley is filled with 200–2000 m of Pleistocene turbidite sediment and hosts both active and inactive hydrothermal mounds. The active Dead Dog field is an elliptical array of thermally indurated sediments, covering an area of ~900 x 275 m.

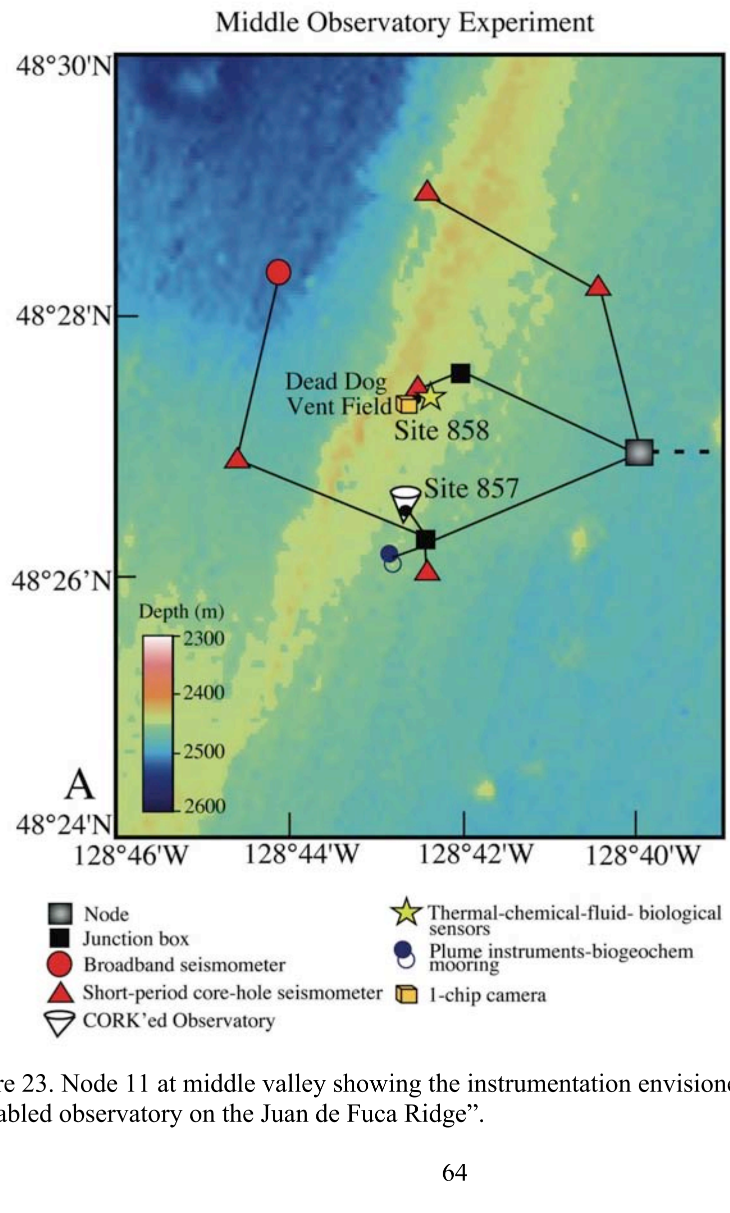


Figure 23. Node 11 at middle valley showing the instrumentation envisioned in the RFA proposal "A cabled observatory on the Juan de Fuca Ridge".

Within this area, >25 distinct vents have been identified, where hydrothermal fluids up to 280°C discharge through the sediment. Two Ocean Drilling Program (ODP) boreholes within the Dead Dog field are CORKed, one within the active zone of upwelling (Hole 858G), the other within a hydrothermal reservoir located 1.6 km south of the Dead Dog field (857D). The sediment cover, the presence of biological communities that are vastly different from the other sites, and the availability of boreholes make this a unique site on the Juan de Fuca Ridge.

Middle Valley (H-1) has one current working CORK - 857D, 1.6 km south of the Dead Dog vent field. This has the longest history of pressure recording *of any* CORK and has provided useful signals of several known seismic events. There is also a currently non-working CORK at 858G in Dead Dog field. It was a producing hole at 260-270°C, and could be a prime candidate for reinstrumentation for fluid sampling etc. This site is also of great interest to mid-ocean ridge investigators for examining linkages among geological, hydrothermal and biological processes: it is one of only a very few sites where microbiological measurements and characterizations have been made several hundreds of meters beneath the seafloor.

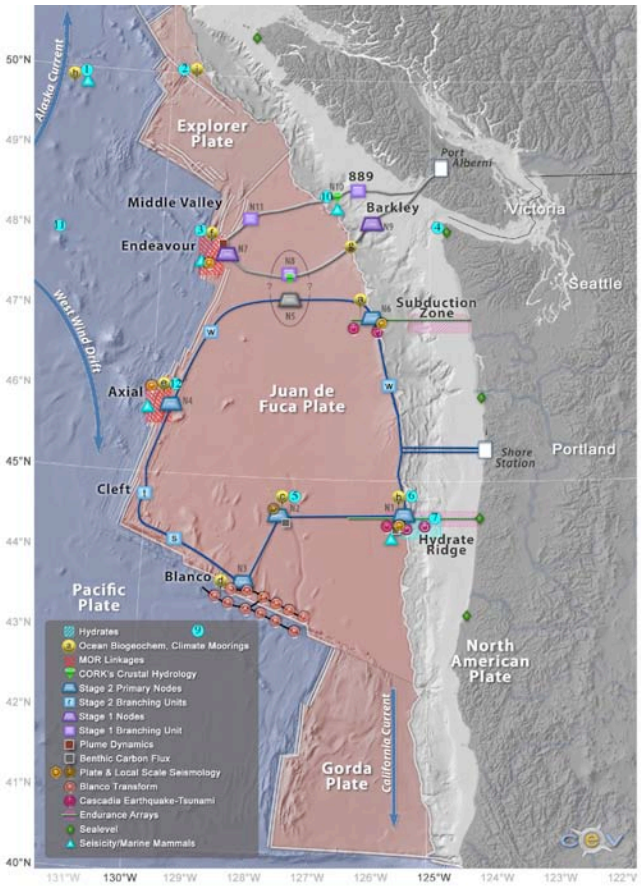
Middle Valley is part of the NEPTUNE Canada cabled observatory. The availability of a node at this site is dependent on a proposal currently in review at the Canadian Foundation for Innovation. Alternatively, it might be served by a branching unit. For the conceptual design it was envisioned that experiments would be developed at Middle Valley at a later stage in the lifetime of the RCO in conjunction with IODP. No funds are budgeted for this site

Infrastructure. Although this site was a very high priority site for multiple RFA's, proposed funding was removed in this version of the CND. The hope is that NEPTUNE Canada will be successful in obtaining additional funds for installation of a node and extension cables at this site.

7.11 Sites a-i: Cabled profiling moorings for RCO water column access

Proposed water column sites

The original water column access proposal has been down-scaled to 8 sites from the 12 sites recommended by the RECONN meeting in 2003. The remaining sites are those required to provide the necessary spatial aperture for the gyre-scale multi-disciplinary science questions outlined above.



Site	Original #	Location/type
Ra	7, moved north	11
Rb	6	3
Rc	5	5
Rd	8	6
Re	12	8
Rf	3	12 (Neptune Canada)
Rg	10	Extension cable to base of shelf from Neptune Canada (Barkley Canyon, node 9 or ODP 889, node 10)
Rh	1	Stand-alone acoustically-coupled mooring

Figure 24. Location of moorings in based on the initial RFA (blue-green circles with numbers) and a redced version outlined in this document (yellow circles with letters). Moorings h and I will be buoys, but are included in the RCO infrastructure costs because they are key in examining bifurcation of the Alaska and WWD currents and in studies of cross and along strike currents. Profiling mooring "g" is now removed to help achieve the $90 RCO target.

Changes from original set of 12 moorings:

4 Major site for larval retention, harmful algal blooms, and source of deepwater renewal for large areas of inner coastal waters.

Dropped because of distance from both backbone cables, high fishing pressure.

7 Site for questions related to upwelling-driven production, physical-biological retention mechanisms, cross-shelf transport of organisms and particulate flux, fisheries, and marine mammals and bird dynamics.

Assumed this site will be occupied by coastal component of OOI

9 (across Blanco fault on Pacific plate
Provide data on boundary mixing that may be critical to understanding the maintenance of the observed abyssal stratification.
Dropped because of distance from backbone, extreme topography, single-use

11 (across Juan de Fuca Ridge in subtropical gyre)
Dropped because of distance from backbone.

Proposed water column sites: specific science objectives outlined in RFA

Sites	Science objectives
Rh, Re, Rd	Resolution of N/S fluctuations in the WWD and its bifurcation; comparison of different ecosystems (subarctic and subtropical gyres).
Rf, Rg	Biophysical variability in WWD advected towards coast; delineate variability of mass and biogenic fluxes in the N/S divergence.
Rh-Ri Rf-Rg Rc-Rb	Comparison of onshelf/slope/offshelf processes and fluxes at locations of different upwelling and mean current regimes
Ri, Rg	Located in a highly dynamic and ecologically diverse region of the NE Pacific; will provide insights into climate-scale (seasonal-to-interannual and interdecadal time scale) impacts on regional physics and ecology
Ri,Rg,Ra,Rb	Provide estimates of along-slope variability in biophysical fields. Despite the coarse spatial scale, co-variability (or lack thereof) between extended time series observations in these two locations would provide improved tests of various hypotheses relating ocean productivity to the success of commercially important fisheries
Rc, Rb (plus coastal cabled mooring on shelf)	Sampling of biophysical processes from the exceptionally productive upwelling zone (over the shelf) to the nutrient-poor, subtropical waters west of the shelf break. Sustained observations of the upper water column (mixed layer/euphotic zone) will provide insights into climate-scale (seasonal to interannual and interdecadal time scales) impacts on regional physics and ecology
Rf, Re	Located at major hydrothermal vents (Endeavor Ridge and Axial Volcano) that will be intensively studied by the geophysical community. Water column observations will provide measurements of along-ridge flows; transport of vent larvae, and measurements of mega-plumes.
Ri, Rg, Ra, Rb (shelf break) Re,Rf (ridge)	Provide data on boundary mixing. Diapycnal mixing near the seafloor helps transport mixed water, nutrients, etc. from coastal margins into the interior ocean. Continuous, high-frequency (subtidal time scale) and spatially distributed sampling across the complex bottom topography of the shelf-break and ridge will provide information necessary to quantify the statistics of bottom-water mixing that vary on a broad spectrum of time scales (shorter than tidal to seasonal and interannual).

Cabled profiling moorings: infrastructure components

The fundamental infrastructure for a cabled profiling mooring consists of an EOM cable supporting: three secondary mooring nodes (at the bottom, on a 600 m float, and on a 200 m float, where instruments may receive power and transfer data), a profiler winch mounted on the

200m platform (enabling instrument package access to the surface layer) and two profiling units operating over the 200-600 m and 600 m-bottom segments of the cable.

Infrastructure Costs for Moorings:

Mooring NRE (builds on Aloha mooring	$2,000,000
Vertical Profiling Mooring System ($748,000*8)	$5,984,000
Core Instrumentation	$1,000,000
Total	**$8,984,000**

Power Requirements

A summary of the average power requirements is given in the table below. The major infrastructure loads for the moorings are two profilers (average, 64 W), the winched profiler (70 W) and hotel (300 W, includes resistive losses, secondary node controllers and switches, etc). The major sensor loads (now known) are bubble size (20 W, acoustic resonator), zooplankton imaging (25 W, SIPPER), multispectral fluorescence (10 W), Zooplankton volume backscatter (8.4 W, TAPS-6), nitrate (6.5 W, ISUS), and acoustic tomography source (~11 W average, with 2% duty cycle, 521 W when transmitting). The average power demand is not a major factor for the cabled deployments, but will require a reduced sensor suite and reduced duty cycles on an acoustically-coupled stand-alone mooring.

Infrastructure	Watt
Winch	70
Profiler (2)	64
Hotel (200 m float)	300
Sensors	
0-200m	79
200m	24
200-600m	38
600m	15
600-bottom	12
bottom	14
Total	616

Bandwidth requirements

It is difficult to determine the average bandwidth requirement for the mooring as a whole. Many of the instruments, such as CTDs, fluorometers, etc do not have extremely high data rates. Instruments with the highest bandwidth will likely be broadband hydrophones (~1 Mbit/s) and optical imaging systems such as the zooplankton imaging SIPPER (~10Mbits/s). However many of these high data rate instruments are unlikely be run continuously, so average data rates may be adjusted by adjusting duty cycles relative to available bandwidth. The standard cable bandwidth of 100Mbits/s should be more than adequate for the full cabled mooring; the lowered bandwidth of the acoustically-coupled moorings will require reduced duty cycles and a reduced sensor suite.

7.12 Branching Units

This costing exercise includes branching units at three locations on the Stage II portion of the RCO. However, this is not an optimal design and it is strongly recommended that all six of the branching units be included in the final RCO final design. These are critical and provide a low-cost means of building in the flexibility to access sites that are likely to be of scientific interest during the 30-year lifetime of the RCO but which in this current conceptual design may not be initially instrumented.

Mid-Newport Line. This branching would facilitate the addition of another node along the Newport line

Western Blanco. This would allow expansion of the experiments on the Blanco Transform. Perhaps the most spectacular fluid behavior observed to date at the Blanco was the 18 ºC drop in the high temperature vent fluids on the Cleft Segment of the JDFR following the June 2000 M 6 earthquake in this region. This earthquake was preceded by a ~16 hour long foreshock sequence that probably reflected fluid migration within the fault-zone. Additionally, the first ever documentation of an active high-T vent field and biological community within a transform fault zone was located here. Thus, the interactions between the transform fault and the Cleft Ridge segment and hydrothermal/biological sites are expected to be a significant target of study during the lifetime of the RCO.

Cleft Segment. The Cleft segment is one of the sites identified for studies of the Juan de Fuca Ridge. In particular, the abundant evidence for recent volcanic activity and the narrow axis of spreading at the Cleft segment make it an ideal location for real time multidisciplinary experiments that aim to reveal the segment-scale interactions between volcanic/tectonic events and changes induced in hydrothermal and biological systems. Cleft is also unique because the Blanco Fracture Zone at its southern end provides a crustal window that has been extensively characterized. The presence of the Blanco transform fault also provides the opportunity to document perturbations to the ridge-crest system from nearby large-magnitude earthquakes. In formulating the design presented in this document, it was recognized that the ridge community will not have the resources necessary to develop full scale experiments at all the ridge sites early in the lifetime of the RCO. Although, scientific viewpoints are likely to differ on the relative merits of the different ridge sites, This design assumes that the Cleft will have a lower priority for two reasons. First, the Endeavour is already slated for an instrumented node on the NEPTUNE Canada observatory while Axial Seamount is a high priority site for one of the moorings that will be deployed for the interdisciplinary water column studies. Second, one scientific advantage of the Cleft segment is its suitability for conducting experiments to study the coupling between processes on the western Blanco and the ridge. Because the western Blanco has been identified only as a second priority site for the Blanco Transform experiment, it was felt that it made sense to provide cable breakouts at both the western Blanco and Cleft that would facilitate the development of a coupled experiment later in the lifetime of the RCO.

Northern Symmetrical Ridge. Although this segment was not identified in the RFA's submitted for studies, this branching unit breaks a long segment of cable and would facilitate the addition of a node that could contribute to various experiments such as plate scale seismic observations and the response of the Juan de Fuca Ridge system to distal and proximal earthquakes. This area has not been will explored for venting activity, but it is underlain by an axial magma chamber.

East Plate North. This branching unit breaks a long segment of cable and would provide the flexibility to add another mid-plate node.

Astoria Canyon. This branching unit provides the flexibility to add a node in a region that is of potential interest to coastal studies and to seismic experiments in the subduction zone.

Appendix 1. Timetable of Regional Cabled Observatory Development

1998	
June	National Oceanographic Partnership Program (NOPP) funds U.S. NEPTUNE feasibility study
1999	
June	Canada's Institute for Pacific Ocean Science and Technology invited by U.S. to undertake feasibility study of Canadian partnership with U.S. NEPTUNE
2000	
June	U.S. NEPTUNE feasibility study completed and published
June	National Science Foundation (NSF) funds development of cabled-observatory communications system
Sept	Meeting at Emerald Lake, British Columbia - NEPTUNE organizational structure established; Executive Team formed of partner representatives: University of Washington, Woods Hole Oceanographic Institution, Monterey Bay Aquarium Research Institute, Institute for Pacific Ocean Science and Technology (Canada), and Caltech's Jet Propulsion Laboratory
Oct	NEPTUNE Canada feasibility study completed and published
2001	
June	NSF funds development of regional cabled observatory power system
July	W.M. Keck Foundation grants award for proto-NEPTUNE experiment
Dec	University of Victoria joins NEPTUNE partnership
2002	
Feb	Victoria Experimental Network Under the Sea (VENUS) test bed in Straits of Georgia and Juan de Fuca funded by Canada Foundation for Innovation (CFI), contingent on matching funds
Feb	NEPTUNE cable-route desktop study completed
Mar	NOPP funds NEPTUNE system engineering, program office, and science planning
May	Memorandum of Understanding and Rules of Operation for NEPTUNE Affiliation approved by NEPTUNE partners
June	Roughly half of Canadian portion of NEPTUNE costs funded by CFI, contingent (among other conditions) on matching funds from other Canadian sources
Aug	Grant from Province of British Columbia completes VENUS funding
Sept	NSF funds the Monterey Accelerated Research System (MARS) cabled-observatory test bed in Monterey Bay
2003	
April	NEPTUNE Pacific Northwest Science Planning Workshop held at Portland State University, Portland Oregon
July	Workshop on linkages between the Ocean Observatories Initiative and the Integrated Ocean Drilling Program held in Seattle, Washington
Oct	Canada Foundation for Innovation and British Columbia Knowledge Development Fund announce CAN$62.4 million in funding to University of Victoria for NEPTUNE Canada
Oct	Cabled Regional Observatory Workshop, San Francisco, sponsored by NSF. Northeast Pacific Ocean designated as site of first regional cable observatory
2004	
Jan	ORION workshop, San Juan, Puerto Rico, sponsored by NSF and Canada's NSERC. Science and education planning for regional, global, and coastal ocean observatory components of the Ocean Observatories Initiative
Feb	President's FY2005 budget released, showing out-year commitment of FY2006 start of $245 million in funding for the NSF Ocean Observatories Initiative
May	NEPTUNE Canada Ocean Observing Systems Workshop, University of Victoria, 3-5 May
2005	
April	Collaborative Enhancement Workshop Skamania Lodge for Responses to the RFA, April 14-15
May	Community Proposals due to ORION Office in Response to RFA call
Sept	NSF-Panel bins proposals into 3 groupings based on a combination of factors that included readiness and maturity of required technologies and proposed science.
Oct	Science and Technology Advisory Committee (STAC) meets and a subcommittee for the RCO is formed. Neptune Canada signs contract for $39M with Alcatel to design, manufacture and install northern portion of the RCO
2006	
	STAC meets Jan 30-Feb 1 in Washington DC to discuss Science User Documents for global, regional, and coastal
	February 6th the OOI is listed in the President's FY2007 as a new MREFC start at $301M
	March 1-2 RCO RFA proponents and engineers meet in Seattle to formulate Conceptual Design for the RCO
	March 27-30 Orion Design & Implementation Workshop; Community provides additional recommendations
	March-April RCO CND is revised, recosted based on recommendations
	April 26-27 subgroup of proponents, engineers and ROV operators meet in Seattle to work out O&M costs
	May 1-3 STAC committee meets in DC, RCO subgroup works to get costs down to ~ $90M target, provides priorities
	May 24th CND presented to ORION office for formal review in August

Appendix 2: Regional Cabled Observatory and Associated RFA's

PI/Contact	PI Contact/ Engineering contact	Title
A) Barth Horne	barth@coas.oregonstate.edu Bill Kirkwood	A Multi-Scale Ocean Observatory for Ocean Dynamics and Ecosystem Response along the Northeast Pacific Continental Margin
B) Becker Brown	kbecker@rsmas.miami.edu Mark Zumberge	Regional arrays of borehole observatories for sustained time-series observations of (a) subseafloor hydrogeological processes and (b) formation pressure as a proxy for plate-scale strain
C) Brown Becker	trehu@coas.oregonstate.edu Gene Massion	A Northeast Pacific Hydrate Observatory System (NEPHOS) at South Hydrate Ridge
D) Daly Kelley	kdaly@marine.usf.edu Gary Harkins	An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from basin to Regional Scales
E) Kolber Paull	zkolber@mbari.org	Distributed pH Observatory: Assessing the Effects of the Anticipated Shift in the Upper ocean on the Oceanic Energy and Carbon Cycle
F) McGuire Wilcock	jmcguire@whoi.edu Mark Zumberge	An Earthquake, Physics, and Fault Mechanics Observatory on the Blanco transform Fault
G) Rona Kelley	rona@imcs.rutgers.edu Gary Harkins	VIA (Vent Integrated Acoustics) Cabled Experiment: Main Endeavour Field, Juan de Fuca Ridge
H) Smith Brown/Paull	ksmith@ucsd.edu Gene Massion	The Coupling of Pelagic Particulate Matter Fluxes and Benthic Community Processes Across the NE Pacific Continental Margin: Long Time-Series Monitoring With Real-Time Data Acquisition and Control
I) Stephen Wilcock	rstephen@whoi.edu Gene Massion	Regional Ocean Hydrophone Array Observatory (ROHAO)
J) Toomey Kelley	drt@uoregon.edu Gary Harkins	A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific
K) Trehu Brown	trehu@coas.oregonstate.edu Mark Zumberge	Seismic and Geodetic Observations of the Cascadia Continental Margin: Towards an Effective Real-Time earthquake and Tsunami Warning System
L) Wilcock Becker	wilcock@ocean.washington.edu kelley@ocean.washington.edu Gene Massion	A Cabled Observatory on the Juan de Fuca Ridge