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

Issued by the ORION Program Office
March 15, 2006
[revised March 18, 2006]
ORION Science and Technical Advisory Committee
Doug Luther, Chair, STAC* (U Hawaii)
Antonio Baptista, CSO (OHSU)
Keir Becker, RCO (U Miami)
Claudia Benitez-Nelson GSO (U So. Carolina)
John Collins, Co-Chair, GSO (WHOI)
Tommy Dickey, GSO (UCSB)
Jim Edson, CSO & GSO (U Connecticut)
John Horne, RCO (U Washington)
Deb Kelley, Co-Chair, RCO (U Washington)
Wade McGillis, CSO (LDEO)
Mark Moline*, CSO (CalPoly)
Charlie Paul, RCO (MBARI)
Collin Roesler, Co-Chair, CSO (Bigelow)
Uwe Send, Co-Chair, GSO (SIO)
Tim Short, CSO (U South Florida)
John Trowbridge, Co-Chair, CSO (WHOI)
Francisco Werner, CSO (UNC)
William Wilcock, RCO (U Washington)

ORION Cyberinfrastructure Committee
Larry Mayer, Chair* (UNH)
Ilkay Altintas (UCSD)
Matthew Arrott (LOOKING)
Suzanne Carbotte (LDEO)
Yi Chao (JPL)
Wu-chi Feng (Portland State U)
John Graybeal (MBARI)
Matt Howard (TAMU)
Jason Leigh (UI-Chicago)
Andy Maffei (WHOI)
Benoit Piret (U Victoria - NEPTUNE Canada)
John Orcutt (SIO)

ORION Education and Public Awareness Committee
George Matsumoto, Chair* (MBARI)
Julie Bursek (NOAA/CIMS)
Roman Czujko (American Institute of Physics)
Annette deCharon (Bigelow)
Sharon Franks (SIO)
Sharon Gilman (CCU)
Amy Holt-Cline (UNH)
Darryl Keith (EPA)
David Malmquist (VIMS)
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
Keith Raybould, Chair* (MBARI)
Andrew Barnard (Wet Labs)
Alan Chave (WHOI)
Dan Frye (WHOI)
Jason Gobat (U Washington/APL)
Gary Harkins (U Washington)
Bruce Howe (U Washington/APL)
Bill Kirkwood (MBARI)
Kate Moran (URI)
Frank Vernon (SIO)
Gary Wieboldt (Oceaneering)
Mark Zumberge (SIO)

ORION Sensor/Technology Committee
Scott Gallager, Chair (WHOI)
Jim Ammerman (Rutgers)
Brian Bornhold (NEPTUNE Canada)
Mike DeGrandpre (U Montana)
Ann Gargett (ODU)
Ken Johnson (MBARI)
Larry Langebrake (U South Florida)
Marlon Lewis (WETSAT)
George Luther (U Delaware)
Mario Tamburri (CBL)
Robert Weller (WHOI)

Observatory Steering Committee
Robert Detrick, Chair* (WHOI)
Jim Yoder (WHOI)
Mary Jane Perry (U Maine)
John Barth (OSU)
John Delaney (UW)
Rick Jahnke* (SkiO)
Kim Juniper (UMontreal)
George Luther (U Delaware)
Gene Massion (MBARI)
Blanche Meeson (OCEAN.US)
Peter Mikhailovsky (SAIC)
John Orcutt (SIO)
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

Draft Regional Conceptual Network Design
15 March 2006

This draft Regional Conceptual Network Design was constructed by the efforts of members of the following ORION committees and the ORION Program Office.
# Conceptual Network Design Framework for the Regional Cabled Observatory

## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.0 Introduction</strong></td>
<td></td>
</tr>
<tr>
<td><strong>2.0 A Regional Plate Scale Experiment Science Drivers</strong></td>
<td>9</td>
</tr>
<tr>
<td>2.1 Oceanic Physical and Biogeochemical Processes</td>
<td>9</td>
</tr>
<tr>
<td>2.2 Biogeochemical Cycles and the Benthic Community</td>
<td>9</td>
</tr>
<tr>
<td>2.3 Seismic Activity and Stress Propagation</td>
<td>10</td>
</tr>
<tr>
<td>2.4 Crustal Hydrology-Geobiology-Plate Scale Strain</td>
<td>10</td>
</tr>
<tr>
<td>2.5 Crustal Formation and Life</td>
<td>11</td>
</tr>
<tr>
<td>2.6 Heat and Chemical Fluxes</td>
<td>11</td>
</tr>
<tr>
<td>2.7 Ridge-Transform Interaction: The Blanco Transform Fault</td>
<td>11</td>
</tr>
<tr>
<td>2.8 Subduction Zone Seismic and Studies</td>
<td>12</td>
</tr>
<tr>
<td>2.9 Understanding Gas Hydrate Formation</td>
<td>13</td>
</tr>
<tr>
<td><strong>3.0 Summary of RCO Requirements &amp; Costs</strong></td>
<td>13</td>
</tr>
<tr>
<td>3.1 Primary or Backbone Node</td>
<td>13</td>
</tr>
<tr>
<td>3.2 Branching Unit</td>
<td>14</td>
</tr>
<tr>
<td>3.3 Secondary Node</td>
<td>14</td>
</tr>
<tr>
<td>3.4 Benthic Node</td>
<td>15</td>
</tr>
<tr>
<td>3.5 Timing Requirements</td>
<td>15</td>
</tr>
<tr>
<td>3.6 Costing</td>
<td>15</td>
</tr>
<tr>
<td>3.6.1 Scenario 1 Full Design of Stage II</td>
<td>15</td>
</tr>
<tr>
<td>3.6.2 Scenario 2 Stage II of Stage II</td>
<td>21</td>
</tr>
<tr>
<td><strong>4.0 Summary of RCO Nodes, Science Objectives, and Infrastructure</strong></td>
<td>22</td>
</tr>
<tr>
<td>4.1 Node 1 Hydrate Ridge-California Current Transect</td>
<td>23</td>
</tr>
<tr>
<td>4.2 Node 2 Newport Line West</td>
<td>29</td>
</tr>
<tr>
<td>4.3 Node 3 Blanco Fracture Zone</td>
<td>31</td>
</tr>
<tr>
<td>4.4 Node 4 Axial Seamount</td>
<td>33</td>
</tr>
<tr>
<td>4.5 Node 5 Junction of Stages I and II</td>
<td>36</td>
</tr>
<tr>
<td>4.6 Node 6 Subduction Zone</td>
<td>37</td>
</tr>
<tr>
<td>4.7 Node 7 Endeavour Segment</td>
<td>40</td>
</tr>
<tr>
<td>4.8 Nodes 8 ODP1027</td>
<td>44</td>
</tr>
<tr>
<td>4.9 Node Barkley Canyon</td>
<td>47</td>
</tr>
<tr>
<td>4.10 Node 10 ODP 889</td>
<td>49</td>
</tr>
<tr>
<td>4.11 Node 11 Middle Valley</td>
<td>51</td>
</tr>
<tr>
<td>4.12 Cabled Moorings a-I for water column access</td>
<td>51</td>
</tr>
<tr>
<td>4.13 Branching Units</td>
<td>55</td>
</tr>
<tr>
<td><strong>5.0 Instrument Packages for Stage 1 and 2 of the RCO</strong></td>
<td>57</td>
</tr>
<tr>
<td>5.1 Cabled profiling mooring instrumentation</td>
<td>57</td>
</tr>
<tr>
<td>5.2 Core Seismic Packages</td>
<td>57</td>
</tr>
<tr>
<td>5.3 Pelagic/Benthic Monitoring System</td>
<td>58</td>
</tr>
</tbody>
</table>
FIGURES

Figure 1A. Global, Regional, and Coastal locations in the Northeast Pacific and relationship to currents 4
Figure 1B. Synergy of locations for linked experiments on the RCO 4
Figure 2. Location of nodes for Stage I of the RCO to be deployed in 2007 5
Figure 3. Scenario 1 for the Regional Cabled Observatory 7
Figure 4. Scenario 2 for the Regional Cabled Observatory with prioritized nodes 8
Figure 5. Primary Node 14
Figure 6. Secondary Node 14
Figure 7. Benthic Node 15
Figure 8. Node 1 location: Hydrate Ridge 23
Figure 9. Backscatter and bathymetry of Hydrate Ridge experimental site 24
Figure 10. Schematic illustration of comprehensive conceptual gas hydrates observatory 25
Figure 11. Node 3 on the Blanco Transform Fault 31
Figure 12. Node 4 on Axial Volcano 33
Figure 13. Topographic map of Cascadia accretionary margin 37
Figure 14. Schematic illustration of a seismic-geodetic experiment 38
Figure 15. Node 7 on the Endeavour segment of the Juan de Fuca Ridge 41
Figure 16. Experimental layout for instrumented borehole observatories at Node 8 45
Figure 17. Node 10 at ODP site 889 48
Figure 18. Middle Valley 49
Figure 19. Mooring locations for Scenario 1 and 2 51
Figure 20. Pelagic/Benthic Explorer 58

TABLE

Table 1. Location of the shore station and primary and secondary nodes for the RCO 6
Table 2. Scenario 1: Summary of science, infrastructure, and costs for each node on the RCO 16
Table 3. Scenario 2. Summary of science, infrastructure, and costs for each node on the RCO 19
Table 4. Infrastructure Component Costs for the RCO 21
CONCEPTUAL NETWORK DESIGN FRAMEWORK FOR THE REGIONAL CABLE OBSERVATORY

1.0 Introduction

The Regional Cabled Observatory (RCO) is an unprecedented plate scale experiment focused on integrated investigations spanning the subseafloor biosphere to the hydrosphere, the entire ocean water column, and the sea surface-atmosphere interface. Spatially associated with the Juan de Fuca tectonic plate, the RCO will enable in-depth study and decadal time-series observations of regional oceanography--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 timescales. 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 fundamentally change the way we view and study our planet and how we educate and interact with researchers, students and the public. 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.

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 (Fig. 1; Appendix 1). In October 2003, an NSF-supported RECONN workshop identified the Northeast Pacific as the location of the first Regional Cabled Ocean Observatory (http://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 Ocean Observatories Initiative- global, regional, and coastal. For example, station PAPA (50°N, 145°W) in the N.E. Pacific is a high priority acoustically-linked buoy site to study global circulation, biogeochemistry, air-seas flux, and geophysical processes and pioneer and enduranc arrays at two locations along the Washington-Oregon margin have been suggested as high priority coastal sites key to studying linkages among chemical and biological processes and climate-change (Fig. 1).

Significant national and international leveraging opportunities are likely to come about 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 Canada 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. 2). 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. 2).
Figure 1A. The Regional Cabled Observatory (RCO) provides an unprecedented opportunity for long-term all-water observing capabilities that will allow the capture of intermittent episodic events that are dynamically and ecologically very significant, as well as the interannual and interdecadal variability. The mean currents in this RCO area transport heat, salt, nutrients, plankton and invertebrate larvae north and south and are crucial to the ecosystem response of the region. Sustained arrays of instruments throughout the water column and on the seafloor will lead to breakthroughs in our understanding of the physical, chemical, and biological processes influenced by bifurcation of the West Wind Drift, Alaska Current, and California Current. The plate-scale RCO is the only planned observatory that links global scale studies such as those being conducted at Station PAPA, and Coastal investigations such as those along the Washington and Oregon Margin.

Figure 1B. This figure is one example of many scenarios for an RCO in the Northeast Pacific that community-wide workshops have produced regarding the science that can be achieved with such a system. This scenario is reproduced from the NEPTUNE Pacific Northwest Workshop report, which resulted from a meeting at Portland State University, April 2003. This figure illustrates the synergies of location among the different working groups at that meeting. The groups were formed around broad science themes that included:

- Fisheries and Marine Mammals
- Ocean Dynamics
- Seismology and Geodynamics
- Fluid Fluxes and Geophysical Processes in Sediments and Crust
- Ecosystems and Carbon Cycle

Results from this workshop can be downloaded at: http://www.neptune.washington.edu/pub/workshops/PNW_Workshop/ws_reports_documents.html
Figure 2. 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.

In addition to this significant funding effort, 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 lays out plans for Stage II of the RCO.

In response to the NSF Request for Conceptual Science Proposal RFA’s sixteen proposals that included > 175 participants were submitted in May 2005 focusing on the RCO and closely related studies (Appendix 2). In late September 2005 an NSF-appointed panel ranked 9 of these proposals as ready to go forward, 2 as needing some additional development, and 5 preliminary. In October 2005, a subcommittee of the Science and Technology Advisory Committee (STAC) was formed at a meeting in Washington D.C. to summarize these proposals in terms of their location and science and technological requirements, and to prioritize these experiments based on a budget of $90M allocated to the RCO efforts. Subcommittee members include:
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, Science User Requirement (SUR’s) summaries were completed in January 2006 for all proposals recommend as ready to go forward by the NSF panel. Based on these documents, two preliminary integrated network designs for the Stage II were drafted that include $150M and $107.4M infrastructure options (Fig. 3 & 4; Tables 1-3). In Section 3 and Table 3A&B, these two designs are presented with the requirements and costs, the rational and assumptions used for these designs, and cable route-node prioritization. Summaries of the science and instrumentation proposed at each node are presented in Section 4.

Table 1. Location of Primary Nodes and Branching Units on the RCO Scenario 2

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

*Proposed pending funding from Canadian Foundation for Innovation. Note that primary nodes and branching units are described in detail in sections 3.1 and 3.3 respectively.

In early March 2006 several of the RFA lead PI’s and a subset of the RCO STAC committee met in Seattle, resulting in a modification of the Conceptual Network Design that is presented in this document.
Figure 3. Scenario 1 showing location of 12 nodes, 2000 km of cable, and 12 moorings with a total cost of $150 million. This ambitious plan was significantly over the $90 million targeted by NSF and was modified in Scenario 2 to be more closely aligned to the latter funding target.
Figure 4. Stage 2, Scenario 2 of the RCO showing location of 6 nodes, 6 branching units, and 9 moorings. Also shown are the locations of nodes and experiments on Stage 1 that will be in the water in 2007. Branching units provide ease in future expansion for this 30-year experiment. Scenario 2 includes costs to augment this system with extension cables, connectors, and moorings at key locations.
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, 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 Seismic Activity and Stress Propagation
The RCO presents an exceptional opportunity to observe seismogenic failure throughout a
tectonic plate with known boundary conditions, 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 intraplate 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.

2.4 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
Juan 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 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.

2.5 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.

2.6 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.

2.7 Ridge-Transform Interactions: The Blanco Transform Fault
The observatory proposed for the Blanco Ridge section of the Blanco Transform fault is capable of making measurements of seismicity, deformation, and possibly fault-zone fluid discharge over multiple earthquake cycles. 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 18°C 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.

**2.8 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 accommodate 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. 


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.

2.9 Understanding 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 Summary of RCO Requirements & Costs
This section describes the process used during the February 2006 ORION Engineering meeting 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 work done on NEPTUNE Canada, MARS, VENUS and other programs. The task was then to put the costing pieces together to come up with a total system estimate. In the following sections, we define the components that make up the RCO and associated costs.

3.1 Primary Node or Backbone Node $2.3M-$2.5M ea (cost uncertainty ±10%)
An RCO Primary Node provides the connection between the backbone cable and the RCO instruments. Its function is to provide a source of regulated energy to power these 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:
3.2 Secondary Node: $1.5M (cost uncertainty ± 30%)

Secondary nodes are connected to the backbone via the primary node and an extension cable that can be up to 100 km in length. Under the current design, each of the Secondary Nodes would have the following characteristics:

3.3 Branching Unit $500K ea

The Branching Unit (BU) is a relatively inexpensive subsystem that acts as an “empty” Node. A BU will be installed at places in the backbone cable that have high expectations of becoming full-up Nodes in the near future. The unit consists of the outer trawl-resistant framework of a Node, 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 Node status without requiring the services of a cable laying ship.

3.4 Benthic Node (BN): $175k
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. Under the current design, each of the Benthic Nodes would have the following characteristics:

![Benthic node characteristics](image)  

3.5 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.

3.6 Costing
A list of the estimated costs for each of the main components to be used in Stage II scenarios is shown in Table 4. The primary node cost and backbone cable costs were derived from the NEPTUNE Canada Stage 1 estimates. The vertical profiler cost was taken from the Aloha Mooring project. These estimates while certainly not final should provide a good start for determining the actual cost of the RCO infrastructure.

3.6.1 Scenario 1 Full Design of Stage II
The first scenario for design of the Stage II network included 2,000 km of backbone cable, 12 primary nodes, 12 vertical profilers and a physical connection to Stage 1 (Fig. 3; Table 2). When costs for the required extension cables, secondary nodes and instrumentation were summed, the total cost of the system was $150M (Scenario 1), far above the $90M budget allocated by NSF.
## Table 2. Scenario 1: Regional Cabled Observatory Integrated Experimental Design

<table>
<thead>
<tr>
<th>Location Primary RFA's</th>
<th>Science</th>
<th>Requirements Scenario 1</th>
<th>Cost ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODE 1 Astoria Canyon North</td>
<td>Required for Scenario 1 and 2 with a node every 150 km, over 30-year period could be used as an extension for coastal</td>
<td>1 backbone node</td>
<td>$2.5</td>
</tr>
<tr>
<td>NODE 2 Astoria Canyon South</td>
<td>Required for Scenario 1 and 2 with a node every 150 km, extension for coastal research</td>
<td>1 backbone node</td>
<td>$2.5</td>
</tr>
<tr>
<td>NODE 3 Hydrate Ridge 1-7,9,10,13-15</td>
<td>Understand dynamic processes that control methane transport and hydrate formation, biogeochemical 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</td>
<td>2 secondary nodes, 70 km + 50 km extension cables, ship ROV time connect secondary nodes, optical connectors</td>
<td>$3.0 $2.4 $0.15 $0.12</td>
</tr>
<tr>
<td>NODE 4 Mid Newport Line</td>
<td>Required for Scenario 1 and 2 with a node every 150 km, useful for Newport line science</td>
<td>1 backbone node</td>
<td>$2.5</td>
</tr>
<tr>
<td>NODE 5 Newport West 7,13,14</td>
<td>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</td>
<td>300 km of extension cable</td>
<td>$6.0</td>
</tr>
<tr>
<td>NODE 6 Blanco Transform 5,8,14</td>
<td>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</td>
<td>2 secondary nodes, 2 X 50 km extension cables, 10 BN@$135K*, 2.5  km extension cables (ROV laid, $10k/km), 20 day ship time ROV lay X 2 (east and west)</td>
<td>$3.0 $2.0 $1.35 $1.0 $1.0 $7.35</td>
</tr>
<tr>
<td>NODE 7 Cleft Segment</td>
<td>Understanding plate scale hydrology and seismicity, ocean carbon cycles, linkages among crustal formation, subseaefloor biosphere, and hydrothermal flow, marine mammal tracking, connectivity of hydrothermal flow along spreading centers and impact on organisms</td>
<td>2 secondary nodes, 70 km extension cables, ship ROV time, optical connectors</td>
<td>$3.0 $1.4 $0.4 $0.12</td>
</tr>
<tr>
<td>NODE 8 Axial Volcano 5,12,14,16</td>
<td>Understanding crustal accretion at large active volcanoes, hydrothermal flow, seismic tremor and linkages to plate scale seismicity and hydrology, ocean carbon cycles, biogeochemical processes across a plate, subseaefloor biosphere, tracking marine mammals</td>
<td>5 secondary nodes, 5 extension cables (5,15,10,10.5 km), 5 day lay extension cables, Optical connectors. 5 X $30K, 10 days ship deployment</td>
<td>$7.5 $0.45 $2.5 $1.5 $0.50</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>$15.7 $4.92 $8.85</td>
</tr>
<tr>
<td>Location</td>
<td>Primary RFA’s</td>
<td>Science</td>
<td>Requirements Scenario 1</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------</td>
<td>------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------</td>
</tr>
<tr>
<td>NODE 9</td>
<td>N. Sym. Ridge 14,16</td>
<td>Required for Scenario 1 with a node every 150 km, future JdF Ridge extension</td>
<td>1 backbone node</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NODE 10</td>
<td>East Plate N</td>
<td>Required for Scenario 1 with a node every 150 km, future plate scale seismology/hydrology</td>
<td>1 backbone node</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NODE 11</td>
<td>Subduction Zone 2,4,5,12,14,15</td>
<td>Understanding seafloor deformation and slides, elastic strain along subduction zone, plate scale hydrology and seismicity, large-scale along coast gradients in productivity- community structure, hypoxia, carbon dynamics and cross-margin flux</td>
<td>3 secondary nodes, 75 km extension cable breakouts</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NODE 12</td>
<td>Endeavour 5,11,12,14,16</td>
<td>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, subsea floor biosphere, carbon cycle, heat flux, tracking marine mammals</td>
<td>2 secondary nodes, extension cables (13, 20, 10 km), 6 connectors 4 days ship deployment</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NODE 13</td>
<td>IODP –ODP Sites 1026, 1027, 1301, SR2 3,14,16</td>
<td>Understanding crustal hydrology, seismicity and hydrothermal flow in vigorously venting sedimented system, ocean carbon cycle, biogeochemical processes carbon cycle, heat flux, vent macrofauna, hydrocarbon formation</td>
<td>6 km extension cables, optical connectors 4 days Ship + ROV lay</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NODE 14</td>
<td>Barkley Canyon</td>
<td>Neptune Canada Node</td>
<td></td>
</tr>
<tr>
<td>NODE 15</td>
<td>Cascadia Margin SITE 889 3,4,12,14,15</td>
<td>Understanding hydrate formation, seismicity, hydrological connectivity at a plate scale, subsea floor biosphere, biogeochemical cycles, carbon budget, tsunami, megathrusts events</td>
<td>3 km extension cable, optical connectors 1 day ship + ROV lay</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NODE 16</td>
<td>Middle Valley 3,7,9,14,16</td>
<td>Understanding crustal hydrology, seismicity and hydrothermal flow in vigorously venting sedimented system, biogeochemical processes carbon cycle, heat flux, vent macrofauna, hydrocarbon formation</td>
<td>1 secondary node, 2 km extension cables, 3 optical connectors 2 days ROV lay</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacific-Juan de Fuca-Explorer (O1-12) 2,3,4,5,7,8,9,11,12,14,15,16</td>
<td>Understanding ocean turbulence and dynamics, role of ocean in global climate, nonequilibrium ecosystem dynamics, linkages of physical, chemical and biological processes, transport and flux across shelf-slope-plain, tsunami, temporal-spatial variability of plankton blooms</td>
<td>12 ~ 2500 m profiler moorings @ $1.5</td>
<td>$18</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Primary RFA’s</td>
<td>Science</td>
<td>Requirements</td>
</tr>
<tr>
<td>----------</td>
<td>---------------</td>
<td>---------</td>
<td>--------------</td>
</tr>
<tr>
<td>Cross Transform (nodes 5-8-9) 5,8,14</td>
<td>Understanding flow-topography interaction, seismicity along plate boundaries, gradients in coastal upwelling and impact on biogeochemistry, bottom mixing, differences in onshore-offshore processes and fluxes</td>
<td>240 km extension cable</td>
<td>$4.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>$4.8</strong></td>
</tr>
<tr>
<td>Backbone +Cable</td>
<td></td>
<td>2000 km cable, $17k/km installed</td>
<td><strong>$34</strong></td>
</tr>
<tr>
<td>Backbone nodes</td>
<td>$2.5m per node (includes installation)</td>
<td></td>
<td><strong>$30 (12 nodes)</strong></td>
</tr>
<tr>
<td>Mob/ demob</td>
<td></td>
<td></td>
<td><strong>$5</strong></td>
</tr>
<tr>
<td>NRE</td>
<td></td>
<td></td>
<td><strong>4</strong></td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td></td>
<td></td>
<td><strong>$150.02</strong></td>
</tr>
</tbody>
</table>

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) subseaflow hydrogeological processes & (b) formation pressure as a proxy for plate-scale strain; 4 = A Northeast Pacific Hydrate Observatory System 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 & 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 & 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 & Classification of Marine Species with Length Scales of Microns to One Meter; 11 = VIA (Vent Integrated Acoustics) Cabled Experiment: Main Endeavour Field, JdF Ridge; 12 = Regional Ocean Hydrophone Array Observatory; 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

*BN = branching units

**(20k/km installed with repeaters)**
Table 3. Scenario 2: Regional Cabled Observatory Integrated Experimental Design

<table>
<thead>
<tr>
<th>Location</th>
<th>Primary RFA’s</th>
<th>Science</th>
<th>Requirements</th>
<th>Cost (SM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODE 1 (N1)</td>
<td>2,4,5,7,12,14,15</td>
<td>Understand dynamic processes that control methane transport and hydrate formation, biogeochemical 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</td>
<td>Cost: $4.5, 25 km, 14 secondary nodes, 6 optical connectors (6)</td>
<td>$1.2</td>
</tr>
<tr>
<td>Hydrate Ridge</td>
<td></td>
<td></td>
<td>$0.18</td>
<td></td>
</tr>
<tr>
<td>NODE 2 (N2)</td>
<td>5,7,13,14</td>
<td>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</td>
<td>Cost: $0.135, 1 km cable, 2 optical connectors (2)</td>
<td>$0.06</td>
</tr>
<tr>
<td>Newport Line West</td>
<td></td>
<td></td>
<td>$0.017</td>
<td></td>
</tr>
<tr>
<td>NODE 3 (N3)</td>
<td>5,8,14</td>
<td>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</td>
<td>Cost: $2.46m, 145 km extension cables (surface laid), 12km double armored cable, 12 BN@$135K*</td>
<td>$1.62m</td>
</tr>
<tr>
<td>Blanco Fracture</td>
<td></td>
<td></td>
<td>$0.36m</td>
<td></td>
</tr>
<tr>
<td>Zone</td>
<td></td>
<td></td>
<td>$1.62m</td>
<td></td>
</tr>
<tr>
<td>NODE 4 (N4)</td>
<td>5,7,12,14,16</td>
<td>Understanding crustal accretion at large active volcanoes, hydrothermal flow, seismic tremor and linkages to plate scale seismicity and hydrology, ocean carbon cycles, biogeochemical processes across a plate, subseaftloor biosphere, tracking marine mammals</td>
<td>Cost: $3.0, 3 secondary nodes, 6 Electro. conn. 6 X $30K</td>
<td>$0.66</td>
</tr>
<tr>
<td>Axial Seamount</td>
<td></td>
<td></td>
<td>$0.18</td>
<td></td>
</tr>
<tr>
<td>NODE 5 (N5)</td>
<td>14,15</td>
<td>Critical for connection of Stages I and II networks, but it also serves an important mid-plate site for the plate-scale seismology program</td>
<td>Covered in total Node</td>
<td>$3.975</td>
</tr>
<tr>
<td>Mid-Plate N</td>
<td></td>
<td></td>
<td>$3.975</td>
<td></td>
</tr>
<tr>
<td>NODE 6 (N6)</td>
<td>2,4,5,12,14,15</td>
<td>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</td>
<td>Total</td>
<td>$4.39</td>
</tr>
<tr>
<td>Subduction Zone</td>
<td></td>
<td></td>
<td>$0.12</td>
<td></td>
</tr>
<tr>
<td>NODE 7 (N7)</td>
<td>5,11,12,14,16</td>
<td>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, subseaftloor biosphere, carbon cycle, heat flux, tracking marine mammals</td>
<td>Total</td>
<td>$2.93</td>
</tr>
<tr>
<td>Endeavour</td>
<td></td>
<td></td>
<td>$0.27</td>
<td></td>
</tr>
</tbody>
</table>

Total: $5.88

Total: $0.312

Total: $4.44

Total: $3.975

Total: $4.39

Total: $2.93
<table>
<thead>
<tr>
<th>Location</th>
<th>Primary RFA's</th>
<th>Science</th>
<th>Requirements</th>
<th>Cost (SM)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NODE 8 (N8)</strong></td>
<td>ODP 1027, 3,14,16</td>
<td>Understanding crustal hydrology, seismicity and hydrothermal flow in vigorous off-axis system, in sediment-covered permeable basement, related biogeochemical and microbiological processes, heat flux</td>
<td>2-km ext. cables, 12 pr optical connectors @$7k, 6 days Ship + ROV lay</td>
<td>0.120</td>
</tr>
<tr>
<td><strong>NODE 9 (N9)</strong></td>
<td>Barkley Canyon</td>
<td>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.</td>
<td>Mooring costs are included in cabled profiling moorings below</td>
<td>0.504</td>
</tr>
<tr>
<td><strong>NODE 10 (N10)</strong></td>
<td>Cascadia Margin</td>
<td>Understanding hydrate formation, seismicity, hydrological connectivity at a plate scale, subseafloor biosphere, biogeochemical cycles, carbon budget, tsunamiis, megathrust events</td>
<td>2-km ext. cables, 4 pr optical connectors, 2 days ship + ROV lay</td>
<td>0.020</td>
</tr>
<tr>
<td><strong>NODE 11 (N11)</strong></td>
<td>Middle Valley 3,7,9,14,16</td>
<td>Understanding crustal hydrology, seismicity and hydrothermal flow in vigorously venting sedimented system, biogeochemical processes, heat flux, vent macrofauna</td>
<td>1 secondary node, 2 km extension cables, 4 pr optical connectors, 2 days ship + ROV lay</td>
<td>0.024</td>
</tr>
<tr>
<td><strong>Cabled Moorings</strong></td>
<td>2,3,4,5,7,8,9,11,12,14,15,16</td>
<td>Understanding ocean turbulence and dynamics, role of ocean in global climate, nonequilibrium ecosystem dynamics, linkages of physical, chemical and biological processes, transport and flux across shelf-slope-plain, properties and propagation of tsunamiis over rough topography, temporal-spatial variability of plankton blooms</td>
<td>6 profiler moorings @$1.7, 2 profilers (acoustic modem moorings) @$1.6, 1 mooring @$1.7 with SN $1.5, 40 km, opt conn @ $0.06 extension cable $0.68</td>
<td>1.648</td>
</tr>
<tr>
<td><strong>Backbone + Nodes</strong></td>
<td></td>
<td>1750 km backbone cable, cable ship mob/demob, 6 science nodes, 6 backbone breakouts, NRE contractor engineering OCS, DMAS, SIIM engineering</td>
<td>$35, $5, $15, $3, $4, $4</td>
<td>17.3</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td></td>
<td>$107.46</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 Hydrotectonics 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 (Vertically 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.
### 3.6.2 Scenario 2 Stage II

In collaboration with the RCO science subcommittee for STAC, a second scenario was investigated with the backbone cable requirements shortened to 1,750 km and the number of primary nodes on Stage II reduced to 6. In addition, many of the extension cables and secondary nodes were eliminated and the number of vertical profilers was reduced to eight. The total estimate for this new scenario was $107.619M (Fig. 4; Table 3), comprised of $58M for the cable backbone and primary nodes, and $17.3M for moorings necessary for water column studies, $24.319M for additional secondary infrastructure that would access the locations of scientific interest on and beneath the seafloor, and $8M for engineering. The alternate system involving repeaters, which was adopted by Stage I, is also within this cost estimate. The goal now is to further refine the estimates to determine the real Stage II budget requirement, while at the same time optimizing the overall infrastructure that can be procured with the money available.

<table>
<thead>
<tr>
<th>Item</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Node</td>
<td>$2.5M</td>
</tr>
<tr>
<td>Backbone Cable installed</td>
<td>$20K/km*</td>
</tr>
<tr>
<td>Secondary Node</td>
<td>$1.5M</td>
</tr>
<tr>
<td>Major Extension Cable installed</td>
<td>$17K/km</td>
</tr>
<tr>
<td>Small Benthic Node</td>
<td>$175K</td>
</tr>
<tr>
<td>Vertical Profiler (No Instruments)</td>
<td>$1.7M</td>
</tr>
<tr>
<td>ROV Laid Extension Cable*</td>
<td>$10K/km</td>
</tr>
<tr>
<td>Ship +ROV</td>
<td>$50K/Day</td>
</tr>
<tr>
<td>Optical Connector</td>
<td>$30K/Pair</td>
</tr>
<tr>
<td>Shore Station</td>
<td>TBD</td>
</tr>
<tr>
<td>Backhaul System</td>
<td>TBD</td>
</tr>
</tbody>
</table>

*does not include installation

Several major factors must be decided before we can determine the total system cost. 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. Without going into technical details, 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 was 1,750 km, at least 11 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). Stage II could then 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, 6 nodes (N1-N6) have been included with a series of 6 branching units (r-w) (Fig. 4) on Stage II.

There are significant benefits if Stage I and Stage II are connected in terms of system redundancy for backup of communication and power. For example, the Stage I system is now equipped with
six nodes and there are at least four unused wavelengths in each direction on the cable. Each wavelength can carry a minimum of two GbE signals. Therefore, if Stages I and II were connected, the Stage I cable could provide transmission to shore for a minimum of sixteen GbE signals from Stage II. By the time Stage II is installed, it is likely that this capacity will have increased fourfold.

Another advantage to connecting the two systems is that the connection could provide backup power for each of the networks. Problems in either system’s power network could be overcome by using the other system’s power supplies to temporarily operate both systems. This function would be an extremely valuable asset to have, and would overcome the vulnerability of the RCO to damage to the cable on the continental shelf shutting down the entire system. If this does not happen, the only connection possible between the two systems will have to be done over the terrestrial grid.

Because of the important benefits attained by having both Stage I and II connected, we have incorporated this into the working scenario with a cable cunning between Nodes 5 and 8 in the benign environment of the mid-plate (Figs. 4 & 5). It should be noted, however, that if Stage II is not directly mated to the Stage I system, instruments and additional cable can be easily added that are directly compatible. In both of the designs presented, we have leveraged the initial Stage I cable route and augmented their planned experimental arrays at a fraction of the cost it would take if the system were solely covered by the Stage II infrastructure.

**Implementation Office-Non Recurring Engineering Costs (IO-NRE):** 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 are considered outside the scope of responsibility of the RCO commercial subcontractor. For example, items such as Benthic Nodes, Extension Cables, Desktop Simulators, Observatory Control System, and SIIMS need to be designed and prototyped before they can be fabricated in quantity: 4 FTE for 3 Years is $3M

**4.0 Summary of RCO Nodes, Science Objectives, and Infrastructure**

Using a target budget of $90M for capital and installation costs, the RCO subgroup focused on Scenario 2 for an initial Conceptual Network Design (CND) (Fig. 4; Table 3). As discussed in the previous section, this design includes 1750 km of cable forming a single loop, 6 nodes, 6 branching units, 9 profiling moorings with 120 km of extension cable, and extension cables and secondary nodes at Endeavour and Middle Valley, ODP889, and ODP-IODP 1027 sites on Stage I. Estimated cost for this design is $107.6M.

An important philosophy behind this CND is the recognition that this experiment is a 30-year sustained effort and that getting the initial infrastructure in place to allow optimal flexibility and lowest cost for future instrumentation and expansion of experiments is the critical first step. Therefore, costs associated with Scenario 2 do not include core instruments, minor extension cables or connectors. We assume that these types of costs will be much easier to attain than installation of the backbone and primary and secondary nodes, and that this implementation design most closely meets the spirit and intent of the MRETC. Looking towards the future, we have prioritized 6 backbone nodes, and 6 branching units that allow future expansions. The name, location, and depth of the primary nodes are included in Tables 1 & 3 and shown in Figure
4 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.

4. 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 Control
- Seismic and Geodetic Observations of the Cascadia Continental Margin: Towards an Effective Real-Time earthquake and Tsunami Warning System
- A 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 & 9). 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.

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.

Figure 8. Map showing location of subnodes at Node 1. Gas hydrate related studies are primarily focused at subnode NP1 on the southern summit of Hydrate Ridge. Oceanographic and subduction zone related objectives are addressed by benthic and mooring instrumentation placed at each of the three proposed subnodes (NP1 - NP3).
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/CO₂ release from margin settings may combine with increasing atmospheric CO₂ 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.

Figure 10. 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

- 70 km of ship laid cable $1,200K
- 3 secondary nodes $4,500K
- 6 optical connectors $180K
- TOTAL $5,880K

**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 $9,387,677

**Subsurface instrumentation (under development):**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Components</th>
<th>Development status</th>
<th>Sampling rate</th>
<th>Power</th>
<th>Est. cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>CORK</td>
<td>pre-perforated casing for a 200 m hole; pressure and temperature sensors; ROV-removable seal; bio-traps; broad-band fluid sampler and sensor</td>
<td>Some development needed to adapt broadband fluid sampler, seals and bio-traps.</td>
<td>5 MByte per day</td>
<td>&lt;0.1 W background; 2.5 W intermittent 15 W peak</td>
<td>~$1,500K (?)</td>
</tr>
<tr>
<td>mini-CORKs</td>
<td>Similar to CORKs but for shallow holes</td>
<td>Package under development</td>
<td>5 MByte per day</td>
<td>&lt;0.1 W background 2.5 W intermittent</td>
<td>$500K (?)</td>
</tr>
<tr>
<td>SCIMPI</td>
<td>Phase 1: monitor temperature, pressure, resistivity to constrain fluid flow and gas hydrate formation through the</td>
<td>Phase I proposal well reviewed but not funded. Will be resubmitted.</td>
<td>1 Hz for each data stream; ~15 Hz/SCIMPI</td>
<td>NA</td>
<td>$320K/SCIMPI 9 SCIMPIs</td>
</tr>
</tbody>
</table>
hydrate stability zone in and underlying fluid conduit. | ~5 MBytes/day | = $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):**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Components</th>
<th>Development status</th>
<th>Sampling rate</th>
<th>Power</th>
<th>Est. cost</th>
</tr>
</thead>
</table>
| 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 engineerin g)  
$3K each 30 units proposed = $30K |
| 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 continuously  
~2 W needed intermittently | $50K each 3 units proposed = $150K |
| 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 6 units = $120K |
| 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 unit  
6 units = $120K |
<p>| 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 | 12 MBytes per day | 6 W | $75K one unit at SHR3 |</p>
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Components</th>
<th>Development status</th>
<th>Sampling rate</th>
<th>Power</th>
<th>Est. cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water column mooring with methane and other sensors</td>
<td>measure water column chemistry</td>
<td>Same technology proposed for NEPCM RFA. Two additional units needed for SHR.</td>
<td>4 MBytes per day</td>
<td>3 W</td>
<td>$390 each/ 2 units proposed. $780K</td>
</tr>
<tr>
<td>Seabird CTD</td>
<td></td>
<td></td>
<td>3 MBytes per day</td>
<td>6 W</td>
<td></td>
</tr>
</tbody>
</table>
4.2 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:

- 1 km cable ship laid $0.02K
- BentHic node $0.135M
- Optical connectors (2) $0.06M
2 d Ship?ROV time $0.1M
Total $0.315M

Instrumentation. The cost of instrumentation is as follows:
Core seismic monitoring package $80,000
1-day ROV –ship time $50,000

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
4.3 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. Scenario 2 (Figure 11) focuses on the segment of most interest and envisions a network of low cost Benthic Node type infrastructure that can cover a ~60 by 20 km wide area with a network of relatively low power instruments like seismometers, fluid temperature sensors, and geodetic transponders. Scenario 1 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.

Figure 11. 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.** In scenario 2 the cost of infrastructure excluding a water column mooring is

- 145 km of ordinary ship laid cable @ $17K/km  
  \[145 \times 17 = 2,465K\]
- 12 km of double armored cable to cross the Blanco Ridge @ $30K/km  
  \[12 \times 30 = 360K\]
- 12 benthic nodes @ $135K  
  \[12 \times 135 = 1,620K\]

**TOTAL**  
\[2,465K + 360K + 1,620K = 4,445K\]

**Instrumentation.** The cost of instrumentation are

- 18 WHOI broadband/strong motion OBS & pressure sensor @$80K*  
  \[18 \times 80 = 1440K\]
- 10 acoustic ranging geodetic stations @$40K  
  \[10 \times 40 = 400K\]
- 10 temperature sensors @$2K  
  \[10 \times 2 = 20K\]

**TOTAL**  
\[1440K + 400K + 20K = 1860K\]

*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 ROHАО acoustic experiment would cost $1M
4.4 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 12. Map of Node 4 on Axial Volcano showing the configuration of the experiment as originally envisioned in the RFA proposal “A cabled observatory on the Juan de Fuca Ridge”, and the location of OOI installed infrastructure that would be installed in Scenarios 1 and 2.
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 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 be covered by the hydroacoustic monitoring and plate scale seismology experiments.

Infrastructure. In Scenario 2, 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:

- 20 km of ship-laid cable from primary node to east secondary node: $340K
- 15 km of ship-laid cable between east and west secondary node: $255K
- 2 secondary nodes: $3,000K
- 3 km of ship-laid cable to benthic node at Castle vent site: $51K
- Benthic node: $135K
- TOTAL: $3,781K

Additional Infrastructure. Additional benthic nodes and ship-laid cable that is not included in the OOI budgeted infrastructure will be required to support a seismic/geodetic array and additional hydrothermal sites.

- A seismic/geodetic array will require:
  - 10 benthic nodes: $1,350K
  - 10 days ship/ROV to install benthic nodes: $500K
  - 50 km ship-laid cable: $850K
- TOTAL: $2,700K

- A benthic node at the ASHES vent field will require:
  - 1 benthic node: $135K
  - 1 day ship/ROV to install benthic node: $50K
  - 6 km ship-laid cable: $102K
- TOTAL: $287K

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
- 5 days ship/ROV to install: $250K

**TOTAL**: $849K

3 days of ship/ROV per year will be required to maintain each hydrothermal site.

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
- 10 days ROV to install: $500K

**TOTAL**: $1,325K

5 days of ship/ROV per year will be required to maintain a seismic/geodetic array.

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
- 3 days ship/ROV to install: $150K

**TOTAL**: $567K

2 days of ship/ROV per year will be required to maintain a static mooring.
4.5 Node 5 Junction of Stages I and II  
Location: 47°02’N 127°44’W  
Overlapping RFA’s at this Node:  
• A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific  

Science: 
This node provides one of the few mid-plate sites for plate-scale seismology and geodynamics. Observations at this node will enable an understanding of stress propagation through the plate as well as intraplate deformation and its relation to plate boundary failure. This nodes forms a critical link to Stage I and Stage II of the RCO and ~ 100 km of backbone cable is included in the infrastructure costs for this connection.  

Infrastructure. No infrastructure other than the primary node would be funded by the OOI, although this would be an important site for a seismic suite of instruments should funds be available for a secondary or benthic node and a minor extension cable.
4.6 Node 6 Subduction Zone
Location: 46°39.0’N 125°50.0’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
- 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 Section 4.12. 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 in the past. 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 the 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 13. Topographic map of the Cascadia accretionary margin offshore central Washington showing the location of Node 11 and the associated seismic/geodetic transect.](image)
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 tsunamiic 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 X 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.

Estimated total cost of each seismic/geodetic station is $579K (seismometer - $80k; short-period geophones – 6 x $20k; acoustic array for strainmeter - $230k; GPS/acoustic link - $90k assuming

Figure 14. Schematic illustration of a seismic/geodetic station.
that a water column buoy will be co-located; temperature probes – 3 x $3k; bottom current meter - $10k; cable - $40k). Figure 14 shows a schematic illustration of a seismic/geodetic station.

**Summary of costs for Node 6:** $4,397K for cables and nodes; $1,737 for 3 seismic/geodetic stations (+ water column mooring).

**Instrumentation for a seismic/geodetic station:**

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

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.
4.7 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 be 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 Scenario 1, one cable will connect to a secondary junction box in the axial valley 15 km to the south of the primary node to an additional mooring for water column experiments. A second junction box will be deployed to the east of the axial volcanic high at the latitude of high rise and will connect to branching nodes at High Rise and Sasquatch and to a cable that links branching nodes and instruments on a geodetic profile that crosses the axial valley. In Scenario 2, both secondary nodes are preserved by only the branching node to Sasquatch is funded.
Figure 15. Map of Node 7 on the Endeavour segment showing the location of the configuration of the experiment as originally envisioned in the RFA proposal “A cabled observatory o the Juan de Fuca Ridge”, and the location of OOI installed infrastructure that would be installed in Scenarios 1 and 2.

**Infrastructure.** The costs of the Scenario 2 infrastructure is as follows:

1. 1 secondary node $1,500K
2. 2 Benthic nodes (Sasquatch and High Rise) $8270K
3. 4km + 4km +3km extension cables and geodetic transponder breakout cable with 4 BN’s $1M

**TOTAL** $2,770K

**Additional Infrastructure.** Additional infrastructure envisioned in Scenario 1 is as follows

1. 3 km of ship-laid cable to High Rise $51K
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**
- **Vertical hydrophone array on profiling mooring**
- 5 days ship/ROV time to install

**Total**

**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**
- **CTD**
- **2 x Seapoint Light Backscatter Sensor**
- **3 x Time-series Sediment/Larval Trap**
- **2 x Water Transfer System**
- **Laser Scattering / Transmissometry**
- **Iron, Manganese, pH analyzer**
- 3 days ship/ROV to install

**Total**

2 days of ship/ROV per year will be required to maintain a static mooring.

At each of the four instrumented vent fields, an illustrative suite of 10 instruments might comprise:
- **Short period seismometer**
- **Bottom pressure recorder**
- **T-resitivity-hydrogen**
- **Microbial incubator**
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
5 days ship/ROV to install $250K
TOTAL $849K

3 days of ship/ROV per year will be required to maintain each hydrothermal site

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
10 days ROV to install $500K
TOTAL $1,200K

3 days of ship/ROV per year will be required to maintain the geodetic profile.
4.8 Nodes 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?
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 ~60°C 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.**

**Instrumentation.** Downhole CORK instrumentation would be funded through IODP.
4.9 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 below 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 metabolic 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 highly 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.

Infrastructure:

**Instrumentation:** See Section 4.12
- Profiling Mooring $251K
- Installation 4 days transite, 4 days installation, 1 weather day $350K
- Total $601K
4.10 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 17. Node 10 at ODP site 889.

Infrastructure. In Scenario 2, the OOI is funding an extension cable to the CORK’ed observatory site and connections to the borehole.
4.11 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 18. 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.** In Scenario 2, the OOI funds extension cables to the CORKed observatory.
4.12 Sites a-i: Cabled profiling moorings for RCO water column access

Proposed water column sites

In Scenario 2, the original water column access proposal has been down-scaled to 9 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.

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

<table>
<thead>
<tr>
<th>Sites</th>
<th>Science objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rh, Re, Rd</td>
<td>Resolution of N/S fluctuations in the WWD and its bifurcation; comparison of different ecosystems (subarctic and subtropical gyres).</td>
</tr>
<tr>
<td>Rf, Rg</td>
<td>Biophysical variability in WWD advected towards coast; delineate variability of mass and biogenic fluxes in the N/S divergence.</td>
</tr>
<tr>
<td>Rh-Ri, Rf-Rg, Rb</td>
<td>Comparison of onshelf/slope/offshelf processes and fluxes at locations of different upwelling and mean current regimes</td>
</tr>
<tr>
<td>Ri, Rg</td>
<td>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</td>
</tr>
<tr>
<td>Ri, Rg, Ra, Rb</td>
<td>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</td>
</tr>
<tr>
<td>Rc, Rb (plus coastal cabled mooring on shelf)</td>
<td>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</td>
</tr>
<tr>
<td>Rf, Re</td>
<td>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.</td>
</tr>
<tr>
<td>Ri, Rg, Ra, Rb</td>
<td>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).</td>
</tr>
</tbody>
</table>

### 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 600m float, and on a 200m 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 200-600m and 600m-bottom segments of the cable.
Costs of water column access at 9 primary nodes

Cabled moorings: Costs include components (the most secure figure), and estimates for assembly and deployment\(^{(1)}\).

Sites RA-RF: Vertical infrastructure, installed at main nodes,
6 sites @ $1.7M = $10.2M

Site RG: Infrastructure components as A-F, 20-40 km of extension cable from Stage 1 Barkley Canyon node, underwater connectors
1 site @ $4.2M

Site RH and RI: stand-alone acoustically-coupled moorings
2 sites @ $1.6M = $3.2M

Total infrastructure costs: $17.6M

\(^{(1)}\) Estimated deployment costs
Sites RA-RF : 4 days per mooring, no transit costs = $200K/mooring
Site RG : separate calculation, including installation of necessary extension cable
Sites RG-RI : 4 days transit, 4 days/mooring + 2 weather days = 14 days
= $700K for both, $350K each

**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.

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Watt</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Winch</strong></td>
<td></td>
</tr>
<tr>
<td>Profiler (2)</td>
<td>64</td>
</tr>
<tr>
<td>Hotel (200 m float)</td>
<td>300</td>
</tr>
<tr>
<td><strong>Sensors</strong></td>
<td></td>
</tr>
<tr>
<td>0-200m</td>
<td>79</td>
</tr>
<tr>
<td>200m</td>
<td>24</td>
</tr>
<tr>
<td>200-600m</td>
<td>38</td>
</tr>
<tr>
<td>600m</td>
<td>15</td>
</tr>
<tr>
<td>600-bottom</td>
<td>12</td>
</tr>
<tr>
<td>bottom</td>
<td>14</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>616</td>
</tr>
</tbody>
</table>
**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.
4.13 Branching Units
Scenario 2 includes branching units at 6 locations on the Stage II (OOI) portion of the RCO. These 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 the conceptual design anticipates will 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 °C 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 developing Scenario 2, it was recognized that the ridge community will not have the resources necessary to develop full scale experiments 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, Scenario 2 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. Since 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 RFAs 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.

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.
5.0 Instrument Packages for Stage 1 and 2 of the RCO

5.1 Cabled profiling mooring instrumentation

The following table contains "core" instrumentation considered presently ready for extended deployment on the RCO cabled moorings; costs not included in Scenarios I or II estimates.

<table>
<thead>
<tr>
<th>Instrument Package</th>
<th>Core Cost</th>
<th>Additional Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface layer profiling package</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-T-D-O₂</td>
<td>$12K</td>
<td></td>
</tr>
<tr>
<td>PAR</td>
<td>$10K</td>
<td></td>
</tr>
<tr>
<td>FL-Tr</td>
<td>$5K</td>
<td></td>
</tr>
<tr>
<td>NO₃</td>
<td>$25K</td>
<td></td>
</tr>
<tr>
<td>ADV</td>
<td>$10K</td>
<td></td>
</tr>
<tr>
<td>pCO₂/pH</td>
<td>$20K</td>
<td></td>
</tr>
<tr>
<td>SIPPER camera</td>
<td>$60K</td>
<td></td>
</tr>
<tr>
<td>200 m float</td>
<td>$38K</td>
<td></td>
</tr>
<tr>
<td>150KHz ADCP (up-looking)</td>
<td>$10K</td>
<td></td>
</tr>
<tr>
<td>hydrophone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200-600 m profiler</td>
<td>$12K</td>
<td></td>
</tr>
<tr>
<td>C-T-D-O₂</td>
<td>$12K</td>
<td></td>
</tr>
<tr>
<td>F-Tr</td>
<td>$5K</td>
<td></td>
</tr>
<tr>
<td>NO₃</td>
<td>$25K</td>
<td></td>
</tr>
<tr>
<td>ADV</td>
<td>$20K</td>
<td></td>
</tr>
<tr>
<td>TAPS (up-looking multiple frequency acoustics)</td>
<td>$100K</td>
<td></td>
</tr>
<tr>
<td>600 m float</td>
<td>$25K</td>
<td></td>
</tr>
<tr>
<td>NO₃</td>
<td>$4K</td>
<td></td>
</tr>
<tr>
<td>Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 m-bottom profiler</td>
<td>$12K</td>
<td></td>
</tr>
<tr>
<td>C-T-D-O₂</td>
<td>$12K</td>
<td></td>
</tr>
<tr>
<td>Tr</td>
<td>$4K</td>
<td></td>
</tr>
<tr>
<td>ADV</td>
<td>$10K</td>
<td></td>
</tr>
<tr>
<td>Tomography transducer</td>
<td>$250K</td>
<td></td>
</tr>
<tr>
<td>bottom package</td>
<td>$30K</td>
<td></td>
</tr>
<tr>
<td>PIES</td>
<td>$4K</td>
<td></td>
</tr>
<tr>
<td>Tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADV</td>
<td>$75K</td>
<td></td>
</tr>
<tr>
<td>75KHz (up-looking)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADCP</td>
<td>$50K</td>
<td></td>
</tr>
</tbody>
</table>

CTD = conductivity, temperature, depth, DO = dissolved oxygen, PAR = Photosynthetically Active Radiation, FL = fluorescence, Tr = optical backscatter, NO₃ = nitrate sensor, ADCP = Acoustic Doppler Current Profiler, ADV = acoustic doppler velocimeter, PIES = current meter/pressure sensor/inverted echo sounders.

5.2 Core Seismic Packages

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. To reduce environmental noise the broadband seismometers must be installed below the seafloor or placed in bore-holes at ~ 200 m depth and be located at least 20 m away from other instrumentation. Power, timing and communications requirements are:
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.

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

### 5.3 Pelagic-Benthic Monitoring System

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. Ideally, the third site would be west of the Juan de Fuca Ridge.
Figure 20. Pelagic/Benthic Monitoring System. Moored platform also includes cameras and sediment traps and sensors.
Conceptual Network Design for Benthic/Pelagic Monitoring System

1. Two nodes along Newport Line (#3, #5) and one extension beyond Plate. 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 Sta. PAPA attractive for 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 three 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 three sites = $4,517,029.
### Appendix 1. Timetable of Regional Cabled Observatory Development

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>June</td>
<td>National Oceanographic Partnership Program (NOPP) funds U.S. NEPTUNE feasibility study</td>
</tr>
<tr>
<td>1999</td>
<td>June</td>
<td>Canada's Institute for Pacific Ocean Science and Technology invited by U.S. to undertake feasibility study of Canadian partnership with U.S. NEPTUNE</td>
</tr>
<tr>
<td>2000</td>
<td>June</td>
<td>U.S. NEPTUNE feasibility study completed and published</td>
</tr>
<tr>
<td></td>
<td>Sept</td>
<td>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</td>
</tr>
<tr>
<td></td>
<td>Oct</td>
<td>NEPTUNE Canada feasibility study completed and published</td>
</tr>
<tr>
<td>2001</td>
<td>June</td>
<td>NSF funds development of regional cabled observatory power system</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>W.M. Keck Foundation grants award for proto-NEPTUNE experiment</td>
</tr>
<tr>
<td></td>
<td>Dec</td>
<td>University of Victoria joins NEPTUNE partnership</td>
</tr>
<tr>
<td>2002</td>
<td>Feb</td>
<td>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</td>
</tr>
<tr>
<td></td>
<td>Mar</td>
<td>NEPTUNE cable-route desktop study completed</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>NOPP funds NEPTUNE system engineering, program office, and science planning</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>Memorandum of Understanding and Rules of Operation for NEPTUNE Affiliation approved by NEPTUNE partners</td>
</tr>
<tr>
<td></td>
<td>Aug</td>
<td>Grant from Province of British Columbia completes VENUS funding</td>
</tr>
<tr>
<td></td>
<td>Sept</td>
<td>NSF funds the Monterey Accelerated Research System (MARS) cabled-observatory test bed in Monterey Bay</td>
</tr>
<tr>
<td>2003</td>
<td>April</td>
<td>NEPTUNE Pacific Northwest Science Planning Workshop held at Portland State University, Portland Oregon</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>Workshop on linkages between the Ocean Observatories Initiative and the Integrated Ocean Drilling Program held in Seattle, Washington</td>
</tr>
<tr>
<td></td>
<td>Oct</td>
<td>Canada Foundation for Innovation and British Columbia Knowledge Development Fund announce CAN$62.4 million in funding to University of Victoria for NEPTUNE Canada</td>
</tr>
<tr>
<td></td>
<td>Oct</td>
<td>Cabled Regional Observatory Workshop, San Francisco, sponsored by NSF. Northeast Pacific Ocean designated as site of first regional cable observatory</td>
</tr>
<tr>
<td>2004</td>
<td>Jan</td>
<td>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</td>
</tr>
<tr>
<td></td>
<td>Feb</td>
<td>President's FY2005 budget released, showing out-year commitment of FY2006 start of $245 million in funding for the NSF Ocean Observatories Initiative</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>NEPTUNE Canada Ocean Observing Systems Workshop, University of Victoria, 3-5 May</td>
</tr>
<tr>
<td>2005</td>
<td>April</td>
<td>Collaborative Enhancement Workshop Skamania Lodge for Responses to the RFA, April 14-15</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>Community Proposals due to ORION Office in Response to RFA call</td>
</tr>
<tr>
<td></td>
<td>Sept</td>
<td>NSF-Panel bins proposals into 3 groupings based on a combination of factors that included readiness and maturity of required technologies and proposed science.</td>
</tr>
<tr>
<td></td>
<td>Oct</td>
<td>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</td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td>STAC meets Jan 30-Feb 1 in Washington DC to discuss Science User Documents for global, regional, and coastal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>February 6th the OOI is listed in the President’s FY2007 as a new MREFC start at $301M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>March 1-2 RCO RFA proponents meet in Seattle to formulate Conceptual Design for the RCO</td>
</tr>
</tbody>
</table>
### Appendix 2: Regional Cabled Observatory and Associated RFA’s

<table>
<thead>
<tr>
<th>PI/Contact</th>
<th>PI Contact/ Engineering contact</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Barth</td>
<td><a href="mailto:barth@coas.oregonstate.edu">barth@coas.oregonstate.edu</a> Bill Kirkwood</td>
<td>A Multi-Scale Ocean Observatory for Ocean Dynamics and Ecosystem Response along the Northeast Pacific Continental Margin</td>
</tr>
<tr>
<td>B) Becker</td>
<td><a href="mailto:kbecker@rsmas.miami.edu">kbecker@rsmas.miami.edu</a> Mark Zumberge</td>
<td>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</td>
</tr>
<tr>
<td>C) Brown</td>
<td><a href="mailto:trehu@coas.oregonstate.edu">trehu@coas.oregonstate.edu</a> Gene Massion</td>
<td>A Northeast Pacific Hydrate Observatory System (NEPHOS) at South Hydrate Ridge</td>
</tr>
<tr>
<td>D) Daly</td>
<td><a href="mailto:kdaly@marine.usf.edu">kdaly@marine.usf.edu</a> Gary Harkins</td>
<td>An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from basin to Regional Scales</td>
</tr>
<tr>
<td>E) Kolber</td>
<td><a href="mailto:zkolber@mbari.org">zkolber@mbari.org</a></td>
<td>Distributed pH Observatory: Assessing the Effects of the Anticipated Shift in the Upper ocean on the Oceanic Energy and Carbon Cycle</td>
</tr>
<tr>
<td>F) McGuire</td>
<td><a href="mailto:jmceguire@whoi.edu">jmceguire@whoi.edu</a> Mark Zumberge</td>
<td>An Earthquake, Physics, and Fault Mechanics Observatory on the Blanco transform Fault</td>
</tr>
<tr>
<td>G) Rona</td>
<td><a href="mailto:rona@imcs.rutgers.edu">rona@imcs.rutgers.edu</a> Gary Harkins</td>
<td>VIA (Vent Integrated Acoustics) Cabled Experiment: Main Endeavour Field, Juan de Fuca Ridge</td>
</tr>
<tr>
<td>H) Smith</td>
<td><a href="mailto:ksmith@ucsd.edu">ksmith@ucsd.edu</a> Gene Massion</td>
<td>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</td>
</tr>
<tr>
<td>I) Stephen</td>
<td><a href="mailto:rstephen@whoi.edu">rstephen@whoi.edu</a> Gene Massion</td>
<td>Regional Ocean Hydrophone Array Observatory (ROHAO)</td>
</tr>
<tr>
<td>J) Toomey</td>
<td><a href="mailto:drt@uooregon.edu">drt@uooregon.edu</a> Gary Harkins</td>
<td>A Plate-Scale Observatory for Seismology and Geodynamics in the Northeast Pacific</td>
</tr>
<tr>
<td>K) Trehu</td>
<td><a href="mailto:trehu@coas.oregonstate.edu">trehu@coas.oregonstate.edu</a> Mark Zumberge</td>
<td>Seismic and Geodetic Observations of the Cascadia Continental Margin: Towards an Effective Real-Time earthquake and Tsunami Warning System</td>
</tr>
<tr>
<td>L) Wilcock</td>
<td><a href="mailto:wilcock@ocean.washington.edu">wilcock@ocean.washington.edu</a> <a href="mailto:kelley@ocean.washington.edu">kelley@ocean.washington.edu</a> Gene Massion</td>
<td>A Cabled Observatory on the Juan de Fuca Ridge</td>
</tr>
</tbody>
</table>
Appendix 3 Science User Requirements for the RCO

A) Barth and Hickey: A Multi-Scale Ocean Observatory for the Northeast Pacific Continental Margin (Horne)

(1) Primary scientific issues/hypotheses/objectives,

Primary scientific issues include large-scale transport of water and biogeochemical properties; large-scale along-coast gradients in productivity and community structure; mesoscale ecosystem response in contrasting coastal regions (central Oregon and central Washington); hypoxia; harmful algal blooms; carbon dynamics and cross-margin flux; and tidally generated internal solitary waves.

Objectives include development of sensors and ocean environment modeling and examination of large-scale transport of water and biogeochemical properties, large-scale along-coast gradients in productivity and community structure, flow-topography interaction and ecosystem response over Heceta Bank, Oregon, river-influenced coastal ocean dynamics and ecosystem response in Washington, hypoxia in the Pacific northwest, harmful algal blooms, carbon dynamics and cross-margin flux, tidally generated internal bores and nonlinear internal wave packets, and flow interaction with hydrate ridge methane source.

(2) Observatory Components

1a. Endurance Lines: Oregon

(A) Time Periods
- sustained study

(B) Infrastructure
- part of Regional Cabled Observatory (RCO) or an extension from RCO backbone
- if extension, then junction box and cabling required
- vertical profiling systems, bottom-mounted ADCP, water column moorings with surface buoys
- depths: 25, 50, 80, 150, 500, 1500, 3000 m
- profiler payload capacity and power requirements?
- ADCP requirements?

(C) Location
- Newport hydrographic line (44.65 N)
- from inner shelf, across the continental slope into the deep ocean
- assume some flexibility in location as long as a continuous transect in vicinity of historic sampling transect

(D) Feasibility
- instruments are available off the shelf
- packages have not been integrated
- bio-fouling considered

(E) Power, Communications, and IT requirements
- 

(F) Service Requirements
- 

(G) Pre-Experiment Requirements
- 


1b. Endurance Lines: Washington
(A) Time Periods
- sustained study
(B) Infrastructure
- part of Regional Cabled Observatory (RCO) or an extension from RCO backbone
- if extension, then junction box and cabling required
- if moorings, then autonomous deployments telemetering data to shore
- vertical profiling systems, bottom-mounted ADCP, water column moorings with surface buoys
- depths: 25, 50, 80, 150, 500, 1500, 3000 m
- mooring payload capacity?
- profiler payload capacity and power requirements?
- ADCP requirements?
(C) Location
- central Washington state (46.5N)
- assume exact mooring locations are somewhat flexible if conformed to depth contours
(D) Feasibility
- instruments are available off the shelf
- packages have not been integrated
- bio-fouling considered
(E) Power, Communications, and IT requirements
- 
(F) Service Requirements
- 
(G) Pre-Experiment Requirements
- 

1c. Pioneer Arrays: Oregon
(A) Time Periods
- sustained study
(B) Infrastructure
- 6 vertical profiling moorings
- 3 additional (two on shelf, one off) water column moorings with surface buoys
- moorings > 200 m: hybrid profiling with traveling profiler & winched platform
(C) Locations
- Heceta Bank area, 3 lines: 43.5, 43.825, 44.25 °N
- depths: 25, 50, 80, 150, 500, 1500, 3000 m
(D) Feasibility
- 
(E) Power, Communications, and IT requirements
- 
(F) Service Requirements
- 
(G) Pre-Experiment Requirements
- 

1d. Pioneer Arrays: Washington
(A) Time Periods
- sustained study

(B) Infrastructure
- 9 vertical profiling moorings
- 3 central moorings add: imaging cytometers, video, secondary profiling mooring (CTD, ADV at 1, 3, 5, 10, 20 m)

(C) Locations

- 

(D) Feasibility

- 

(E) Power, Communications, and IT requirements

- 

(F) Service Requirements

- 

(G) Pre-Experiment Requirements

- 

2a. Profiling Moorings (as part of Lines and Arrays): upper ocean

(A) Time Periods
- sustained study

(B) Infrastructure
- can hide on bottom to minimize bio-fouling
- 200 m or less
- sensors: pressure, temperature, salinity, velocity, chlorophyll fluorescence, zooplankton acoustics, dissolved oxygen, nitrate, spectral downwelling irradiance, beam attenuation, backscattering
- vertical resolution of less than 0.25 m

(C) Locations

- 

(D) Feasibility

- 

(E) Power, Communications, and IT requirements

- 180 day deployment
- 8 profiles/day minimum
- sampling at 0.5-1 m/s
- cable sampling length 800 km (?)
- real-time telemetry (radio, cell phone or Iridium phone)
- data transmission and power from seafloor junction box when connected to cable
- ~40 W @ 12V DC; 380 Amp-hours per 180 days
- winch: ~70 W @ 48 V DC; 255 Amp-hours per 180 days
- total power ~ 150 W;

(F) Service Requirements

- 6 month autonomous operation

(G) Pre-Experiment Requirements

- CO₂ sensor systems
- FLOW-CAM integration
- genome-based sensors

2b. Profiling Moorings (as part of Lines and Arrays): deep ocean
(A) Time Periods
- sustained study

(B) Infrastructure
- can hide on bottom to minimize bio-fouling
- ~3000 m to within 200 m of surface
- platform for other sensors including upper ocean profiler
- docking station with inductive coupler
- McLane moored profiler (MMP)
- sensors at top and bottom of wire

(C) Locations
- 

(D) Feasibility
- 

(E) Power, Communications, and IT requirements
- attached to cable
- profiling at 0.25 m/s
- secondary junction box: several hundred watts and 1100 Mb/s ethernet

(F) Service Requirements
- subsurface float with secondary junction box for servicing of instrument packages

(G) Pre-Experiment Requirements
- 

2c. Profiling Moorings (as part of Lines and Arrays): bottom package

(A) Time Periods
- sustained study

(B) Infrastructure
- stable platform connected to cable
- ADCP
- sensors: pressure, temperature, conductivity, chlorophyll, dissolved oxygen and suspended particle load

(C) Locations
- 

(D) Feasibility
- 

(E) Power, Communications, and IT requirements
- connected to cable or powered autonomously
- data transmitted through cable or acoustic or inductive telemetry to upper ocean profiler

(F) Service Requirements
- 

(G) Pre-Experiment Requirements
- 

2d. Profiling Moorings (as part of Lines and Arrays): sea surface

(A) Time Periods
- sustained study

(B) Infrastructure
- mooring with large surface buoy
(C) Locations
- several cross-shelf locations
- sensors (at various depths): temperature, conductivity
- ADCP 1200 kHz
- meteorological package: wind velocity, atmospheric pressure, air temperature, humidity, solar radiation, infrared radiation
- communications platform

(D) Feasibility

(E) Power, Communications, and IT requirements
- 1 min intervals
- provides communication platforms for data collection and telemetry

(F) Service Requirements

(G) Pre-Experiment Requirements

2e. Acoustic Tomographic Array

(H) Time Periods
- sustained study

(I) Infrastructure
- full water column profiling
- temperature and average velocity
- 10 transceivers (for resolution of 130 km)

(J) Locations
- deep water RCO nodes at RECONN report

(K) Feasibility

(L) Power, Communications, and IT requirements
- ~100 W transmission
- ethernet communications
- accurate timing

(M) Service Requirements
- estimated duration of transceivers 8 – 60 years

(N) Pre-Experiment Requirements

2f. Autonomous Underwater Vehicles (gliders)

(A) Time Periods
- sustained study

(B) Infrastructure
- 2 gliders along Endurance Lines
- 4 additional lines
- sensors: temperature, conductivity, pressure, chlorophyll fluorescence, dissolved organic matter fluorescence, light backscatter, dissolved oxygen, hydrophone

(C) Locations
- east-west and north-south lines
- Endurance Lines at 44.6 and 46.5 °N to at least 130 °W, the edge of the proposed regional cabled observatory on the Juan de Fuca plate
- along Line P to 130 °W
- 41.9 N Canadian hydrographic line
- 41.9 N off Crescent City

(D) Feasibility

- (E) Power, Communications, and IT requirements
  - 3 to 6 months power

(F) Service Requirements

- (G) Pre-Experiment Requirements

---

2g. Coastal HF Radar

(A) Time Periods
  - sustained study

(B) Infrastructure
  - long-range (4-5 MHz) at 100 km separation distance
  - 2 short-range sub-arrays (2 km spacing, 40 km range)

(C) Locations
  - short range: in Heceta Bank area and central Washington Shelf

(D) Feasibility

- (E) Power, Communications, and IT requirements
  - shore power

(F) Service Requirements

- (G) Pre-Experiment Requirements

-
B) Regional Arrays of Borehole Observatories for Sustained Time-series Observations of (a) subseafloor hydrologic processes Becker et al.

The proposal aims to cable the ODP/IODP boreholes in the Pacific NW. The scientific objectives of the holes are of various types. Principally the following:

1) Hydrate Objectives – similar to Hydrate Ridge borehole component but with CORKS), Site mostly on the Cascadia margin off Vancouver. Unsure what the full suite of measurements is no suggestion of major geophone arrays so probably low data rates unless iBorehole seismomenter indicated.

2) Mid plate Hydrology/Tectonics

   A) Seismic monitoring with borehole seismometers. One or more boreholes will have a broadband seismic monitoring station in it (moderate power/data rate).

   B) Plate Scale Hydrology - Pore pressure monitoring for background hydrologic tests. All the boreholes will be equipped with pore pressure sensors (low power/data rate).

   C) Plate scale strain (Poro-elastic effects). This objective primarily concerns the propagation of tectonic strain events across the plate interior. (predominantly utilizing transient pore pressure signals low power/data rate).

   D) Deep biosphere. Principal objective is to look for evidence and the nature of microbial activity in basement rock. Several boreholes will be equipped with pumps and filtering systems to filter out microbes. Possibility will want to add biological incubators and sensors (undefined power/data rate low).

   E) Subsurface temperature measurements at all sites (Thermistor strings, low power/date rate).

   F) Subsurface fluid chemistry/transience- Some chemical sensors to check for changes in chemistry. Need to evaluate stability of their in situ electro-chemical analyzer (how stable is this?) Want to measure, O2, H2O2, HS, S (0), Sx2, S2O3, S4O6, Fe (II), Mn (II), Ley redox- sensitive components. (Power probably relative low, data rate low).

   G) Seabed measurements at regions of surface basement out crop. Where altered fluids are being expelled. Biogeochemistry (sampling and sensors), flow measurements, pore pressure probes, Not yet well define as to the full suite of measurements but can be similar (power/data rate to the surface suite of measurements at Hydrate sites).

2) Tracer testing mentioned with fluorometers (I have issues with this but perhaps they are being dealt with). There is also a plan to do osmotic water sampling (not cable connected experiment).
There are nine sites suggested. The locations are fixed because they relate to borehole locations.

<table>
<thead>
<tr>
<th>Site</th>
<th>IODP number</th>
<th>Lat</th>
<th>Long</th>
<th>Water Depth (m)</th>
<th>Priority Top/middle/bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-1</td>
<td>857</td>
<td>48° 26.52' N</td>
<td>128° 42.65' W</td>
<td>2500</td>
<td>Basement, sediment; Seis, Tsun++</td>
</tr>
<tr>
<td>H-2</td>
<td>1024</td>
<td>47° 54.5' N</td>
<td>128° 45.0' W</td>
<td>2600</td>
<td>Basement, sediment; Seis</td>
</tr>
<tr>
<td>H-3</td>
<td>1025</td>
<td>47° 53.3' N</td>
<td>128° 39.0' W</td>
<td>2600</td>
<td>Basement, sediment; Seis</td>
</tr>
<tr>
<td>H-4</td>
<td>1029</td>
<td>47° 49.9' N</td>
<td>128° 22.6' W</td>
<td>2600</td>
<td>Sediment; Seis</td>
</tr>
<tr>
<td>H-5a</td>
<td>1026</td>
<td>47° 45.76' N</td>
<td>127° 45.55' W</td>
<td>2600</td>
<td>Basement</td>
</tr>
<tr>
<td>H-5b</td>
<td>New approved SR-2</td>
<td>47° 45.66' N</td>
<td>127° 45.67' W</td>
<td>2600</td>
<td>Basement</td>
</tr>
<tr>
<td>H-5c 1</td>
<td>1301A/B (50 m apart)</td>
<td>47° 45.22' N</td>
<td>127° 45.83' W</td>
<td>2600</td>
<td>Basement, sediment; Seis, Geod, Tsun++</td>
</tr>
<tr>
<td>H-5d</td>
<td>1027</td>
<td>47° 45.39' N</td>
<td>127° 43.87' W</td>
<td>2600</td>
<td>Basement, sediment; Seis, Geod, Tsun++</td>
</tr>
<tr>
<td>H-5e</td>
<td>5e Baby Bare Outcrop</td>
<td>47° 42.6' N</td>
<td>127° 45.83' W</td>
<td>2500</td>
<td>Seafloor experiments</td>
</tr>
<tr>
<td>H-6a</td>
<td>Proposed</td>
<td>48° 14.0' N</td>
<td>127° 32.0' W</td>
<td>2600</td>
<td>Sediment; Seis</td>
</tr>
<tr>
<td>H-6b</td>
<td>Zona Bare</td>
<td>48° 11.3' N</td>
<td>127° 33.0' W</td>
<td>2400</td>
<td>Seafloor experiments, Outcrop</td>
</tr>
<tr>
<td>H-7</td>
<td>Proposed</td>
<td>34° 0' N</td>
<td>127° 10.0' W</td>
<td>2600</td>
<td>Sediment; Tsun++</td>
</tr>
<tr>
<td>H-8</td>
<td>889</td>
<td>48° 41.91' N</td>
<td>126° 52.23' W</td>
<td>1400</td>
<td>Sediment; Seis, Hydrates, Tsun++</td>
</tr>
<tr>
<td>H-9</td>
<td>Proposed</td>
<td>46° 40.0' N</td>
<td>126° 43.5' W</td>
<td>1100</td>
<td>Sediment; Tsun++</td>
</tr>
</tbody>
</table>

Power requirements of heated incubators proposed on some CORKS are an unknown (perhaps 1-100w) - depends on insulation
Max power/Data rates of CORKS dictated by seismometers
Seafloor experiments undefined

**Science**
Activity 5 years+

**Orion Cable Infrastructure**
Mostly IODP infrastructure: Not sure ORION pays much for borehole instrumentation Principal Orion Costs: Cable Extension (from Canadian system?).
C) Brown et al NE Pacific Hydrate Observatory (NEPHOS) RFA Summary

(Brown)

(1) Primary scientific objectives: To (a) characterize dynamic processes (geophysical, hydrological, chemical and biological) that control methane transport and hydrate formation, and (b) understand impact of hydrate processes on global carbon cycles.

Strong justification for (a) is spelled out in OOI Science Plan under research theme 3.5, fluid-rock interaction and the subsurface biosphere, especially the “key scientific question” on hydrates on p. 54., and summarize in appendices of the Science User Requirements documents. Good justification for (b) can be derived from OOI research theme 3.1, climate variability, ocean food webs, and biogeochemical cycles, although that section highlights other factors.

(2) Both objectives are to be addressed by intensive time-series observations in the water-column, at the seafloor, and in the subseafloor at a well-characterized focused hydrate deposit, that at South Hydrate Ridge in the Cascadia accretionary complex offshore Oregon.

(A and C) The proposed activity is a spatially-focused, intermediate-term (5-10 year) location for sustained observations to capture a variety of tectonic and oceanographic forcing functions and their effects on the hydrate system. The plan specifies three main nodes within ~1km on Hydrate Ridge, and a secondary node ~1km to the east (see attached figure). The overall location (Hydrate Ridge) cannot be changed owing to the unique nature of the focused hydrate deposit, as well as the investment to date to characterize the setting. Main node positions could probably be adjusted by “a little,” (tens of meters?) as long as they could still serve the tightly constrained instrument locations.

(B) The attached summary figures also clearly specify the proposed arrays of moorings, seafloor instruments, and subseafloor instruments at each of the three proposed main nodes. Primary junction boxes would be required at each of the main nodes, with extensions to secondary junction boxes serving some of the nearby instruments. It is probably an engineering decision whether the proposed three main nodes need to be independent nodes on a larger RCO system or could all be served by extensions to a single node on that RCO. (Given the proposed intermediate term (5-10 years) for the experiment, it might also partly be an engineering decision whether the proposed observatory could be supported by an OOI mooring with local cabling if RCO facilities do not extend to this location.

Aside from the junction boxes, the proposed infrastructure includes two profiling moorings near two of the three main nodes, and subseafloor installations of three types: standard ODP/IODP CORKs, simpler ODP/IODP “SCIMPI” installations, and short probes installed by submersible. One figure shows an AUV, but there is no specification for an AUV docking station; hence the shown AUV is assumed to be an auxiliary experiment from an oceanographic ship.

(D) Much of the proposed work is feasible with current instrumentation or straightforward adaptation/design of existing capabilities (see attached sensor table). Some development is required for the SCIMPI and CORK components, and this would be done in cooperation with IODP and the NSF-ODP program. Prototype SCIMPI development has already been proposed to NSF, but the funding status isn’t specified; once funded, this would probably require ~2 years.
Additional development would be required to add the “SeisCORK” capability to the SCIMPI, and this is to be proposed to NSF soon. Some development is also required for the so-called “mini-CORKs” to be deployed from submersible; that work has also been proposed to NSF.

(E) Cumulative power for all three nodes is stated to be 100W continuous, with intermittent needs up to 200W. Cumulative communication requirement is estimated to be 1.4 GBytes, but this would increase by an order of magnitude if/when the “SeisCORK” capability is added to the SCIMPI design. Data management/dissemination needs are proposed to via a dedicated web site requiring 3 FTE’s (one scientist, one data manager, two half-time students).

(F) Instrument servicing is proposed to be by annual ROV visits, with perhaps two expeditions during the first year when the observatory would be set up after the proposed IODP drilling that includes the proposed CORK and SCIMPI installations. The drilling proposal has been well reviewed in the initial IODP review stages at the level of the Science Steering and Evaluation Panel, but further review stages have yet to be completed (external review, review and ranking by Science Planning Committee, forwarding for potential scheduling) so a decision on scheduling the drilling probably won’t occur for minimum ~2 years.

(G) The location is probably sufficiently well-characterized by previous work, which includes ODP drilling during Leg 204 and associated site surveys. There should be no special EIS requirements.
D) Daly et al., RFA Concept Proposal An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from Basin to Regional Scales (Howe) 

Started 25 January 2006 by Bruce Howe 

(1) Highlight the primary scientific issues/hypotheses/objectives.
This proposal covers a very broad spectrum of water column research in the areas of ocean turbulence and dynamics, the role of the ocean in global climate, and non-equilibrium ecosystem dynamics. The emphasis is on interdisciplinary observations of processes offshore of the continental margin, a region forced by basin-scale atmosphere and ocean phenomena, variations in the North Pacific circulation, air-sea interactions, and shelf-slope interactions with the deep sea. See Appendix for long list of science questions in each of these 3 areas, as well as the “Locations” section below.

(A) Science drivers from the OOI Science Plan
Relevant to several OOI science themes.
3.1. Climate Variability, Ocean Food Webs, and Biogeochemical Cycles - main emphasis of this proposal
3.2. Coastal Ocean Dynamics and Ecosystems – tied with Barth et al.
3.4. Turbulent Mixing and Biophysical Interactions – significant part
3.6. Modeling and Data Assimilation - essential
3.7. Interaction Between Science and Technology in Ocean Observatories – will drive sensor development/robustness

From the NSF Millennium Report (2001): Ocean turbulence and dynamics, the role of the ocean in global climate, and non-equilibrium ecosystem dynamics.

From the RECONN report: Turbulent Mixing and Biophysical Interactions, Ecosystem Dynamics, Ocean, Climate, and Biogeochemical Cycling

(2) For each scientific issue/hypothesis/objective and its experimental plan:
(A) Time Period
Proposal is written for 6 years with installation of equipment the first 5 years and the last year representative of a sustained observation program, with yearly visits for science and maintenance. Many of the objectives require a sustained (30-year infrastructure lifetime) study.

(B) Observatory Infrastructure.
12 fully loaded moorings with associated seafloor extension cables and secondary nodes/junction boxes.

Each mooring has a combination of fixed and mobile instruments. On a particular mooring, fixed instruments reside on or are adjacent to two subsurface floats, one at ~200 m, one at ~600 m, as well as on the bottom. An acoustic tomography transceiver sits just below the lower subsurface float in the sound channel. Profilers with sensors move up and down the both sections of mooring cable; a winched profiler covers the upper ocean to the surface. (It may be best to have
two moorings, one with only fixed instrumentation and one with only a profiler(s).) Secondary
nodes reside on the floats and the bottom for instrumentation called out in this proposal, as well
as for guests. A seafloor cable connects the seafloor secondary node to the (assumed) nearby
RCO primary node.

Many of the fixed instruments are acoustic remote sensing devices probing the adjacent water
column, and in the limit, reaching to the other moorings as well as other hydrophones of
opportunity in the RCO area as well as reaching into the NE Pacific basin.

(C) Locations
Twelve locations are specified. These locations are taken from the RECONN report:
“The proposed sites, recommended by three working groups, are located on all major
bathymetric features (continental shelf, continental slope, bathyal basin, abyssal basin, midocean
ridge, transform fault) and will allow a N/S sub-artic/sub-tropical comparison, the resolution of
N/S fluctuations in the West Wind Drift (WWD) and its bifurcation (Sites 1,11,12, and 9),
studies of offshore-onshore transports (Sites 1-2, 3-4, and 5-7) and shelf-slope interactions (Sites
6-7 and 4-10), studies of tidal flows and topography interactions (Sites 5,8, and 9), and
comparisons of N/S along-shelf flows (Sites 4 and 7). The location of several sites (3, 6, 7,8, 12)
coincide with high-priority sites identified for plate dynamics and fluids studies. Sites are also
located in the proximity of hydrothermal vent communities (3 and 12) and methane hydrate-rich
environments (6). Sites 5-7 take advantage of the long-time-series observations along the
“Newport Line”. … The distribution of high-priority stations spans several gradients in ocean
productivity, ranging from gradients in the intensity of coastal upwelling, north-south gradients
in productivity (related partially to the WWD), and major onshore/offshore gradients in ocean
temperature and upper ocean productivity.”

See Table A in the proposal for more information on sites and rationales, as well as in the main
proposal text.

(i) How firm are these locations?
Locations are flexible, within limits that depend on the various rationales for the general
locations.

(ii) Can the science be achieved if the locations are moved a little?
Yes

(iii) Can the science be achieved if the locations are moved a lot?
Yes, to some degree, TBD

Some sites are tied to specific geographical features, others, such as the northwest set of 4, could
move hundreds of kilometers, as long as the sub-arctic and sub-tropical gyre boundary is
resolved.

(iv) Does the proposed instrumentation require sole use of a node.
No. Other uses are encouraged.
(D) Is the proposed activity feasible and ready to go
Generally yes. The basic infrastructure technology will have been demonstrated in the on-going ALOHA-MARS mooring project (mooring, secondary nodes, profiler, inductive power transfer, etc), and the Barth et al NSF-funded shallow profiler development project (and others). Actual integration of the large number of sensors with the mooring system will be a challenge and will require time for test deployments

Continual development/improvement of biological and chemical sensors and combination of acoustic and optical imaging systems is required.

(E) What is the cumulative (from all instruments) power requirement (continuous and peak demand) at each node? What are the cumulative communications requirements (continuous and peak bandwidth; unusual protocols or command & control requirements)? What are other cyberinfrastructure needs, e.g., data management, processing, web dissemination?

NB. At this time (2006.01.25) the sensor spreadsheet is incomplete. Assumed 1 W average power for those sensors with unknown power requirement. Would expect high frequency acoustics to have modest duty cycles and low average power. However, Caution!

A summary of the average power requirements is given in the table below. The major infrastructure loads for the moorings proposed here 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). To handle peak loads, a combination of adding more copper (easy and inexpensive) to the cables, scheduling major loads to not conflict, and providing energy storage (e.g., rechargeable batteries or ultracapacitors) is suggested. See sensor spreadsheet for details.

<table>
<thead>
<tr>
<th>Watt</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
<td></td>
</tr>
<tr>
<td>0-200</td>
<td>79</td>
</tr>
<tr>
<td>200</td>
<td>24</td>
</tr>
<tr>
<td>200-600</td>
<td>38</td>
</tr>
<tr>
<td>600</td>
<td>15</td>
</tr>
<tr>
<td>600-3000</td>
<td>12</td>
</tr>
<tr>
<td>3000</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>182</td>
</tr>
<tr>
<td>Infrastructure</td>
<td></td>
</tr>
<tr>
<td>Winch</td>
<td>70</td>
</tr>
<tr>
<td>profiler(2)</td>
<td>64</td>
</tr>
<tr>
<td>Hotel</td>
<td>300</td>
</tr>
<tr>
<td>Total</td>
<td>434</td>
</tr>
<tr>
<td>Total</td>
<td>616</td>
</tr>
</tbody>
</table>
At this time (2006.01.25) the sensor spreadsheet is missing most information about data rates. The total of 8 broadband hydrophones produces 5 Mbit/s. The zooplankton imager produces 10 Mbit/s. These are significant; more work needs to be done to more precisely define this requirement.

Timing Accuracy:
~1 ms for general time stamping, mesoscale tomography
~10 microsecond, for reciprocal (velocity) tomography
~1 microsecond, for internal wave tomography, geodesy

CI
This system will generate significant amount of continuous time series data that must archived in the ORION data center. Adaptive sampling will require coordinating power and communications resources.

(F) What are the servicing requirements and life cycle costs for the planned instrumentation
Most of the acoustic instrumentation should have service periods years to a decade (probably based on electronics failures). Other instrumentation will require annual servicing for calibration/biofouling issues.

The basic mooring infrastructure (seafloor cable, seafloor secondary node, mooring cable, subsurface floats, float secondary nodes) probably will need servicing on 3-10 year time frame; the profilers will likely require annual maintenance depending on their technology.

(G) What are the pre-experiment requirements.
Per the experiment plan, moorings need to be deployed in a serial fashion so that lessons can be learned and problems corrected. Present profiler capability needs improvement (see list in proposal). Site surveys in some cases will have to be performed where the physics is tied to local topography; otherwise the expected desk-top study/cable route survey should be adequate.

Development is needed for a broad-purpose acoustic package that would accommodate a wide range of science objectives to decrease the number of deployed sensors.

The US (and Canadian) Navies may raise security concerns

Comments:
The proposed science and moorings are strongly linked with the Barth “coastal” proposal and the Worcester “global”/NE Pac proposals.

Appendix: Specific Science Questions

Ocean Turbulence and Dynamics
ß What is the long-term trend of barotropic and baroclinic variability in relation to atmospheric forcing and bathymetry?
ß How are the properties of tsunamis and infra-gravity waves affected by propagation over areas of rough, shoaling seafloor topography?
ß What factors drive the interannual variability of the location of the West Wind Drift bifurcation and transport volume flux?
ß What factors control the seasonal depth of the surface mixed layer, the entrainment of stratified waters into the mixed layer, and air-sea exchange?
ß Is the structure of Rossby waves altered by bottom topography?
ß Do instabilities from meridionally trending currents provide a potential energy source to the interior ocean in addition to wind forcing?
ß What is the relative importance of tides, internal waves intersecting topography, double diffusion, intrusions, shear, and fronts on diapycnal mixing? How does seafloor roughness influence mixing rates in deep water? For example, does barotropic turbulence driven by mid-ocean ridge topography influence diapycnal mixing and abyssal stratification?
ß Is non-linear interaction among tides and inertial motions in rough topographic regimes important for cascade of tidal and wind energy to higher-frequency motions?
ß What is the role of vertical mixing in the distribution of heat, momentum, and dissolved gas?
ß What is the role of near-surface vertical and horizontal mixing, as it modulates irradiance, nutrients, and biological encounter rates, in determining plankton community structure and function?
ß What is the spatial variation (onshore to deep waters) of turbulence in the photic zone, the nutricline and the benthic boundary layer? How does that variation affect the distribution of plankton and fish as mediated by behavioral responses (e.g., vertical migration)? How does the variation in these processes affect plankton population dynamics through recruitment, mortality, and lateral transport?
ß How do ocean productivity and plankton stocks respond to variations in external forcing? What is the relative importance of high- and low-frequency forcing, such as seasonal, interannual (e.g., ENSO), and interdecadal (e.g., PDO)?

Role of the Ocean in Global Climate
ß Does the oceanic eastern boundary current upwelling system act as a source or sink for atmospheric carbon dioxide and will that role vary in response to additional climate forcing?
ß What are the mean and varying budgets of heat, salt, and biogeochemical variables in a 3-D volume within the study area?
ß How do CO2 profiles vary as a function of sea surface temperature, surface fluxes (boundary transport and breaking waves), biological activity estimated from the effects of net production, and exchange through the base of the mixing layer and horizontal gradient advection?
ß How do climate-driven changes in physical and chemical properties and biological community composition modulate the particulate and dissolved elemental composition and flux near-surface and in the mesopelagic zone?
ß To what extent do fluctuations in food web structure and function control elemental fluxes compared to the fluctuations in abiotic physical/chemical processes?
ß What factors influence variability in the strength and efficiency of the biological pump in different locations over time?
ß What is the ecological response to increasing ocean CO2 concentrations and lower pH in surface waters?

Non-Equilibrium Ecosystem Dynamics
ß What factors govern the spatial variation (N/S, onshore-offshore) and timing of the evolution of phytoplankton blooms?
ß What are the spatial scales of variation (N/S, onshore-offshore) in water mass characteristics, turbulence, and ecosystem response to PDO and ENSO events?
ß What factors control the development and demise of biological thin layers?
ß What role do episodic or extreme events (e.g., storms, ENSO, earthquakes) play in restructuring marine ecosystems?
ß What is the long-term variability in near-bottom flow and turbulence, which affect the physical dispersion, lateral transport and subsequent settlement of benthic organisms that inhabit the central plate and Juan de Fuca Ridge?
ß How do episodic megaplume eruptions from vents influence the chemistry and biology of the overlying and downstream water column?
ß What are the causal mechanisms of regime shifts in marine communities and what controls the synchrony or lack of synchrony among different organisms and between different regions?
ß Do food webs respond to the mean state of forcing mechanisms/events, or to the frequency and magnitude of events?
ß Are regular migration patterns and fluxes of nektonic species (i.e., fish and invertebrates) disrupted during episodic, physical events?

(1) Highlights of the primary scientific issues/hypotheses/objectives of this proposal. This proposal is to use the Orion observatory infrastructure to evaluate and track the impact of the anticipated ~0.3 pH increase in ocean pH that is an inevitable consequence of increase in atmospheric CO$_2$. While this change may have a profound effect on the chemistry and biology of the ocean, little data or understanding of this process exist. Thus, this is the least understood, but potentially most critical aspects of the on-going global changes associated with anthropogenic CO$_2$ additions.

The proposal indicates a four component approach to the problem: (1) Laboratory experiments “to identify the key biological /biophysical variables that will be affected by pH”. (2) Shore based assessments of the affects of these on the oceans energy and carbon cycle. (3) Development of sensors that measure ocean pH and pH sensitive parameters in situ. & (4) Deploying sensors to make in situ measurements on both fixed and mobile Orion assets. The last two components are the most central for the planning efforts and implementation potential associated with Orion.

Instrument/Sensor Development
A new sensor array (Networked Oceanographic Sensor Arrays, NOSA), which are being developed which carry sensors to measure O$_2$, pH, pCO$_2$, Light Induced Fluourensence Transient flurometers, and bacteriochlororoppyll on the same physical frame. Several of the sensors are making the measurements in new and potentially superior ways to the older methods. The NOSA are housed in 64 mm OD and 400 mm long titanium sphere that can go to 4000 m, thus, these can be used on most of the Orion assets. The initial versions are battery powered and have internal data storage. However, the NOSA are capable of running on 12 or 48 v, and will have four serial ports that will allow them to communicate with most mooring controllers.

The Science Drivers, as defined in the OOI Science Plan Summary, are listed in the table below.

<table>
<thead>
<tr>
<th>Climate variability, Ocean food webs, and Biogeochemical cycles</th>
<th>Coastal ocean dynamics and ecosystems</th>
<th>Global and plate-scale geodynamics</th>
<th>Turbulent mixing and biophysical interactions</th>
<th>Fluid-rock interactions and the sub-seafloor biosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

(2A) Is this proposed observatory best utilized for (1) a fixed time period (5 years; pioneer array) or for (2) long-term, sustained (25-year lifetime) studies (endurance array)? The proposal contains both endurance and pioneer elements.

(2B) Observatory configuration:
This proposal is primarily an effort to develop and understand new sensors to make the needed measurements. Deployments are primarily to be done as piggybacks on other moorings. Thus, the infrastructure at each site is not specified in any detail.

(2C) Geographical regions:
The objective is to place the sensors on a subset of all Orion sites as the opportunities arise rather than at specific pre-determined sites. A global distributed array of such sensor package is desirable to assess the range of processes that are happening. However, as the North Atlantic is arguably absorbing a disproportionate amount of CO₂, it is of particular importance. The intent is to gather long time series data at the fixed monitoring points on coastal, regional and global sites. Movable platforms (AUV and ROV) may also be useful for understanding local variations and manipulative experiments. Many of the objectives could be accomplished with deployments anywhere. This effort can be coordinated with almost all Orion observatories.

(2D) Feasibility and readiness:
Many of the sensors are yet to be developed. A detailed deployment plan was not given for either the fixed or mobile NOSA. It is unclear as to how many NOSA sensors to would be deployed at each site, the water depths and deployment configuration, and the sampling rates. Realistically this effort will probably involve a progressive deployment of sensors as they become available on a piggy-back basis with other projects.

(2E) Unusual infrastructure needs:
The power and data needs are not specified and as most of the proposed sensors do not exist yet. However, the systems probably will not place a significant demand on either power or data on a multi-use Orion mooring.
Some of the data will be appropriate for community-wide accessibility, but some will probably need quality control and calibrations that would make it less suitable for immediate public release.

(2F) Servicing:
The servicing and life cycle is unknown at this time.

(2G) Pre-experiment requirements:
No significant pre-experiment survey requirements are anticipated.

Modeling needs?
The proposal contains a recognition of the need to establish the bio-chem-phys effects of pH, which might benefit from some modeling efforts.
F) McGuire et al. An Earthquake, Physics, and Fault Mechanics Observatory on the Blanco transform Fault

(1) Highlight the primary scientific issues/hypotheses/objectives.

Scientific Issues. Understanding the basic physics of earthquake rupture and taking advantage of 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. Developing improved rheological models of oceanic transforms and assessing the implications for the geomorphology of transform fault zones and their environs and for global models linking mantle convection to plate tectonics. Characterizing the interactions between fluid flow, chemical and biological processes in the shallow lithosphere, and the thermal and geological structure of the fault zone.

Scientific Objectives.

Recording of 2 (or more) magnitude ~6.5 earthquakes on the Blanco Ridge fault segment with a strong motion network that can evaluate the consistency of the distribution of fracture energy. Assessing the impact of large earthquakes on hydrothermal fluid discharge. Relating the spatial distribution of coseismic and aseismic slip to geological/compositional layering within the lithosphere. Relating earthquake energetics to conductive and advective heat flow. Construction of an earthquake catalog complete down to magnitude 1 to document earthquake scaling laws and understand the origin of foreshock sequences. Development of refined rheological models for oceanic transform faults.

(A) Science drivers from the OOI Science Plan

Relevant to two science themes.

3.3 Global and Plate Scale Geodynamics – (p. 39-40) Directly addresses the following question from the science plan - “What is the physics of earthquake nucleation and rupture propagation for different types of plate boundaries?”

3.5 Fluid-Rock Interactions and the Sub-Seafloor Biosphere – transform faults represent an important class of plate boundary for the investigation of linkages between hydrological and geological processes owing to the substantial amounts of serpentinization within these zones and the relatively unexplored active vent sites within the Blanco fracture zone.

See text above for the science drivers for the water column mooring.

(2) For each scientific issue/hypothesis/objective and its experimental plan:

(A) Time Period

Sustained (25-year lifetime) study. Recording multiple M>6 earthquakes on the Blanco Ridge segment is expected to take 10-20 years.

(B) Primary Observatory Infrastructure.

An RCO primary node to support experiments centered at
(1) 43.7°N, 128.0°W
(2) 145 km of ordinary ship laid cable  $17k/km*145=$2.5M
(3) An additional 12 km of double armored cable to cross the Blanco Ridge.  $30k/km*12km= $360k
(4) 12 “Benthic Nodes”.  $175k*12 = $2.1M

(C) Locations

The 12 BNs will be located at approximately:
43.65 -128.30
43.66 -128.13
43.56 -128.08
43.53 -127.90
43.47 -127.76
43.44 -127.59
43.58 -128.45
43.54 -128.34
43.48 -128.18
43.42 -128.02
43.40 -127.85
43.35 -127.68

Secondary Infrastructure
One of the water column moorings (as deployed at many of the nodes) will be attached to this node.

Instruments
There will be one or two combined broadband/strong-motion OBSs deployed at each BN. There will also be acoustic ranging geodetic instrumentation installed to monitor shallow fault creep. Many of the geodetic instruments may be battery operated “slaves” interrogated by a “master” transponder that will be connected to one of the BNs. If sites of active venting or diffuse low temperature flow are found during the site survey work, then fluid temperature sensors will be installed at those sites. The RFA proposal does not specify sites but evidence of hydrothermal circulation has been found in the Cascadia Depression.

(i) How firm are these locations?
The location and extent of the sensor network is determined by the location of specific, overlapping, M6.5 earthquakes in the past. These cannot be changed without compromising the science. The location of specific OBS’s sites is flexible although the extent and spatial distribution of the OBS needs to be preserved. Changes to the OBS network design should be made in consultation with the PI. The precise location of extensometer sites is also flexible.
provided that they span the fault, have a line of site and the required spacing (~ 3 km). Changes to the extensometer network design should be made in consultation with the PI

(ii) Can the science be achieved if the locations are moved a little?
See above

(iii) Can the science be achieved if the locations are moved a lot?
No

(iv) Does the proposed instrumentation require sole use of a node.
No. The power requirements of the OBS network are relatively modest, there will be sufficient capability to connect both a water column mooring and possibly a hydroacoustic mooring to the primary node. The PIs envision other hydrothermal sensors will be added to their experiment. Care should be taken to avoid generating acoustic noise near OBSs (e.g., winches)

(D) Is the proposed activity feasible and ready to go
The OBS are ready to go with ten already being constructed. The RFA proposal requested a docked AUV capability for rapid response following large earthquakes. This is a common need of several proposals. Much of the earthquake science can be achieved without the AUV but requires early instillation of the OBSs to catch the next mainshock.

(E) What is the cumulative (from all instruments) power requirement (continuous and peak demand) at each node? What are the cumulative communications requirements (continuous and peak bandwidth; unusual protocols or command & control requirements)? What are other cyberinfrastructure needs, e.g., data management, processing, web dissemination?

Average Power: 18 OBS @ 2 W; 10 extensometers @ 6W = 96 W Peak Power: Extensometers require 120 W for 5% of time but peak OBS/extensometer power could be minimized by operating no more than two extensometers at one time. Additional unspecified power will be required for the AUV dock and hydrothermal sites.

Average data rates: Dominated by 18 OBS @ 44 Mbytes/day = ~1 Gbytes/day

Peak data rates: The OBSs will have local backup rechargeable battery-packs and data storage storage to accommodate network outages. Data rates of at least ~10 Gbytes/day will be required to recover this data efficiently. The AUV and hydrothermal peak data rates should also be considered.

Timing Accuracy: The seismic data is sensitive to timing errors of ~1 ms so the timing needs to be accurate to ~0.1 ms.

CI The seismic data can be stored in the IRIS data center but requires 1 FTE to monitor data quality and ensure the appropriate metadata is added. Extensor and hydrothermal data will also require QC before submission to an ORION data center.
(F) *What are the servicing requirements and life cycle costs for the planned instrumentation?*  
The seismometers will be designed for a 10+ year lifetime. A average servicing interval of ~ 5 years is reasonable (0.5 days of ROV per site). The extensometers will require servicing on average every 5 years (0.5 days of ROV per site).

(G) *What are the pre-experiment requirements.*  
Development of a “Benthic Node” system that can be laid as part of the cable from a surface ship. This is a common need to several nodes.

The RFA proposal envisions an ship-based EM300 survey of the experimental sites, an AUV-based SM2000 bathymetric survey of the fault trace and extensometer sites, an AUV based search for hydrothermal vent sites, and heat flow studies. This is a geologically active and topographically challenging area and so consideration should be given to additional high-resolution surveys along cable routes.

Viii “Core Instrumentation”

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Data Rate/Data Storage</th>
<th>Communications</th>
<th>Timing/Power</th>
<th>Comments</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-20 WHOI Combined Broadband/Strong Motion OBS with Paroscientific pressure sensor</td>
<td>Rechargeable battery pack, onboard data storage capability (hard disk or Flashcard) 100 sps</td>
<td>Internet Protocol</td>
<td>0.2 msec timing accuracy 2.5 W &amp; power to write data to the onboard storage</td>
<td>10 of these instruments already being built and will be plugged into the BNs immediately on installation</td>
<td>~$80k/ea</td>
</tr>
<tr>
<td>Temperature Sensor</td>
<td>1 sps</td>
<td>Internet Protocol</td>
<td>250 mW</td>
<td>Low-T sensors anticipated for diffuse flow regions along the fault.</td>
<td>$2k/ea</td>
</tr>
<tr>
<td>~10 Acoustic Ranging Geodetic Stations</td>
<td></td>
<td>Internet Protocol</td>
<td>See above</td>
<td>Exact system TBD. Maybe primarily battery powered with just one or two cabled sites</td>
<td>~$40k/ea</td>
</tr>
<tr>
<td>Water Column Mooring</td>
<td>See Description for Prior Nodes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
G) Vent Integrated Acoustics (VIA) at the Main Endeavour Field, Juan de Fuca Ridge Co-PIs Peter Rona and Daniela Di Iorio (Kelley)

(1) **Highlight the primary scientific issues/hypotheses/objectives.**
The goals of this project are to use integrated acoustic measurements (acoustic imaging and acoustic scintillation) at the massive sulfide edifice called Hulk in the Main Endeavor Hydrothermal Field (MEF) and acoustic tomography within the MEF to monitor plume properties (volume and heat fluxes, bending, entrainment, particle distribution and turbulence) and partitioning between plume and diffuse flow. Examination of plume and diffuse flow on time scales ranging from hours to years is important in understanding linkages of hydrothermal flow to tides, earthquakes, and changes in biological communities.

Examples of Key Hypotheses include:
- That the behavior of individual plumes and plume clusters is a sensitive indicator of external oceanographic and geological forcing fields.
- Hydrothermal volume flux varies on time scales from tidal (hourly) to geological (months to years) and may be used to discriminate between oceanographic and geologic events.
- The correlation distance between variations of hydrothermal flow and geologic events is plate-wide.

(A) **Identify appropriate science drivers from the OOI Science Plan**
Relevant Science Theme; 3.5 Fluid-Rock Interactions and the Sub-Seaﬂoor Biosphere.

Addresses an important component of the following question from the science plan “How do submarine hydrothermal systems and their associated biological communities vary over time?” in terms of volume, heat flux, and dispersion of dissolved and particulate matter.

This experiment will be integrated with other co-registered measurements that will allow coupling of flux changes to biological blooms and dispersion of organisms through time. Volume flux measurements can also be tied to real-time volatile-chemical concentration data to calculate nutrient fluxes for organisms and expulsion of magmatic gases such as CO₂.

(2) **For each scientific issue/hypothesis/objective and its experimental plan:**
(A) **Time Period**
Acoustic imaging will be sustained for at least 5 years, scintillation can be maintained for 15 years

(B) **Observatory Infrastructure**
Depends on other instrument location but this experiment includes
- 1 200 kHz multi-beam sonar for buoyant plume imaging mounted on a tripod = one junction box
- 1 200 kHz multi-beam sonar for diffuse flow imaging mounted on a mooring = one junction box
- 1 mooring with a transmitter (307 kHz) for acoustic scintillation and one mooring with a receiver. Could be connected to the above junction boxes
- 10 fixed autonomous units for 10 cabled units for tomography: spaced a ways apart so likely need 5 minimum junction boxes.
Seven junction boxes –note will modify when entire MEF array is put together

(i) Moorings
Non profiling moorings
(payload capacity (size, weight)
where in depth?
Moorings for Acoustic Imaging:
1) One mooring for one 200 kHz multi-beam sonar for hydrothermal plume imaging: (estimated sonar head dimensions 32cm x 22cm; weight air/water 15kg/7kg) mounted 3m to 5m above the seafloor (depth 2200m) on a rigid tripod (estimated weight of tripod air/water 100kg/80kg) at a range up to several tens of meters from the vents targeted on the Hulk edifice. The sonar uses digital beam-forming to scan in azimuth and a mechanical rotator to scan in altitude (estimated weight air/water of rotator 50kg/40kg).

2) One mooring for 200 kHz multi-beam imaging sonar for diffuse flow imaging (estimated sonar head dimensions 32cm x 22cm; weight air/water 15kg/7kg) mounted 10 m above the seafloor next to the plume imaging sonar at a water depth of 2200m on a relatively stable 3-point mooring (estimated weight of the mooring air/water 50kg/40kg) to image diffuse flow in an area roughly the size of a football field surrounding the vents. Estimated weight air/water of the two sonars, one rotator, and their moorings is 250kg/174kg together at a water depth of 2200 m.

Moorings for Acoustic Scintillation:
For the acoustic scintillation system we want the acoustic propagation path length separating the transmitter and receiver to be approximately 100 m and this path should be approximately 20 m above the vent orifice of Hulk. The moorings could potentially be up to 40 m in height (depending on the height of the chimney) from a seafloor depth of approximately 2200 m. Each mooring weight would be up to a maximum of 40 kg in water and these would include a bottom anchor, acoustic release (if needed), instrument package, and syntactic foam float.

(C) Locations
(i) How firm are these locations? Locations of the acoustic imaging and scintillation sonars are firm (within 1 m). The sonars must be in specific alignment to the plume and to each other.

(ii) Can the science be achieved if the locations are moved a little? 
    If so, how far? See answer to (i)

(iii) Can the science be achieved if the locations are moved a lot? 
    If so, to where? See answer to (i)

Acoustic Imaging: We plan to use two 200 kHz multi-beam acoustic imaging sonars at the Hulk site. As described under “Moorings”, one of the two sonars will be used for imaging the main plume and the other sonar will be used to image diffuse flow. The two acoustic imaging sonars must be positioned within 20 m of the Hulk edifice and exactly (to within 1 m accuracy) relative to the acoustic scintillation sonars at that site (D. Di Iorio), so that sound paths of the acoustic
imaging sonars cross the Hulk buoyant plume, and that their sound paths intersect the scintillation path (see Acoustic Scintillation below).

The two acoustic imaging sonars should be positioned so that (1) the region ensonified intersects the path between the receiver and transmitter of the scintillation system; (2) the imaging sonars are looking roughly perpendicular to the ridge axis (this is fairly flexible); and (3) the imaging sonars are approximately 10-20 m from the main plume of Hulk (and looking at the plume). One imaging sonar will look down at the diffuse flow around the base of the Hulk edifice (this is the one on the mooring at ~20 m above the seafloor); the other imaging sonar will be looking up at the plume from a tripod (c.10 m tall) and possibly have a mechanical rotation device to cover a 3D volume (we are currently working with engineers at APL to determine whether the use of multiple sonars or a mechanical rotation device is more cost effective and logistically feasible to scan the plume in elevation to obtain 3D coverage). The location relative to the scintillation sonars depends on whether the scintillation travel paths are one-way or reciprocal: If the scintillation path is perpendicular to the ridge axis (one-way scintillation), the imaging sonars should be placed more or less along the scintillation path at ~20 m from the main Hulk plume looking towards Hulk. If the scintillation path is parallel to the ridge axis (two-way scintillation, the imaging sonars should be about 20m from the path near its center and looking perpendicular to it.

**Acoustic Scintillation:**
It is very important that the hydrothermal vent plume of Hulk is between the transmitter and receiver mooring with each mooring approximately 50 m away from the vent. For one-way acoustic scintillation propagation studies, moorings are placed perpendicular to the axial valley at locations approximately: transmitter (TX) 47.9498°N, 129.0987°W; receiver (RX) 47.9496°N, 129.0975°W. The scintillation drift determines the tidally forced axial valley flow component. For two-way reciprocal acoustic scintillation transmission studies, moorings are placed parallel to the ridge axis at locations approximately: transmitter (TX) 47.9493°N, 129.0984°W; receiver (RX) 47.95°N, 129.0976°W. Differences in travel times determine the tidally forced axial valley flow component.

**Tomography**
Please refer to map in Figure 1 of our ORION RFA proposal dated 3 June 2005 showing the preliminary proposed layout for the acoustic imaging, scintillation, and tomography experiments in the Main Endeavour Field for the approximate positions of the 6 sonars in the tomography experiment.

**(i) How firm are these locations?**
These are firm locations, they must be in specific alignment to the plumes and to each other.

**(iv) Does the proposed instrumentation require sole use of a node?**
No

**(D) Is the proposed activity feasible and ready to go?**
Acoustic imaging and acoustic scintillation are essentially ready to go. The acoustic imaging instrumentation is presently suited for mounting on an ROV. Engineering is required to convert
the acoustic imaging instrumentation from ROV to cabled mode of operation, to build the moorings, and to construct the interface for data acquisition and transmission. Year one test of deployment, year 2-5 (or longer) continuous deployment contingent on performance.

For the acoustic scintillation work there are two methods by which we can monitor the vertical buoyant flow, the horizontal tidal flow and the turbulent properties: the reciprocal transmission method gives direct measurement of the temperature and flow fluctuations (assuming mooring motion can be removed), and the one way propagation gives indirect estimates of the temperature fluctuations and mean flow speeds but cannot separate out turbulent velocity effects (mooring motion is not an issue). Depending on resources available we would pursue ONE of the methods but we present the requirements for each for completeness.

Reciprocal acoustic scintillation must be developed and tested within the first year of the project. Dr. Di Iorio and ASL Environmental Sciences have the experience and expertise in developing a reciprocal scintillation system. Funding for the development of such a system would be approximately $175K.

The one way acoustic scintillation method requires software and hardware modifications to existing instrumentation so that it can be plugged into the cabled network. At present both are battery operated and the receiver is internally logging. The transmitter is controlled only by the available power to it and we would like funds to modify it so that we can program the transmission scheme and shut down when necessary. The total cost would be approximately $100K for both transmitter and receiver upgrades.

Year one test of deployment, year 2-5 (or longer) continuous deployment contingent on performance.

Do the instruments exist for tomography? 

Refer to Chris Jones, APL-UW

(E) What is the cumulative (from all instruments) power requirement (continuous and peak demand) at each node? What are the cumulative communications requirements (continuous and peak bandwidth; unusual protocols or command & control requirements)? What are other cyberinfrastructure needs, e.g., data management, processing, web dissemination?

**Acoustic multi-beam imaging sonars (2)**

Power 200W, 10% duty cycle for the two sonars, one sonar for imaging plumes and the other sonar for imaging diffuse flow
Communications: Continuous Ethernet
Data rates/sampling; Variable 10 Mb/s
Bandwidth: based on recording of 1 GB data/day’ 8 hours of transmission/ day; rate 300 kilobits/sec

**Acoustic scintillation sonars** (Di Iorio)

**One-way system**

One receiver and one transmitter
Data acquisition rate ~5 Mb/hr for each tranceiver
Power need 100 ma @ 12 volts each unit
Data rate 115 kbaud for receiver
Acoustic frequency 307 kHz. Transmission 10-20 pings/s, 0.1 ms duration, 10-20 ms separation between transmitters
Max repetition rate 10-20 Hz

The PI generated the following summary of the experiment needs

**Vent Integrated Acoustics (VIA) at the Main Endeavour Field, Juan de Fuca Ridge**

The proposal integrates two complementary acoustic methods comprising acoustic imaging (scalar and vector properties of buoyant plumes and scalar properties of diffuse flow; Rona et al.) and acoustic scintillation (vertical buoyant flow velocity of plume, horizontal advective flow of ocean current, and temperature fluctuations in plume; Di Iorio). A third method, acoustic tomography, is planned for a future phase on the project (estimated 5 years) and will measure water temperature and flow rates on a field-wide scale (C. Jones et al.). 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.

1) Map: We refer to a node(s) at a position (to be determined) in the Main Endeavour Field, and present maps to show the proposed positions of our instruments in possible different configurations plotted on the 2005 high-resolution ABE bathymetric map (Figures 1-4).

2) Node within Main Endeavour Field (MEF):
   i) Node(s) within MEF: location not constrained by this experiment alone, although it will affect the costs below in terms of cable lengths to connect our sonar instruments to the node(s). Note that latitude/longitude and Universal Transverse Mercator (UTM) positions need to be reconciled and standardized for the MEF area.

Variables to be measured: Time series of plume and diffuse flow from Hulk or equivalent vent including diffuse flow in immediate surrounding area

a) Acoustic imaging (requires two sonars on two co-located moorings):
   • Imaging sonar 1 (200 kHz multi-beam sonar): 3D imaging and flow rates of (Hulk) buoyant hydrothermal plume. This sonar will be mounted 3m to 5m above the seafloor (depth 2200m) on a rigid tripod (estimated weight of tripod air/water 100kg/80kg) at a range up to several tens of meters from the vents targeted on the Hulk edifice. The sonar uses digital beam-forming to scan in azimuth and a mechanical rotator to scan in altitude (estimated weight air/water of rotator 50kg/40kg).
• Imaging sonar 2 (200 kHz multi-beam sonar): 2D mapping (Hulk region) of diffuse flow. This sonar (weight air/water 15 kg/7 kg) will be mounted 10 m above the seafloor next to the plume imaging sonar at a water depth of 2200m on a relatively stable 3-point mooring (estimated weight of the mooring air/water 50kg/40kg) to image diffuse flow in an area roughly the size of a football field surrounding the vents. Estimated weight air/water of the two sonars, one rotator, and their moorings is 250kg/174kg together at a water depth of 2200 m.

b) Acoustic scintillation (requires 2 moorings):
• Acoustic scintillation can be used in either one-way propagation (present set-up) or two-way reciprocal propagation (planned set-up) mode. The shape (~30 m tall) and weight (air/water 74/40 kg) of each mooring will be the same.
• One-way scintillation propagation: System is moored perpendicular to the axial valley (Figures 1 and 2) requires new transmitter sonar (TX) and modifications to existing receiver (RX). Scintillation mooring will be 50 m to the southeast of Hulk. Scintillation TX mooring will be 50 m to the northwest of Hulk. With this setup mean horizontal flow velocity of ocean currents along the axial valley, mean vertical flow velocity of the buoyant plume, and temperature fluctuations in the buoyant plume are measured.
• Two-way reciprocal scintillation propagation: System is moored along the axial valley (Figure 3). Measurements from this setup include mean and turbulent horizontal flow velocity of ocean currents along-the valley axis, mean buoyant vertical flow velocity in the plume, and mean and turbulent temperature fluctuations in the plume. Instrumentation does not exist and would require development. Requires two scintillation transmit/receive (TXRX) moorings. Scintillation TXRX1 will be 50 m to the southwest of Hulk. Scintillation TXRX2 will be 50 m to the northeast of Hulk.

c) Acoustic tomography (future phase of project excluded from current cost estimation):
• Vent field scale measurements of temperature and flow velocity field using acoustic tomography for future development.

iii) Primary infrastructure requirements for this node/mooring (two acoustic imaging sonars and two acoustic scintillation sonars):
• Junction box near Hulk
• 3 or 4 extension cables with ROV mateable connections to sonar moorings
• 2 of these cables to scintillation transmitter TX/receiver RX moorings (each of two alternative scintillation configurations use 2 cables)
• imaging sonar moorings need one of the following:
  a) Either 1 extension cable, a secondary junction box at the moorings and 2 very short cables to the moorings
  b) Or 2 cables, one to plume imaging sonar and one to diffuse flow imaging sonar.

iv) Additional infrastructure:
• ROVs for installation and servicing of all 4 sonar moorings (2 acoustic imaging moorings; 2 acoustic scintillation moorings)
• Adaptation of both the imaging and scintillation sonars to connect with the MEF node(s) and the development of two-way scintillation (and vent field-scale tomography) remain to be funded.

v) **Required instruments:**

• This RFA requires modification and deployment of at least 4 sonar systems (2 sonars for acoustic imaging and 2 sonars for acoustic scintillation).

• This RFA does not specify any general purpose sensors, but does assume that other PIs will be installing and monitoring in-situ instruments at Hulk for measurements of vent temperature, chemistry, and possibly flow velocity.

vi) **Primary infrastructure costs:**

• Modify acoustic imaging and scintillation sonars and obtain junction boxes and cables to mate with MEF node(s) in a manner for mechanical coupling and data transmission: Proposal in preparation for submission to NSF (8/15/06) for the engineering plan, salary, hardware costs (sonars, cables, junction boxes, connectors), and cyber-infrastructure considerations to accomplish this work. The cost of the node(s) is outside the scope of this project. At this time we can only quote the hardware costs for the sonars (below).

• **3D imaging sonar:** purchase SM2000 or equivalent sonar: ~$100k

• **2D imaging/mapping sonar:** purchase SM2000 or equivalent sonar: ~ $100k

• **Modify sonar to mate with cable network.**

• Scintillation system has 2 alternative configurations:

  1) One-way scintillation system requires new transmitter and modified receiver: $100k

  2) Two-way reciprocal scintillation system requires 2 new transmit/receive units: $175k total.

• Annual Operation & Maintenance (O&M) requires ship and ROV use for 8 days once a year (4 days for scintillation, 2 days for 3D imaging, 2 days for 2D mapping).

• Estimated costs for connection to planned Canadian MEF node independent of hardware are at least $50k for imaging and $50k for scintillation instrumentation (R, Thomson, personal communication).

vii. **Acoustic Imaging and Acoustic Scintillation Integrated Configuration Options:**

• **Option 1:** Acoustic imaging of plume + mapping of diffuse flow + one-way scintillation with one junction box (Figure 1).

• **Option 2:** Acoustic imaging of plume + mapping of diffuse flow + one-way reciprocal scintillation with two junction boxes (Figure 2).

• **Option 3:** Acoustic imaging of plume + mapping of diffuse flow + two-way reciprocal scintillation with one junction box (Figure 3).

• **Option 4:** Acoustic imaging of plume + mapping of diffuse flow + one- or two-way scintillation + acoustic tomography (Figure 4)
H) Smith et al., 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 Smith et al., (Paull)

(1) Highlights of the primary scientific issues/hypotheses/objectives of this proposal.

An observatory system that is connected to a regional cable on the Juan de Fuca Plate to make detailed, coupled time-series measurement of both pelagic and benthic processes is proposed. The objective is to use the new observatory capabilities to refine our understanding of the biological pump particularly within the benthic boundary layer.

The biological pump involves the passage of organic matter particles associated with the organisms that live and die in the surface of the ocean and settle to the ocean floor. It is one of the driving forces of deep-sea biology. However, progress in understanding of how the biological pump operates has been frustrated by the low resolution of the measurements we have been capable of making, the temporal and special location, and the inherent natural variability in these processes. The ability to make sustained measurement on this process, afforded by the Orion infrastructure promises to remove many of the historic impediments in studying the biological pump.

The sustained presence and higher sampling rates provided by the observatory will enable data to be collected that will: define the temporal and spatial changes in the quantity and quality of particulate matter; track the changes in sediment community activity, burrowing, megafauna species composition, abundance and characteristics; enable relationships between epibenthos and particulate supply to be assessed; and determine whether relationships are driven by climate and other large scale environmental perturbations.

The Science Drivers, as defined in the OOI Science Plan Summary, are listed in the table below.

<table>
<thead>
<tr>
<th>Climate variability, Ocean food webs, and Biogeochemical cycles</th>
<th>Coastal ocean dynamics and ecosystems</th>
<th>Global and plate-scale geodynamics</th>
<th>Turbulent mixing and biophysical interactions</th>
<th>Fluid-rock interactions and the sub-seafloor biosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
<td>yes</td>
<td></td>
<td>yes</td>
<td></td>
</tr>
</tbody>
</table>

(2A) Is this proposed observatory best utilized for (1) a fixed time period (5 years; pioneer array) or for (2) long-term, sustained (25-year lifetime) studies (endurance array)?

The initial plan outlined in this proposal is for a 5-year experiment, however there is a clear intention to maintain the array after this time period, making this into an endurance array.

(2B) Observatory configuration:

The proponents request that this array be designed to be deployable for 5 year periods in up to 6000 m of water (although water depths in this region are considerably less, >4 km). These observatories will have three major components, all connected to the regional cable:
a). Two moored sedimentation sensors to monitor flux. One at 600 mab and the other near the seafloor (e.g., 2 mab). These will have sediment traps and sensors to collect current and fluorescent measurements.

b). Two stationary benthic observing platforms equipped with bottom observing digital time-lapse cameras each covering 20 m$^3$ of the seafloor and current meters. This may require short extension cables.

c). A mobile benthic Rover to monitor benthic communities, biochemical activity and sediment structures. The self-propelled Rover will carry benthic chambers measuring in situ oxygen consumption, video cameras, acoustic images of the near seafloor sediment, optical imaging of water column POM and currents to measure conditions on fresh undisturbed seafloor. The Rover will communicate with the main array via an acoustic modem.

Data will be transmitted back to shore in real (or near real) time. Sampling frequencies are adjustable from shore. Capacity to add other sensors is important.

(2C) Locations:
Deployments at three sites in the NE Pacific are proposed. These will start with one on the slope off Oregon and extend out to the west of the ridge crest. Locations are not firm and can easily be adjusted as long as the three sites are more or less along an E-W transect and the sites are located over accumulating sediments. The experiment probably could be done in other regions, but is sited here because of the likelihood that this area will be the most likely site for a RCO. These nodes do not have to be for sole usage.

(2D) Feasibility and readiness:
Many of the components are COTS, thus, they are nearly ready to be assembled. Some modest engineering is needed for the mooring design. Some development is needed associated with the Rovers (but is already underway with existing funding). Thus, this is a doable project for the first phase of the RCO effort.

(2E) Unusual infrastructure needs:
The power and data needs are not specified. However, the video imaging is likely to be the most demanding on data streaming and data storage.

(2F) Servicing:
The installation will require ROV support. In principle servicing can be done with an annual visit with a surface vessel.

(2G) The pre-experiment survey needs:
It is unlikely that they proposed deployments would increase the EIS needs beyond those involved with the basic RCO infrastructure. While not specified in the proposal, some data is needed to assure that the specific site is appropriately flat and on accumulating sediments.

Modeling needs?
While modeling may enhance our understanding of any process, it is not clear that it would play a critical role in refining the design or pre-implementation plan associated with this experiment.
I) Stephen: Regional Ocean Hydrophone Array Observatory (ROHAO)

Prepared by Wilcock 1/5/06
Revised by Wilcock with input from Stephen, Worcester 1/26/06

(1) Highlight the primary scientific issues/hypotheses/objectives.


Scientific Objectives. Collect and analyzing continuous acoustic data from horizontal and vertical hydrophone arrays deployed at 4 RCO nodes to address the scientific issues listed above.

(A) Science drivers from the OOI Science Plan

Relevant to several science themes.

3.1 Climate Variability, Ocean Food Webs, and Biogeochemical Cycles – marine mammal monitoring.
3.2. Coastal Ocean Dynamics and Ecosystems – slope stability and failure.
3.3. Global and Plate-Scale Geodynamics – plate scale seismicity.
3.5. Fluid-Rock Interactions and the Sub-Seaﬂoor Biosphere – monitoring regions of magmatic, tectonic and hydrothermal activity.

(2) For each scientific issue/hypothesis/objective and its experimental plan:

(A) Time Period

Proposal is for 8 years with the full experiment operating for the last 4 years. Many of the objectives (earthquake and slope monitoring) require a sustained (25-year lifetime) study

(B) Observatory Infrastructure.

To monitor hydroacoustic activity within the array requires at least four stations, two of which are horizontal arrays (triads), or at least six single hydrophones. The redundancy is necessary because a given station could be down for engineering reasons, could be ineffective because of intermittent high amplitude noise, or could be blocked from an event by topography. The proposal called for four RCO junction boxes for the US component of NEPTUNE; two with vertical and two with horizontal moored hydrophone arrays.

The horizontal hydrophone arrays will each comprise 3 hydrophones moored about 500 m below the sea-surface and 500 m apart to form an equilateral triangle. The vertical mooring will each include 10 hydrophones at depths from ~400-600 m below the sea surface (Figure 8).

Peter Worcester writes

“Horizontal hydrophone arrays: Three hydrophones moored about 500 m below the sea surface and 500 m apart to form an equilateral triangle. As I suspect you are aware, this is actually a fairly difficult geometry, at least if the moorings are in deep water. Three closely spaced moorings will be required. The issues will be the deployment scenario, rather than the mooring payload. The actual payload required for a single hydrophone is minimal. I know that Maripro has achieved geometries something like this for the CTBT monitoring stations. One possible approach
is to package the moorings for deployment at the same time as the cable. The flotation in the packages would be commanded to release after deployment, and the moorings would deploy themselves from the bottom up. I know that Maripro has actually done this sort of thing in the Santa Barbara Channel. I'm not sure how they deployed the CTBT systems. The relative mooring motion would need to be measured, probably using a long-baseline system, if data from the three hydrophones are to be coherently combined.

Vertical hydrophone arrays: Ten hydrophones moored at depths of 400-600 m below the sea surface. For the MARS system we proposed deploying two of our Simple Tomographic Acoustic Receiver (STAR) systems back-to-back. Each STAR has four channels, and this geometry would yield eight channels. Each STAR represents a fairly minimal payload. The existing STARs are deployed in titanium cages that are about 1.5 m long. The total weight of each STAR is less than 100 pounds in water, even with a one-year lithium battery pack. The arrays are quite lightweight and are attached to the mooring cable with rubber clamps and tie-wraps.

The existing STARs use Analog Front End (AFE) chips that have two channels each. Recently AFEs with six channels each have become available. It would therefore be relatively straightforward to develop a 12-channel STAR, reducing the number of instruments required, without significantly expanding the size of the instrument."

US versus Canada stations - Note that the PI’s proposed four stations (two triads (also called horizontal arrays) and two vertical arrays) each to both Neptune Canada (NOHAO) and ORION (ROHAO). The Canadian stations have not been funded yet within the Neptune Canada project. It is not clear to the PIs whether Neptune Canada wants a stand-alone system just on the Canadian network, whether ORION wants a stand-alone system just on the US network, or whether there will be some co-operative effort to combine Neptune Canada and ORION RCO stations and networks. If the latter, the PIs recommend six stations all together for the combined program. Hybrid schemes where ORION funds sensors and experiments on the Neptune Canada nodes are conceivable.

(C) Locations
Two ROHAO locations are to be close to or on the continental slope and two further offshore. Many of the PIs on the ROHAO RFA proposal are interested in T-phases from earthquakes on the Juan de Fuca Ridge. Ideally hydro-acoustic networks should surround the earthquake events of interest. So to get the best coverage of JdeF events, at least one offshore station should be deployed on the Pacific Plate west of the JdeF Ridge.

Locations are not critical provided there is a quadrilateral geometry. The spacing of nodes should be > ~50 km and < ~1000 km. A separation of ~500 km is close to idea.

An example of a good design for a 6 station (combined NOHAO/ROHAO system) would have stations located at

Example locations based on Deb Kelley’s Jan 2, 2006 draft RCO figure would be

1) A triad (horizontal array) at the Northern Cascadia Margin site (yellow dot labelled 10) (48.5°N, 127°W)

2) A vertical array at the Endeavor Ridge (yellow dot labelled 3) ~(48°N, 129°W)

3) A vertical array on the Pacific Plate (yellow dot labelled 1) ~(49.5°N, 132°W)
4) A triad (horizontal array) at the Southern Cleft Segment ~ (44.5°N, 130.5°W)

5) A vertical array at Hydrate Ridge (yellow dot labelled 6) ~ (44.5°N, 125.5°W)

6) A vertical array on the Pacific Plate (purple dot with arrow) ~ (45°N, 132°W)

(i) *How firm are these locations?*
Flexible

(ii) *Can the science be achieved if the locations are moved a little?*
Yes

(iii) *Can the science be achieved if the locations are moved a lot?*
Yes

(iv) *Does the proposed instrumentation require sole use of a node.*
No. Care should be taken to avoid generating acoustic noise near the arrays (e.g., mechanical noise from winches)

(D) *Is the proposed activity feasible and ready to go*
Yes

(E) *What is the cumulative (from all instruments) power requirement (continuous and peak demand) at each node? What are the cumulative communications requirements (continuous and peak bandwidth; unusual protocols or command & control requirements)? What are other cyberinfrastructure needs, e.g., data management, processing, web dissemination?*

**Average Power:**
- Vertical Arrays – 400 W
- Horizontal Arrays – 50 W

**Peak Power:**
Same as average

**Average data rates:**
- Vertical Arrays – 800 kbits/sec for 2500 Hz sampling (1000 Hz bandwidth)
  - (10 hydrophones x 2500 Hz x 24 bit samples x 1.33 overhead)
- Horizontal Arrays – 240 kbits/sec

**Peak data rates:**
- Some components of the system may be required to sample at up to 250 kHz (100 kHz bandwidth) for short intervals. For example, 10 kHz bandwidth recordings would facilitate studies of odontocete (toothed) whales (p. 9). Thus peak data rates might reach:
  - Vertical Arrays – 80 Mbits/sec
  - Horizontal Arrays - 24 Mbits/sec
Timing Accuracy: For work in the 5-100 Hz range (earthquakes, landslides, acoustic tomography) a timing precision of 1 ms is adequate. Short-range differential tomographic measurements require much higher accuracy, about 10 microseconds.

CI This system will generate significant amount of continuous time series data that must archived in the ORION data center. The proposal envisions developing automated algorithms to detect and process events of interest.

(F) What are the servicing requirements and life cycle costs for the planned instrumentation

There are no moving parts in these acoustic systems, and they could be designed for multi-year deployments with proper attention to corrosion issues. The lifetimes of the moorings would be the limiting factor.

(G) What are the pre-experiment requirements.

Deployment of a triad of autonomous hydrophones for 1 year. Data will be used to optimize mooring design and develop processing algorithms.

The US (and Canadian) Navies may raise security concerns.
XNEW VERSION DONE

A Plate scale Observatory for Seismology and Geodynamics in the Northeast Pacific

(1) **Highlight the primary scientific issues/hypotheses/objectives.**

This plate-scale proposal is focused on long-term observations of the inter-related processes that control the formation, evolution, and destruction of an oceanic plate and the interactions of that oceanic plate with the leading edge of a continental margin. Achieving these objectives requires a geophysical observatory on the scale of a tectonic plate using a packaged array of 19 three-component broadband seismometers (~500 s – 50 Hz), hydrophones, and pressure sensors. This assemblage will also provide an early warning system for tsunamis, allow tracking of marine mammals, and investigation into the impact of seismic events on crustal hydrology. Very strong science drivers for this proposal are found in the OOI Science Plan under the overarching themes presented in sections 3.3. Global and Plate-Scale Geodynamics and 3.5 Fluid-Rock Interactions and the Subseafloor-Biosphere. In particular, this proposal draws on important questions described in several community-generated reports (e.g. Science planning for the NEPTUNE Regional Cabled Observatory in the Northeast Pacific Ocean, Report of the NEPTUNE Pacific Northwest Workshop, and RECONN). Relevant questions that the proposal specifically addresses include:

1. **Understanding the mechanisms of intraplate deformation and plate boundary interaction:**
   - Deformation across a whole plate will allow us to understand the balance of forces acting on the plate.
   - The plate acts as a stress guide; this results in action at a distance such as triggering of seismicity and fluid flow by remote events. Earthquake ground motion will constrain the physics of such triggering.
   - By monitoring radiated energy over the full spectrum we will record as-yet unobserved 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.

2. **Understanding the dynamics of the lithosphere/asthenosphere system at the plate scale including:**
   - The pattern of mantle flow at the plate scale
   - Variations in lithospheric structure and how this affects intraplate deformation
   - Lithosphere-asthenosphere coupling.

This proposal focuses on plate-scale science objectives that cannot be addressed only with local observatories, specifically on the need to understand inter-linked and temporally variable processes across the plate. The RCO presents a unique opportunity to make observations of seismicity and deformation across an entire plate with known boundary conditions. RCO data will constrain temporal and spatial variations in stress propagation, the styles and causes of intraplate 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.

(2) For each scientific issue/hypothesis/objective and its experimental plan:
(A) Time Period
This a phased experiment with 13 sites planned for a deployment period of at least 10 years Six sites would be deployed year 5 of the experiment with a deployment period of at least 5 years. The number of sites assumes that there will be 4-6 nodes covered by Neptune Canada.

(B) Observatory Infrastructure
The key design criterion is to have plate-scale coverage with a relatively even distribution of sites. System would consist of 19 broadband seismometers that each requires a node. Each deployment site also includes a hydrophone and pressure sensor for part of a tsunami early warning system. Nine sites are co-located with other proposed experiments and would be an integral component of the experiments. They could easily be integrated without adding substantial infrastructure. Extension cords would be needed for 3 intraplate nodes. Intraplate sites require an ~ 100 km extension cable each.

Broad-band instrument installation require noise-free environment that can be accommodated by a 20 m extension cable. In addition, all broad-band seismometers should be buried beneath the seafloor or placed in bore-holes ~ 200 m below the seafloor.

(C) Locations
Instruments that are part of complex experiments (e.g. Axial) can be moved 10’s-100’s of meters, and intraplate instruments can be moved kilometers. The intraplate experiments, with the current RCO configuration, would require their own node, as would some of the locations on the margin. Some of the nodes must be 50-100 km across the plate. Proposed locations are given in Table 1. There is flexibility in instrument placement and instruments can be moved to accommodate the final design of the RCO.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Own node required</th>
<th>Water Depth (meters)</th>
<th>Cable length extension</th>
<th>Deploy (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endeavour</td>
<td>-129.0</td>
<td>48.0</td>
<td>No</td>
<td>2000</td>
<td>20 m</td>
<td>10</td>
</tr>
<tr>
<td>Middle Valley</td>
<td>-128.7</td>
<td>48.5</td>
<td>No</td>
<td>2500</td>
<td>20 m</td>
<td>10</td>
</tr>
<tr>
<td>Jdf Strait</td>
<td>-126.3</td>
<td>47.3</td>
<td>Yes</td>
<td>2400</td>
<td>20 m</td>
<td>5</td>
</tr>
<tr>
<td>Grays Harbor</td>
<td>-125.9</td>
<td>46.7</td>
<td>No</td>
<td>2000</td>
<td>20 m</td>
<td>10</td>
</tr>
<tr>
<td>Newport</td>
<td>-125.4</td>
<td>44.5</td>
<td>No</td>
<td>2800</td>
<td>20 m</td>
<td>10</td>
</tr>
<tr>
<td>Cape Blanco</td>
<td>-125.3</td>
<td>42.5</td>
<td>Yes</td>
<td>3000</td>
<td>20 m</td>
<td>5</td>
</tr>
<tr>
<td>Crescent city</td>
<td>-125.3</td>
<td>41.7</td>
<td>No</td>
<td>3000</td>
<td>20 m</td>
<td>10</td>
</tr>
<tr>
<td>Mendocino</td>
<td>-125.0</td>
<td>40.5</td>
<td>Yes</td>
<td>2600</td>
<td>100 km</td>
<td>5</td>
</tr>
<tr>
<td>Blanco-Gorda</td>
<td>-128.8</td>
<td>42.8</td>
<td>Yes</td>
<td>2000</td>
<td>20 m</td>
<td>10</td>
</tr>
<tr>
<td>E Blanco</td>
<td>-128.0</td>
<td>43.5</td>
<td>No</td>
<td>3000</td>
<td>20 m</td>
<td>10</td>
</tr>
</tbody>
</table>
(D) Is the proposed activity feasible and ready to go?
The proposed experiment is ready to go. Broadband instruments described in this experiment have been previously deployed in Monterey Bay and on the Explorer, Juan de Fuca and Pacific plates as part of the Keck experiment.

(E) What are the cumulative power and communication requirements? What are other cyberinfrastructure needs?
Three-component broad-band sensors (~500 s – 50 Hz) could be used for entire experiment. 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>
<thead>
<tr>
<th>Instrument</th>
<th>Data Rate/Data Storage</th>
<th>Communications</th>
<th>Timing/Power</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad-band seismometer (500 sec to 50 Hz)</td>
<td>Rechargeable battery pack, onboard data storage capability (hard disk or Flashcard) 300 sps</td>
<td>Internet Protocol</td>
<td>0.3 msec timing accuracy 2.5 W &amp; power to write data to the onboard storage</td>
<td>All three instruments can be attached to a single data logger 6 x 24 bit A/D channels.</td>
</tr>
<tr>
<td>Hydrophone</td>
<td>100 sps</td>
<td>Internet Protocol</td>
<td>250 mW</td>
<td></td>
</tr>
<tr>
<td>Pressure sensor</td>
<td>100 sps</td>
<td>Internet Protocol</td>
<td>250 mW</td>
<td>4 differential 16 bit, 1 Hz, A/D channels</td>
</tr>
</tbody>
</table>

(F) What are the servicing requirements and life cycle costs?
One day of ROV bottom time is required for installation of each seismic monitoring package. Servicing interval of each package would be every 5 years with a cost of ~ $7,000 for expendables and replacement parts.

(G) What are the pre-experiment requirements.
Cable route surveys that includes sonar data on sediment thicknesses. Each deployment requires ~ 1 m of sediment for burial of caissons.
K) Trehu: Cascadia Continental margin; Towards an Effective Real-Time Earthquake and Tsunami Warning System (Brown)

No detailed maps provided,
The arrays would be in the water for 5-25 years+
The arrays could be moved along strike a bit
6 arrays proposed along the margin, Newport/hydrate ridge is proposed as the primary array.

Scientific Objectives

1) Earthquake prediction
2) Earthquake hazard-real time warning. Rapid real-time emergency response to transmission of P-wave and bottom pressure data (shut down infrastructure and give tsunami warning.

3) Where is the up dip limit of seismogenic activity and are there transient strain events associated with it.
4) Also potential for looking at seismic asperities. Do gravity highs indicate weak or strongly locked patches.
5) How do micro-seismicity patterns vary along the forearc

Planning 6 transects- they can be moved. One is near Hydrate Ridge. They can be move and can be reduced in number.

Instrumentation:

One Broad band seismometers, buried via ROV
Strong motion accelerometer
Short period seismic arrays 6 instruments, 4-componet seismometers in each transect
Bottom pressure recorder
Acoustic strain meter array (could be battery driven in part).
Marine GPS- plate observatory scale array for horizontal component.
Temperature probes at each nodes (??? Seem odd for this purpose).

Cable/nodes extensions at each of the six proposed measurement transects:

New Port (hydrate ridge) suggested as the prime location. Each transect would include as a basic backbone a primary extension cable from main RCO- typical extensions that would be between 45-75 km long from the main RCO backbone cable. There would be a secondary node. As stated in the proposal there would be a big grouping of the instruments around this secondary node.

It was brought up at the STAC that perhaps we want a secondary extension cable that extends 2-9km parallel to the strike of the margin. Instruments would be distributed along this extension cable from several secondary nodes.
I would think that to obtain a good geodetic signal of locking patterns the array would have to be distributed across the margin not parallel to it (although a full surface aerial 2D array with an along strike component would be good!!). Due to the cost, it may be better to distribute the secondary nodes in a linear array across the fore arc between the trench and across the shelf/slope break (perhaps 2 or three secondary nodes).

There are big issues with fishing at water depths shallower than 800m!! Cables will have to be buried and shallow nodes will have to be trawl hardened.

2) Some regions have a local coastal buoy integration (Bath proposal collaboration). As suggested in the original proposal mostly co-located with Barth for efficiencies in instillation. Some oceanographic information will help with achieving some of the seismogenic goals. (The proposed/pending simplified SIO GEOCE buoy system will actually integrate the geodetic and oceanographic components).
L) Wilcock and Kelley et al. A Cabled Observatory on the Juan de Fuca Ridge (Becker)

(1) This is a very comprehensive proposal for sustained time-series observations focused on 4 primary ridge axis sites on the Juan de Fuca plate, complemented by an off-axis/plate-scale component. The proposal addresses a complete range of objectives motivated by “three overarching goals” of ridge-crest studies to understand:

- the geological processes that form and age the oceanic lithosphere
- the role of mid-ocean ridges in fostering diverse and productive biological communities above and below the seafloor
- the fluxes of heat, chemicals, and biomass across the seafloor and their effect on the overlying ocean.

Very strong science (and technology) drivers are found in at least three of the seven research themes and opportunities highlighted in the OOI Science Plan: Fluid-Rock Interactions and the Sub-Seafloor Biosphere, the plate-scale component of Global and Plate-Scale Geodynamics, and Interaction Between Science and Technology in Ocean Observatories. Strong drivers can also be found in the RECONN report as well as a host of RIDGE and R2K documents dating back over two decades.

(2) Six primary subsets of objectives and experimental types are justified and described in considerable detail in the proposal:

1. seismic and acoustic monitoring
2. geodetic observations
3. hydrothermal vent observations
4. water column observations
5. borehole observations
6. in situ AUV’s and event response.

The attached summary of section 3 of the proposal was extracted from the proposal text, stripping out much of the scientific justification to focus on identifying infrastructure and instrumental needs. The figures and sensor table from the proposal are also attached as appendices to this report to summarize the experimental designs and development needs. The remainder of this overall summary attempts to generalize responses to the questions in the minimal template for RFA summaries.

As the proposal is so comprehensive, it is probably beyond the capabilities of a single watchdog, or perhaps even the full STAC committee, to either (a) prioritize among the array of experiments and sites proposed, or (b) accurately tally the full needs for power, communications, and RCO infrastructure.

(A) In general, nearly all aspects of the proposed observatory are for long-term, sustained studies on a time-scale decadal or longer.

(B) Achieving the objectives of this proposal would require the full development of the NEPTUNE RCO facility, although it is noted that some of the off-axis components could also be
accomplished with OOI moorings. Also require would be considerable development of AUV capabilities on the RCO. The attachments extracted from the proposal summarize the infrastructure needs at each location and for each of the six objectives.

(C) The proposed locations required for the RCO infrastructure and moorings are mostly focused on 4 spreading segments of the Juan de Fuca Ridge: the Endeavour segment, Axial Seamount, Cleft Segment, and Middle Valley. These focus areas are absolutely firm, but there would likely be some local flexibility (1m – 1 km?) in locating required nodes and instruments. The proposed work also has an off-axis aspect, for much of which there would be greater flexibility to adjust node and instrument positions to allow coordination with other regional ORION activities on the Juan de Fuca plate.

(D) The attached summary and sensor table indicate many aspects are currently feasible, but that others (e.g., the AUV aspect, certain sensors/instruments) will require significant development efforts.

(E) As noted above, the proposal is so comprehensive that it is difficult to tally total needs for power, communications, or data management. The proposal highlights significant needs for program management and data management needs, e.g., data management, processing, web dissemination?

(F) Servicing requirements are specified to be annual for recovery of hydrothermal and biological samples, and will probably be annual for many other aspects. Considerable submersible support (ROV and HOV) will be required for these efforts.

(G) Pre-experiment requirements (cable surveys, clearances etc) would be those specified elsewhere in NEPTUNE documents.

WILCOCK: SUMMARY OF SPECIFIC OBJECTIVES AND EXPERIMENTAL DESIGN

3.1 Seismic and Acoustic Monitoring

The RCO provides a unique opportunity to deploy a regional network of hydrophones and seismometers to monitor the entire ridge and local networks of seismometers at each focus site. The Endeavour and Middle Valley sites are seismically very active. The Axial Volcano and Cleft segments were active up to 1998 and 1986, respectively, but are currently quiescent (but therefore represent an opportunity to be monitoring at the onset of future seismic activity). In conjunction with the other components of the proposed experiment, the seismic and acoustic networks can address many important questions including:

- What is the style and geometry of the seismic deformation that accompanies magmatic and tectonic events and how does it impact hydrothermal circulation?
- How do distant earthquakes and spreading events trigger seismicity and perturb hydrothermal systems?
- What is the nature of the seismogenic processes that maintain the permeability and control the heat flow of mid-ocean ridge hydrothermal systems?
- What is the full range of broadband seismic signals generated by mid-ocean ridge processes and how are these related to subsurface fluid flow?
- How are T-phases generated by oceanic earthquakes?
Experiment Design. To accomplish the regional monitoring objectives requires the deployment of a broadband seismometer and a hydrophone mooring at each focus site as well as a few additional installations at other sites along the ridge axis and to the west and east of the axis. The proposal also requests installation of broadband seismometers and hydrophone moorings at sites ~50 km to the west and east of the Endeavour, Axial and Cleft focus sites and seismometers near the centers of the Vance, Co-Axial and Cobb segments (Figure 1a). It is stated that the configuration of regional scale installations near the ridge should be determined in collaboration with other ORION efforts regional and plate-scale efforts. In addition, to monitor the local mid-crustal seismicity involved with spreading events and hydrothermal circulation, networks of 7-14 seismometers deployed at spacings of ~2-3 km will be required at each focus site (Figures 3-6).

3.2 Geodetic Observations

The RCO will facilitate geodetic experiments that can help address a number of important questions:

- What is the character and timing of strain that accompanies individual spreading events and what are the implications for adjacent hydrothermal systems?
- What deformation occurs between major spreading events as a result of processes such as magma recharge and fault creep?
- How do plate motions change from punctuated event-driven spreading on axis to steady spreading off-axis?
- What is the amplitude of the daily deformation of the crust due to tides and what are the implications for studies of tidally induced hydrothermal perturbations and tidal triggering of earthquakes?

Addressing these questions will require measurement of horizontal deformation, vertical deformation and tilt.

Horizontal Deformation. A variety of geodetic methods that have been in development for many years and can be adapted for use on a fiber-optic cable (Table 2). The first is horizontal deformation monitoring, which can be accomplished in three ways: 1) direct-path acoustic ranging, in which the distance between pairs of transponders is precisely measured by the round trip travel time of acoustic signals, 2) indirect-path acoustic ranging, in which a network of moored transponders is interrogated from fixed sites to precisely determine the position of the interrogation points, and 3) short-baseline, high-resolution measurements of the length of an optical fiber stretched between fixed points across the spreading axis. These span a range of scales, which is important because the deformation field caused by intrusion or faulting events on-axis can extend many km off-axis, and spatially distributed measurements are critical for constraining deformation models and interpreting what has occurred at depth.

Vertical Deformation. The second geodetic method proposed is vertical deformation monitoring using bottom pressure recorders (BPRs)(Table 2). The BPRs are subject to a long-term instrumental drift, but periodic ROV-based pressure measurements can be used to calibrate the drift rate [Nooner et al., 2004; Chadwick et al., in press].

Tilt. Tiltmeters are proposed as a complementary tool for measuring very subtle ground deformation. Tilt is one of the fundamental monitoring methods used at most volcano observatories on land.
**Experiment Design.** Pairs of instruments for direct ranging will measure from rim to rim across the axial valleys at Endeavour and Cleft, and across the summit caldera at Axial (Figures 3-5). If the ORION nodes are placed just off axis, then one of the pair of instruments can be positioned near the node and the other will require an extension cable of about 2-4 km in length. Each instrument will include sensors for temperature, pressure (BPR) and tilt to make sound speed corrections, ensure site stability, and monitor for any change in attitude during deformation events. In addition, we propose to place one BPR in the floor of the axial valleys at Endeavour and Cleft and 3 BPRs in Axial caldera to monitor for vertical displacements across the valley/caldera bounding faults and to monitor for volcanic inflation/deflation (Table 2). Periodic ROV-based pressure surveys will be required to calibrate the BPRs.

Also, it is requested that ORION nodes be positioned near the mid-points of the Cobb, CoAxial, and Vance segments, to allow for possible expansion of this effort to monitor for spreading events across all segments of the JdFR in the future (Figure 1).

The proposal also plans measurement of off-axis deformation along a profile perpendicular to the strike of the ridge that extends from on-axis to approximately 20 km off-axis at Endeavor, Axial, and Cleft (Figures 3-6). As geodetic markers for the experiment, a total of 10 seafloor acoustic interrogation units are planned to be placed on the seafloor along this profile more closely (~ 1 km) near axis and farther apart (~ 3 km) off-axis. As intermediate tie points, the plan also requires deployment of a total of 12 bottom-moored transponders to the north and south of the seafloor array (Table 2). These units act as intermediate tie points. The seafloor units must connect to the cable to provide power, data access and control over the sampling interval. Optimal off-axis monitoring would be on both the east and west flanks. This can be done by instrumenting the extension cable that will run from the main cable that will likely be located some 20 km from the ridge axis. The seafloor acoustic interrogation units can also be configured with BPRs and tilt sensors.

Tiltmeters would be placed on axis at each focus site, and three sites off-axis on both sides of the ridge (7 sites total per site)(Figures 3-6). The center of the three flank instruments will be at a distance from the axis approximately coincident with the depth of the magma body. This optimizes constraining the signal that would be received from a dike intrusion. For most of these sites, tiltmeters can be incorporated in the other geodesy instruments.

### 3.3 Hydrothermal Vent Observations

By establishing long-term interactive experiments along four diverse segments of the JdFR, which exhibit a range of geologic/tectonic characteristics, we can investigate the relative importance of different factors in determining vent fluid chemistry, deposit distribution, size, morphology, geochemistry and faunal assemblages. The highly transient nature of many of the events at ridges, and the diversity of scales at which processes operate (e.g., metabolic to megaplume formation) require emplacement of long-term sophisticated, interactive experiments that cover the areas from vent field to entire plates. The deployment of diverse suites of sensors, time-series samplers, and cameras (Table 2) in the vent fields at the focused study sites can be coupled with surveys using moorings and autonomous vehicles to address a variety of important questions including:

- What are hydrothermal fluxes of heat and mass at mid-ocean ridges and how are they partitioned between diffuse and high-temperature vents?
- What are the impacts of tectonic and magmatic perturbations on hydrothermal systems
and the biological communities they support?

- What are the hydrological properties and connectivity of flow paths within the subseafloor?
- What are the abundance, distribution, diversity, and spatial and temporal variation of microorganisms found within submarine hydrothermal environments? What is the nature of the interactions between microbes, minerals and fluids? How do microorganisms impact hydrothermal chemical fluxes?
- How are abundance, diversity, genomic structure, growth and reproduction in the macrofaunal community influenced by variability in hydrothermal conditions? How does fluid chemistry effect alterations in physiological and biochemical systems? How do microbes influence macrofaunal community structure? What is the role of processes occurring at sub-annual time scales in community evolution and maintenance? How do the macrofauna interact with mineralization and sulfide accretion?

**Experimental Design**

Within each experimental site there will be a suite of (1) environmental sensors in areas of diffuse and high temperature flow, (2) cameras to image biological communities and flow behavior at key sites, and (3) an array of fluid and biological sampling devices (Figures 3-6). These instrument suites will be integrated with water column experiments to examine effects of currents on flow and for calculation of fluxes. Table 2 provides an overview of the instruments, including the numbers needed. Detailed experimental designs for Endeavour Main Field are shown in Figure 3b. Similar couplings of instruments but on a somewhat smaller scale are planned for three other vent fields in the Endeavour (Figure 3a), three vent sites around the Axial Volcano caldera (Figure 4), two vent sites on the Cleft Segment (Figure 5) and the Dead Dog vent field in Middle Valley (Figure 6).

### 3.4 Water Column Observations

The infrastructure of the ROC will enable water column studies to address a number of important questions including:

- What are the impacts of instantaneous magmatic and tectonic perturbations at Endeavour, Axial Volcano and Cleft?
- What are the total fluxes of heat, chemicals, and biomass from a hydrothermal system? How does seasonal to interannual variability of surface ocean productivity affect the flux of these hydrothermal constituents?
- To what extent are populations at discrete vents connected by dispersal? How do ridge topography and hydrodynamics affect the probability that larvae colonize their natal vent?
- How does current variability affect the physical and chemical character of vent ecosystems? What are the impacts of these changes on microbial and macrofaunal communities?

**Experiment Design.** In the proposal, it is assumed that the water column observations will be made using static moorings although it would be advantageous to include profiling moorings if such systems are developed for the RCO. At Endeavour, the plan includes five combined biogeochemistry and physical oceanography moorings distributed along the ridge axis as shown in Figures 3 and 7. Another three moorings would be located around the margins of the Axial Volcano caldera with deployments of single moorings near the two sites of venting on the Cleft segment and at Middle Valley (Figures 4-6). In addition to the moorings at focused study sites, at least one ADCP should also be moored along the ridge system between each of the four selected study sites and one to the north and to the south of the end point sites (5 total additional ADCP...
moorings to comprise the “Optimal” mooring array).

### 3.5 Borehole Observations (Middle Valley)

The inclusion of the Middle Valley CORKS in the JdFR RCO experiment would help address several important questions:

- How do subsurface formation and fluids respond to natural perturbation events and how are these subsurface perturbations manifested at the seafloor?
- What are the volumetric strains associated with episodes of ridge spreading events and other regional and local tectonic events?
- What can active cross-hole experiments tell us about physical, chemical and biological processes in the subseafloor?

**Experiment Design.** The two existing CORKed boreholes in Middle Valley provide an excellent starting point for a "hydro-tectonic" monitoring array. Hole 857D, drilled into the regional hydrothermal reservoir where sub-hydrostatic conditions exist, has been operational almost continuously since it was established in 1991, and results have demonstrated clearly that active cross-hole communication experiments are feasible, and that the frequency with which seismotectonic events occur that are close and large enough to produce measurable signals. A second CORKed Hole, 858G, was drilled into an active hydrothermal vent field about 2 km north of Hole 857D, but it has proven to be problematic as a monitoring site; substantial overpressures and high-temperature water have caused seals on this CORK to fail after two separate attempts within about 1 year. As a man-made vent, however, the hole provides an excellent opportunity to carry out controlled fluid sampling, and vent temperature and volumetric rate observations. These can be made in the context of pressure monitoring at less hostile sites like Site 857 and in context of local seismic monitoring at seafloor installations to constrain the genetic relationships among hydrothermal, seismic, and geodynamic events. It is anticipated that by the time a cabled observatory infrastructure is available, an efficient means to augment Site 857 monitoring will be in hand. An IODP proposal currently under review focuses on developing an inexpensive, rapid-installation CORK system for strain monitoring. Once such a capability is realized – probably requiring 3-5 years, a multiple-hole array in Middle Valley will become logistically and financially very feasible.

### 3.6 In Situ AUVs and Event Response

Autonomous Underwater Vehicles (AUVs) will contribute to many of the objectives outlined in the water column and vent field observation sections, addressing specific questions such as:

- What is the spatial extent and nature of the water column and seafloor perturbations resulting from a spreading event?
- What are the effusion rates of seafloor eruptions?
- What is the three-dimensional structure of the hydrothermal plumes and how does it vary with time?
- How do macrofaunal communities evolve over areas that are too large to observe with stationary cameras?

**Proposed Developments and Experiment.**

In addition to the development of an optimized sensor suite the use of AUVs in the RCO will require three significant developmental efforts. First, AUVs will have to be designed specifically...
for the experiments envisioned, a process that will require extensive interactions between the engineers and the scientific community. Such design efforts will inevitably lead to compromises between the different scientific objectives and might result in more than one AUV design optimized for different ridge studies. The second development need is a docking system that can accommodate the AUVs. Such a docking system will provide high-speed communications, power for rapid battery recharge, and a safe place for the vehicle to reside between missions. While substantial progress has been made in this area, a system specifically designed for the needs of an observatory does not yet exist. The third development need is an acoustic infrastructure to support vehicle navigation and communications. This capability will rely heavily on the active and passive acoustic systems already envisioned for the observatories and will complement inertial and bottom-lock doppler sensors carried by the vehicles. This infrastructure would provide sub-meter positioning accuracy in the vicinity of vent fields to support repeated surveys and commensurately lower accuracy at ranges to perhaps 100 km to support event response missions to sites far from the nodes. Likewise, higher communication rates (~10 kbaud) should be provided at shorter ranges, with much lower rates acceptable for long ranges. For vent-field scale studies, high-speed optical communications capable of supporting real-time control and video transmission are also envisioned, and a pilot study is presently underway at WHOI.

Although the proposal envisions that at least one AUV will be deployed at each of the four focus sites, the initial objective over the decadal timescale of this proposal is to develop two AUVs, one optimized for small scale survey and one for event response, that might deployed at the Endeavour and Axial focus sites, respectively.