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Title:	A NorthEast Pacific Hydrate Observatory System (NEPHOS) at South Hydrate Ridge		
Proponent(s):	Kevin Brown, Robert Collier, Gary Klinkhammer, Ian MacDonald, Kate Moran, Charlie Paull, Adam Schultz, Marta Torres, Anne Trehu		
Keywords: (5 or less)	gas hydrates, methane flux, fluid flow	Area:	**continental margin off OR**

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Permission to post abstract on ORION Web site: ☒ Yes ☐ No

Abstract: (400 words or less)

We propose an observatory designed to characterize the geophysical, hydrological, chemical and biological processes that drive temporal and spatial variability in the methane-rich environment of South Hydrate Ridge (SHR) in the accretionary complex of the Cascadia subduction zone. The distribution of gas hydrate in SHR is well constrained; however, the dynamic processes that control methane transport and hydrate formationare not well understood. In addition, a full inventory of methane seepage and its impact on carbon cycling is not yet available.

Hydrate Ridge is subject to a variety of transient tectonic and oceanographic forcing factors that vary on time scales that can be monitored with subseafloor instrumentation coupled with seafloor and water column installations. Our long-term goal is to unravel the interrelationships among tectonic, oceanographic and biologic processes in a system in which gas hydrates constitute an important component of the carbon reservoir. We will accomplish this goal through the development of a multidisciplinary NorthEast Pacific Hydrate Observatory System (NEPHOS), designed to facilitate and encourage simultaneous acquisition of correlative data from deep within the sediment to the water column. Our concept builds on results collected during more than 20 years of research in this area. Currently there are a variety of efforts underway to bring the NEPHOS concept to fruition. These include: 1) an IODP drilling proposal to install large-scale borehole observatories in this region; 2) a proposal to NSF to develop and test a new type of subseafloor observing system (SCIMPI); 3) a proposal to NSF to install mini boreholes to characterize the shallow hydrology of the system; 4) Significant investment from NASA for modular fluid and in situ sampling capabilities, including a pending NASA proposal to further develop and test the equipment at HR, Several other instrument design proposals are in the planning stage and will be submitted soon.
Broader impacts: Implementation of NEPHOS impacts outreach and education, future hydrocarbon resource evaluations, and astrobiology. We will take advantage of the public's fascination with "burning ice" to strengthen ongoing and planned outreach efforts. Many of the experimental protocols developed to sample and characterize subseafloor microbes are applicable to exploration for life elsewhere in the solar system. Knowledge of the temporal evolution of this focused gas hydrate deposit is needed to quantify the resource potential of gas hydrates.

Please describe below key non-standard measurement technology needed to achieve the proposed scientific objectives: (250 words or less)

SCIMPI (sensor strings to be deployed in closed boreholes by IODP)
CORKS (sensors and samplers to be deployed in boreholes by IODP)
mini-CORKS (3-5 meter-long borehole fluid samples)
multifrequency acoustic bubble monitor

Proposed Sites:

Site Name	Position	Water Depth (m)	Proposed Duration			Site-specific Comments
			Start Date	Deploy (months)	Revisits during deployment	
SHR1 **SHR2** **SHR3**	**44.577N 125.150W** **44.568N 125.150W** **44.570N 125.147W**	**845** **807** **788**	**1/1/07** **1/1/07** **1/1/07**			**All sites ~50 km from Newport OR; close to other proposed obser-vatories.**

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ABSTRACT

We propose an observatory designed to characterize the geophysical, hydrological, chemical and biological processes that drive temporal and spatial variability in the methane-rich environment of south Hydrate Ridge (SHR) in the accretionary complex of the Cascadia subduction zone. The distribution of gas hydrate in SHR is well constrained; however, the dynamic processes that control methane transport and hydrate formation are not well understood. In addition, a full inventory of methane seepage and its impact on carbon cycling is not yet available.

Hydrate Ridge is subject to a variety of transient tectonic and oceanographic forcing factors that vary on time scales that can be monitored with subseafloor instrumentation coupled with seafloor and water column installations. Our long-term goal is to unravel the interrelationships among tectonic, oceanographic and biologic processes in a system in which gas hydrates constitute an important component of the carbon reservoir. We will accomplish this goal through the development of a multidisciplinary NorthEast Pacific Hydrate Observatory System (NEPHOS), designed to facilitate and encourage simultaneous acquisition of correlative data from deep within the sediment to the water column. Our concept builds on results collected during more than 20 years of research in this area. Currently there are a variety of efforts underway to bring the NEPHOS concept to fruition. These include: 1) an IODP drilling proposal to install large-scale borehole observatories in this region; 2) a proposal to NSF to develop and test a new type of sub-seafloor observing system (SCIMPI); 3) a proposal to NSF to install mini boreholes to characterize the shallow hydrology of the system; 4) significant investment from NASA for modular fluid and in situ sampling capabilities, including a pending NASA proposal to further develop and test the equipment at HR. Several other instrument design proposals are in the planning stage and will be submitted soon.

Broader impacts: Implementation of NEPHOS impacts outreach and education, future hydrocarbon resource evaluations, and astrobiology. We will take advantage of the public's fascination with "burning ice" to strengthen ongoing and planned outreach efforts. Many of the experimental protocols developed to sample and characterize subseafloor microbes are applicable to exploration for life elsewhere in the solar system. Knowledge of the temporal

evolution of this focused gas hydrate deposit is needed to quantify the resource potential of gas hydrates.

PREFACE

This proposal reflects the confluence of many efforts to understand the role of gas hydrates on the carbon cycle in a coastal region. Previous, ongoing, planned and proposed experiments in this area address various aspects of this problem. Integration of these programs constitutes the backbone of the proposed NorthEast Pacific Hydrate Observatory System (NEPHOS) observatory, which hinges, for its full implementation, on the availability of power and telemetry capabilities provided by an observatory node in the vicinity of Hydrate Ridge. Here we summarize some of the ongoing components as they pertain to the overall NEPHOS objective in order to demonstrate the power of a varied suite of instruments that extend from several hundred meters below the seafloor through the water column. Instruments and installations from individual projects will come to full development at various times, and will be progressively incorporated in the NEPHOS network. Fulfillment of this vision will require coordination between ORION, IODP and other initiatives.

1. INTRODUCTION

Gas hydrate, a frozen compound in which hydrocarbons are trapped in a water molecule lattice, comprise a large carbon reservoir (Kvenvolden and Lorenson, 2001; Milkov, 2004). In continental margin settings with high methane concentrations, gas hydrates occur naturally at water depths greater than 300-500 mbsl, wherever enough methane is present. Although the existence of gas hydrates has been known for decades, our understanding of their potential impact on slope stability, the biosphere, carbon cycling, and climate change is still in its infancy.

Numerous laboratory and field studies at gas hydrate bearing sites, including several drilling expeditions in the past decade, have provided critical background data on the conditions of gas hydrate stability, and have given an overall view of the composition and distribution of gas hydrates in nature. These results sparked the development of models relating hydrate dynamics to tectonic and slope stability, and the possible impact of this system on global climate (e.g. Dickens, 2003; Paull et al. 2003; Maslin and Thomas, 2003; Kvenvolden, 2002; Sloan, 2003; Clennell et al., 1999). Work carried out heretofore highlights the complexity of gas hydrate systems. It is now clear that multiple forcing factors operating on a variety of time scales influence the evolution and stability of hydrate fields.

The importance of understanding the role that gas hydrates play in the global carbon cycle and their potential as a future energy resource has been discussed in many recent OOI and IODP planning documents and has been reviewed in the NRC report "Charting the Future of Methane Hydrate Research in the United States" (Doyle et al., 2004). Fundamental questions remain as to the residence time of gas hydrates near the seafloor and deeper within the sediment column, the nature and driving mechanisms for flow and biological interactions in environments where gas hydrates are present and fluid (aqueous and gas) migration occurs, and the role of the ocean in mitigating gas input to the atmosphere from the seafloor. In our view, processes involved in modulating carbon transport within the seabed and in the water column are highly dynamic and can only be understood through monitoring of complementary parameters over decadal or longer time scales.

1.1 NEPHOS: An Integrated Laboratory

The hydrologic structure and processes associated with gas hydrates in accretionary margins involve a deep reservoir of methane generation, a transfer zone, deposition within the temperature/pressure fields of gas hydrate stability, and release through the seafloor to the water column. These components, which are vertically and horizontally linked, respond to forcing functions that may be induced locally or regionally. Thus, a bottom-to-top approach must be employed to allow quantification of time-dependent state, properties, and fluxes.

The proposed integrated NEPHOS observatory is based on a comprehensive strategy that includes continuous monitoring of the water column and seafloor in an area of known surface manifestations of fluid venting and hydrate deposits, linked to borehole monitoring of the methane reservoir, transfer zones and gas hydrate stability zone. The borehole component of the project is dicussed in detail in IODP proposal 635, available on-line at http://chemoc.coas.oregonstate.edu/~mtorres/IODP_635.pdf. This proposal summarizes the borehole observatory and describes its integration with seafloor and water-column instrumentation. Hydrate deposits and evidence for fluid flow, gas discharge and a complex biosphere have been documented at the crest of South Hydrate Ridge (SHR). Many of the components that make up the proposed integrated observatory have been designed as stand-alone systems to ensure timely development, testing, and acquisition of data in what we envision is the first phase of operations. The successful implementation of the full NEPHOS vision requires that we take advantage of cabled ocean observatory technology. The high power requirements for some of the experiments (e.g. fluid pumping, heating of the system to avoid hydrate formation during fluid sampling, operation of seismic sources); the data rates and interaction needed to support a wide range of measurements; the multi-year deployments needed to capture the various time scales operating in this system; and the need for real-time intervention to capture infrequent events, can only be met with access to the power and bandwidth of a seafloor observatory node.

2. WHY HYDRATE RIDGE?

Hydrate Ridge (HR) provides an unparalleled opportunity to site a borehole observatory in an exceptionally dynamic volume of seafloor. Rich hydrate deposits near the seafloor, fluid flow, gas discharge and a complex biosphere have been documented at HR(eg. Suess et al., 2001; Tryon et al., 2002; Heeschen et al., 2003; Trehu et al., 2004a,b; Torres et al., 2002, 2004). Many of the processes occurring at Hydrate Ridge occur along active margins worldwide, and information gathered here will have broad application.

The HR region lies within the ocean margin off central Oregon, where several significant sources of methane have been documented, including thermogenic methane input at various shelf seeps (Collier and Lilley, 2005). We are only now beginning to understand the HR contribution to the margin carbon inventories, and the potential exchange of methane with the atmosphere through coastal upwelling along this eastern boundary current system (EBC). These questions are addressed in various efforts to monitor carbon sources, transport and associated biochemical processes in coastal margins (e.g. Collier and Hales, PI). Clear synergies with the water column observing system proposed for this region (NEPCM, Barth PI) will help constrain the impact of gas hydrates on the oceanic and atmospheric methane budgets.

As the result of previous ODP legs to the area and numerous expeditions using submersibles, towed cameras, coring, 3D-seismics, and other tools, South Hydrate Ridge (SHR) is one of the best-characterized sites of gas hydrate occurrence (Figure 1). The distribution of gas hydrate is known to be very heterogeneous and patchy (Trehu et al., 2004a). Massive gas hydrates (~25% of total sediment volume) are limited to a 150,000 m^2 area at the southern summit that extends to a depth of ~25 mbsf; elsewhere, the abundance is much lower (0-10% of the sediment pore space). Recent studies indicate a very dynamic system, with hydrate formation rates at the summit of SHR on the order of 100 mol/m^2yr (Torres et al., 2004). The complex nature and temporal variability in the hydrologic activity of this subduction-setting is revealed by observations of punctuated gas discharge episodes (Heeschen et al., 2003; A. Schultz, 2004 unpublished data), measurements of highly variable aqueous and chemical fluxes through surface seeps (Tryon et al., 2002), and evidence for tectonically-driven non-uniform flow of warm pore fluid (Davis et al., 1995).

The gas hydrate deposits at the SHR summit are fed by methane gas supplied from below the gas hydrate stability zone (GHSZ). Methane gas is channeled from deep accretionary margin sequences though a permeable layer that has been mapped seismically (Horizon A) (Fig 1). This horizon, characterized by a coarse-grained, glass-rich turbidite (Leg 204 Science Party, 2003), captures and transports significant volumes of gas. Data from this area suggest that a free gas column builds up until it reaches lithostatic pressure and fractures or percolates through the overlying material towards the summit, where it ultimately is incorporated into gas hydrate or expelled to the ocean (Trehu et al., 2004b).

When methane enters the water column at 600-800 m, mostly in the gas phase, it is subject to buoyant transport, dissolution, microbial oxidation and advection within the EBC system (Heeschen et al., 2005). Rehder et al. (2002) show how dissolved methane can be brought to the surface by wind-driven coastal circulation. Depending on transport processes through the thermocline, this mechanism may accelerate the transport of methane from the seafloor on the margin to the atmosphere where methane plays a strong role as a greenhouse gas. While Rehder et al. (2002) demonstrated the existence of this process, the connection to hydrate sources has not been demonstrated and long-term, year-round measurements are needed to quantitatively assess the importance of this link between a sub-seafloor process and ocean-atmosphere dynamics.

The ultimate goal of NEPHOS is to develop a comprehensive model of carbon cycling in gas hydrate bearing accretionary margins, which will be consistent with chemical, microbiological, physical and geophysical data and that can be used to understand the geologic record and predict the response of these systems to oceanic and tectonic perturbations.

The NEPHOS objectives address high priority elements of both the IODP and OOI science plans. The study of gas hydrates has been identified as an important research initiative within the deep biosphere and the sub-seafloor ocean theme (ISSP, 2003). In addition, two national carbon research programs, the North American Carbon Program (NACP) and the Ocean Carbon and Climate Change (OCCC) program have highlighted the necessity of coastal studies in their science and implementation strategy documents (Wofsy and Harriss, 2004; Doney et al., 2004; Denning et al., 2004). In particular, the NACP national plan for carbon cycle research is focused on measuring and understanding sources and sinks of CO_2, CH_4, and CO in North America and adjacent oceans.

2.1 Evidence for episodic forcing on fluid transport HR

The Hydrate Ridge area is subject to transients in tectonic stress, tidal modulations and significant bottom water temperature variations including those linked to el Niño. That episodic events affect fluid flow on SHR has been documented (Tryon et al., 2002). For example, fluid flow rate increased from 0-200 cm/yr to ~1000 cm/yr for 2 days during a 45 day recording period (Figure 2A). The cause of the pulse of outflow remains a mystery because of the short recording time window and because of the lack of complementary instrumentation to help determine what had triggered this event.

An important forcing factor that can modify fluid flow and cannot be studied without a long-term observatory is earthquake activity. Hydrate Ridge lies in a seismically active region associated with the northern Pacific subduction zone. Two moderate-size earthquakes (mag 4.9 and 4.7) occurred recently (July 12 and August 18, 2004) between Hydrate Ridge and the coast of Oregon. Another ORION RFA (Cascadia Seismic and Geodetic Array - SAGA) is designed to monitor seismic and aseismic deformation in this region and will provide data critical for evaluating the impact of seismic activity on the plumbing system feeding gas hydrate formation and on disruption and destabilization of hydrate near the seafloor. The importance of seafloor observatories for understanding hydrologic responses to seismic activity was clearly demonstrated by data collected during and after a seismic event (September 7, 2001) at the seafloor observatory installed on the Middle Valley rift of the Juan the Fuca Ridge (Davis et al., 2004). After the event, no hydrothermal activity was detected in the water column. Instead, it appears that the space created by extension in the crust was filled by water (drawn from the adjacent crust) rather than magma, resulting in a drop in fluid pressure at the CORK. We will establish whether global, regional and local seismic activity leads to measurable changes in the flow regime at SHR.

There is already intriguing evidence for the existence of transient variations, which may be associated with tectonic stresses in this region. Although there are no long-term temperature records available on southern Hydrate Ridge (SHR), a thermal anomaly was observed (increase of 4° K in 5.5 months) after the installation of an instrumented borehole seal (CORK) on northern Hydrate Ridge (NHR) in 1992. This temperature anomaly has been attributed to a change in fluid flow rate within the conduit that feeds the seafloor vents (Davis et al., 1995). Because steady flow at this rate would have a larger impact on the BSR depth than is observed, the authors conclude that the average fluid flux at the drilling site results from short-lived and localized transient flow events.

Strong tidal modulations of gas phase flows have been detected at northern HR (Torres et al., 1999; K. Nakamura, pers. communication, 2002). Such a significant change in observed outflow from such a modest perturbation to seafloor P-T conditions suggests that tidal forcing functions will provide an important tool for probing the stability of the GHSZ (particularly near its lower boundary), and for investigating the details of sub-seafloor hydrology. While tidal pressure changes appear to be less imporant at SHR (Heeschen et al., 2003), there is suggestion of some tidal influence in recent data acquired by A. Schultz (Figure 2B).

Geochemical data available to date from the subsurface of SHR provide only the traditional "snap-shot" view that can be obtained from the analyses of sediments and pore fluids, but even these limited results hint at a dynamic system. Figure 2C illustrates some of the chemical discontinuities that were measured in samples recovered during Leg 204. These and other data have been used to document a deep source for water and gas migrating along Horizon A, and to establish that this is indeed the pathway that supplies methane to the hydrate deposits at the summit (Trehu et al., 2003; Milkov et al., 2004b). Formation of hydrate deposits in the upper 20 mbsf at the ridge summit leads to the formation of high chloride brines, reaching concentrations of up to 1370 mM. Such high chloride values can only be sustained by formation of gas hydrate at very fast rates (Torres et al., 2004). Unfortunately we still lack the data to quantify geochemical fluxes, the nature of their variability, and the factors that control their fluctuations.

On the microbiological front, quantitative PCR analysis of the DNA extracted from samples collect during Leg 204 from the interval around Horizon A indicate anomalously high cell counts, suggesting that enhanced microbial activity here is supported by large methane fluxes along this horizon (Fig. 2B). High abundances of methanogens (> 10,000 cells per gram) at this deep horizon are more typical of cell counts found near the seafloor (Figure 2D). Such high methanogen abundance is particularly striking when compared to levels that are below the detection limit for most of the sediment column sampled, with exception of the shallow sub-seafloor depths (Colwell et al., 2004). Presumably the methanogen communities are associated with the enhanced flow through Horizon A. We do not know, however, how these communities respond to variations in rate and composition of the flow along this highly permeable horizon.

Subseafloor time series data are essential to unravel the complex interactions among the forcing parameters and to quantify the response of the flow regime and its geochemical and microbiologic impact. The examples discussed above illustrate episodic perturbations that affect the flow regime on HR in short time scales that can be monitored with the borehole, seafloor and water column instrumentation connected to a real-time observatory. Moreover, since Hydrate Ridge is located only 50 miles west of Newport, Oregon, it is readily accessible for system maintenance, rapid event response, and classical process-oriented expeditionary science.

3. LAYOUT OF THE PROPOSED OBSERVATORY

NEPHOS will be focused at three sites on the southern summit of Hydrate Ridge (Table 1), although an extension to the northern summit will be considered in the future. At SHR massive gas hydrate occurs virtually at the seafloor accompanied by vigorous venting of bubbles. Multiple efforts comprising several research teams are being conducted in parallel to develop the NEPHOS concept (Table 2; Figure 3), and powerful synergies exist with ongoing efforts to monitor water column processes in this region. Two sites near the southern summit and a third site ~ 800 m to the north have been proposed to IODP for installation of observatory instruments at sites previously drilled and cored during ODP Leg 204 (Sites 1247, 1249 and 1250). We plan to monitor the deep subsurface with a new type of sub-seafloor observing system –dubbed SCIMPI for "Simple Cone Instrument for Measuring Parameters In-situ" and currently under review at NSF (pending NSF proposal, K.Moran, C. Paull and others). This design takes advantage of off-the-shelf components and of the natural tendency of the borehole wall to collapse and seal the system, and is therefore not affected by formation of hydrate within the hole. SCIMPI will allow us to observe changes in the parameters that control flow, are altered by variations in flow, and change as gas hydrates form or decompose. Fluid and deep-biosphere sampling has been planned via an IODP-CORK installation. An open cased hole will facilitate the installation of seismic and electromagnetic sources.

The processes that characterize the shallow subsurface are targeted with "mini-borehole" installations to collect uncontaminated subsurface borehole fluids for chemical and microbiological analyses (pending NSF proposal, M. Torres, A. Schultz, P. Johnson). These installations are also designed to collect flow rate, heat flux and permeability data. The mini-borehole configuration is a cost-effective means of characterizing the shallow subsurface hydrology, thereby providing the necessary bridge between surface observatories and full-scale SCIMPI/CORK observatories under IODP.

We also propose an array of seafloor instrumentation including: flow meters (K. Brown) and temperature probes (Trehu/Schultz) at the summit that will complement the borehole instruments and help constrain the three dimensional aqueous fluid flow field that links the subseafloor with the ocean; seafloor cameras to monitor the growth and shrinkage of seafloor hydrate masses and associated fauna (I. MacDonald); and an acoustic system to quantify methane flux via bubbles from the seafloor into the ocean (to be developed by expanding the capabilities of instruments proposed for hydrothermal vents in an RFA submitted to ORION by D. Di Iorio, P. Rona and others); water column moorings to help constrain methane concentrations and fluxes from the study site (following the NEPCM deep ocean profiler mooring design).

Additional instrumentation critical to NEPHOS has been developed with support from NASA (Medusa and Isosampler projects, A. Schultz PI; ZAPS microanalyzer system , G Klinkhammer PI). A pending NASA proposal includes funds for integrating ZAPS, other in situ chemical sensors (e.g. methane), an *in situ* mass spectrometer, and fluorescent microbial detection (L. Powers, Utah State) into the isosampler platform (see M. Flynn letter of support). Collaboration with colleagues from Europe will allow for coordinated deployment of other seafloor technologies such as the Fluid-Flux-Observatory (FLUFO system, Geomar) and microbial incubation capabilities at in situ pressures (HYACE system, Cardiff University). Development of inter-hole cabling necessary to connect to common data loggers is underway at MBARI, associated in part with the MARS project (www.mbari.org/mars/).

The NEPHOS observatory has well defined linkages with ongoing efforts aimed at understanding the cycling of methane in the coastal ocean and its pathways to the atmosphere (Collier and Hales, PI). A proposed coastal observatory (NEPCM) designed to study processes associated with coastal upwelling and the California Current (in response to ORION RFA, Barth PI) will provide additional water column hydrographic and current information. In the Neptune concept, a single node of the backbone might service the entire NEPHOS/ NEPCM observatories. This node could also service the highest priority transect in an ORION RFA to monitor strain accumulation and release on the Cascadia megathrust.

4. DEEP SUBSURFACE INSTRUMENTATION

IODP drilling on SHR (IODP proposal #635) has been proposed for installation of large-scale borehole observatories to test the hypothesis that the fluid flow field that feeds the massive gas hydrate deposits on SHR responds to pressure, temperature, hydrologic and/or seismic perturbations that occur on time scales of hours to decades. The proposal has been well-reviewed. Availability of an ORION node to facilitate data transmission and provide power would greatly enhance this project by permitting real-time changes in recording parameters and event response.

4.1 Simple Cone Instrument for Measuring Parameters In-situ: SCIMPIs

The backbone of IODP proposal 635 is an array of new closed-hole instruments that continuously monitor temperature, electrical conductivity, pore pressure, ground motion and other parameters at multiple depths beneath the surface. The full capability instrument will be developed in three phases.

The Phase I SCIMPI design project, includes modular sensors to measure temperature, pore pressure and electrical conductivity down a borehole. The design takes advantage of off-the-shelf, proven components that are relatively inexpensive and flexible. The technology for this instrument is taken from cone penetration test equipment (CPT), which has been routinely used routinely for over 50 years in geotechnical practice (Lunne et al, 1997) and in offshore geoscience applications (Morane et al., 1989). The CPT is comprised of rods of tubing with one or more sensor packages at the bottom end. Multiple ~1 m long spacing rods and sensor packages are assembled in a series of sections to make up the desired probe length, which is connected internally with a power/data transmission cable. For the SCIMPI application, the same concept will be used, but the entire sensor package will be comprised of sensor rods that are distributed along its length using spacer rods. The sensors we propose to install along the Phase I SCIMPI include: temperature, electrical conductivity, and pore pressure transducers, but the design will take into account the need to incorporate other sensors for subsequent applications. Each sensor will have its own microprocessor. We expect that these instruments will find a variety of applications in other ORION observatories besides Hydrate Ridge.

A proposal for Phase I SCIMPI development was submitted to NSF this spring. The University of Rhode Island (URI) is will coordinate the project and oversee the development, testing, and calibration. Applied Research Associates, Inc. (ARA) will be responsible for SCIMPI module design and prototype construction. The Monterey Bay Aquarium Research Institute (MBARI) will develop the parts of the SCIMPI that are exposed on the seafloor, service it using ROVs. When the proposal was submitted, the plan was to deploy a pilot SCIMPI in Monterey Bay during IODP Leg 312; however, we learn just as we were about to submit this proposal that drilling in Monterey Bay has been postponed because of permitting concerns. It has not yet been rescheduled, and will probably not be rescheduled before 2007, leading to uncertainty about whether SCIMPI will be tested prior to installation of NEPHOS. Preliminary estimates indicate a cost of approximately $320K per SCIMPI, which is significantly less that that of a CORK (ca. $800k - $1M).

A Phase II seis-SCIMPI design effort will be proposed to NSF by Trehu in the near future to add modules to measure seismic waves and strain (in collaboration with R. Stephen, who will be proposing a seis-CORK for deployment in boreholes in oceanic crust). Seismic modules for shear wave studies are well established in the geotechnical community. For NEPHOS, seismic modules are needed to continuously record microseismic activity as well as controlled sources. Addition of 10 seismic modules at each SCIMPI site would result in several vertical arrays of seismic sensors. By using the beam-forming capability of each vertical array, we will be able to locate the source of microseismic activity more precisely than would be possible with only a single seismic module/site. In addition to regional and local earthquakes, these may include vibrations excited by fluid flow in conduits analogous to those observed in volcanic and hydrothermal regions (e.g. Molina et al., 2004; Kumagi and Chouet, 2000). The ground motion sensors distributed within and beneath the gas hydrate stability zone will also be used in repeated (4-D) active source seismic experiments to monitor changes in the distribution of gas hydrate and in the amount of free gas within the major conduit feeding the shallow gas hydrate deposit.

For the passive seismic experiment, SCIMPI geophones will record data continuously at a sampling rate of 50 Hz. For larger earthquakes that are also recorded onshore (magnitude threshold ~2.5 for regional events from the Cascadia margin), data will be combined with those from onshore seismic arrays and from other seismometers deployed in this region for other ORION experiments to improve hypocenter and source mechanism determinations. Braunmiller et al. (1997) showed the value of having a few offshore instruments when locating continental margin earthquakes. For smaller events not recorded on land, the sub-seafloor array geometry in multiple boreholes will permit application of beam-forming techniques to increase location resolution. It should also result in better signal-to-noise ratio compared to seafloor seismometers (Collins et al., 1998; Duennebier et al., 2002). The SCIMPI approach is especially well suited for achieving good borehole/geophone coupling, compared to open borehole installations, where fluid flow within the borehole has been a problem. However, it may be necessary to develop separate ground motion sensor modules that are mechanically decoupled from the other elements of the seis-SCIMPI.

The seismicity data will be used to evaluate the impact of seismic activity on the plumbing system feeding gas hydrate formation. An observatory permits us to use the seismic data to trigger event response observations using AUVs and ROVs in order to observe whether massive amounts of free gas and gas hydrate are released by such events. Because the gas bubble plumes imaged acoustically disappear and are dissolved at ~450 m below the sea surface (Heeschen et al., 2003), these plume do not directly feed methane to the atmosphere. A more effective mechanism is probably to dislodge chunks of buoyant gas hydrate large enough to float to the sea surface without completely decomposing.

Active source seismic experiments will be conducted every few years. These will include sources within the water column and within a cased borehole installed to allow subsurface seismic and electromagnetic sources and will require that the recording parameters of the ground motion sensors in the seis-SCIMPIs be changed to allow a much higher sampling rate of 0.5-1 ms. This will require resetting the recording program prior to starting the experiment. A cable observatory greatly facilitates this aspect of the science compared to recording in a self-contained seafloor package.

The estimated incremental cost of expanding Phase I SCIMPIs to seis-SCIMPIs will be proposed to ORION after we develop a detailed prospectus for this instrument development effort.

Phase III SCIMPIs comprise development of additional capabilities, which could include additional sensors (eg. X-ray fluorescence, spectrophotometry) or water/gas sampling (by including extruded multi-channel tubing in the design). The infrastructure put in place to permit downhole seismic sources may also be used to support the development of seafloor cross-borehole 4-D electromagnetic tomography (Wilt, et al, 1995). The cross-borehole EM tomographic method is sensitive to changes in porosity, fluid saturation, permeability, and pore fluid chemistry (e.g. salinity), and provides complementary data to that determined from seismic tomography.

4.2 IODP-CORK installation

The existence of a borehole makes possible certain in situ physical measurements, chemical analyses (e.g. Seyfried, et al, 2000) and microbiological studies, and provides a working space in which fluids may be captured for subsequent recovery and analysis. Phase, chemical and isotopic characterization of the fluids is key to our understanding the nature of the aqueous and gas flows in this system. We recognize, however, that there are still some engineering issues that need to be addressed. By moving formation fluids up through the GHSZ to the seafloor, the samples can be made available for those aspects of processing and analysis that cannot yet be performed down-hole. Unless conditions within the fluid sample manifolds that run from the CORK inlets beneath the BSR are modified by direct intervention, we anticipate the fluid sample manifolds would become clogged with gas hydrates. We are considering the use of resistive heating tape around insulated fluid sample manifolds to avoid hydrate formation during episodes of fluid sampling. The heaters can operate continuously, if sufficient power is available (as above, in cabled observatory mode), or episodically (if powered by local batteries), to defrost the sample manifolds at those times fluid samples are drawn. We estimate the power needed to do this is on the order of 100 W, depending on depth to the CORK formation fluid sampling port. Fluids will be pumped from the sampling depths to the seafloor using a pump located at the seafloor. This is in contrast to previous CORK installations, where low rate osmotic pumps have been used in the borehole to extract small volumes of fluid sample. To keep the samples from freezing within the insulated and pressurized titanium sample chambers developed for Isosampler/DALEX (volumes as great as 1 liter may be kept under pressure within any single sample chamber), up to 1-5 W continuous power expenditure is required, for a total heat budget of no more than 15 W.

The original development cost for some of the CORK instrumentation is being pursued as part of a proposal to study the shallow subsurface with “mini-CORKs” (see below). Details of the costs needed to construct additional instruments for the CORK application will be available after the shallow subsurface project is completed and tested.

5. SHALLOW SUBSURFACE INSTRUMENTATION

5.1 mini-CORKs

The extensive pore water database available for the HR region (during TECFLUX and ODP programs) indicates substantial fluid inflow in the upper upper 5 meters of the sediment section (e.g. Torres et al., 2002; Sahling et al., 2002, Trehu et al., 2003). This zone, where carbon cycling is impacted by a variety of process (sulfate reduction of organic matter, anaerobic methane oxidation), cannot be monitored by conventional IODP observatory installations. Thus, in parallel to the IODP program, a proposal was submitted to NSF (PI M. Torres) to install mini-boreholes on HR to generate time series data on temperature, fluid flow rates and chemical composition in the upper 3 to 5 mbsf. These data will better constrain the overall fluid circulation of the ridge.

Stainless steel probes will be used as mini-boreholes (3 to 5 meters long, 4 cm in ID) for the insertion of *in situ* sensors and as ports for the sampling of uncontaminated sub-surface fluids. These probes are similar to those successfully driven into basaltic rock in the previous LEXEN Program at Baby Bare Seamount (Johnson, et al, 2003; Huber et al, 2005), and can be installed using the OSU piston coring facility. The goal is to determine the time dependence of chemical change in the fluid chemistry, using *broadband fluid sensors and sampling systems* derived from components of the OSU *isosamplers*, from *osmo-flowmeters* and from UW *pipeMAVS* flow meters, in order to evaluate how the HR environment responds to long-term external forcing (fortnightly tides, earthquakes, winter storms, bottom water temperature variations). We have proposed a 12 month deployment of free-standing instruments that can be adapted to the NEPHOS observatory environment, with both deployment and recovery using the ROV JASON-II. This effort will also lead to new methods of in situ fluid sensing, sampling and microbial incubation that can be directly applied to future IODP borehole systems at this and other sites. The instrumentation (described below) has been proposed to NSF (total budget ~$1.2M) as a collaboration between OSU (Torres, Schultz) and UW (P. Johnson), and takes advantage of established partnerships with DOE (R. Colwell), Geomar (K. Walmann) and the University of Cardiff (J. Parkes). The cost of each unit for implementation in NEPHOS will be determined after the development and testing of the proposed system.

The mini-CORKS will incorporate a fluid sensor and sampling system capable of operating over a broad range of flow rates, from almost purely diffusive (<0.1 m/year) to vigorously advective (up to 1 m/second). This is required because: 1) we will be perturbing the system for a period of time by inserting mini-boreholes; 2) the underlying dynamic range of the flow regime is not well established; 3) there is no firm understanding of the response of the system to regional seismic events, such as the M4.7 and 4.8 earthquakes along the Oregon margin in July and August 2004. This uses a heated, fluid sampling manifold integrated into the top seal of the mini-borehole casing, providing a hydraulic connection between borehole formation fluids and a seafloor instrument frame. The available OSU *isosampler* instrument provides a modular collection of sensors, high pressure sample bottles, dynamic pressure compensators, valves and pumps from which a sampling/sensing platform may be constructed. A variety of sensors can be integrated into this platform including existing *thin film* flow rate/temperature sensors, *pipeMAVS* acoustic flow sensors, conductivity sensors, ultra-low flow rate fluid displacement sensors, osmo-flow meters, *in situ* chemical sensors including ZAPS/ZMAS, methane sensor, mass spectrometer and *in situ* fluorescent microbial detectors (all of which are already in existence, and the integration of which into the *isosampler* platform is pending under NASA and NSF support).

We require fluid and gas samples for geochemical analysis, and for microbial incubation. For high flow rates, large volume (1 liter) *isosampler* high pressure, flow-through titanium bottles are available. Such high flow rates are anticipated early in the experiment for some days following the insertion of the mini-boreholes, providing a good sampling of presumed subsurface microbial mass. High flow rates may also follow tectonic events. The isosampler controllers provide sufficient onboard logic to shunt fluids through the high volume samplers in response to periods of high flow rate, as determined by the thin-film flow sensor. Two high volume samplers will be equipped at each site. More typically, extended periods of low flow rate will be the norm, generally in the range of 0.01-1 m/year. This requires a different strategy. The osmo-sampler (Jannasch, et al, 2004) has been used for many years to obtain chemical samples from low flow rate environments. In 1999 in collaboration with H. Jannasch we (Schultz) produced a prototype broadband flow instrument, combining our earlier Medusa system with osmosampler for use at ODP 1025C. While osmosampler is ideally suited to conventional I/ODP deployment, the mini-boreholes are small bore and small volume, we do not want to pump fluids out of such a small reservoir – rather we intend to permit natural flow to be captured passively within the 1 mm diameter "spiral sampler". By installing PTFE and copper tubing in parallel (only PTFE spiral is shown in Fig 5B for clarity), the spiral sampler will allow for collection of fluids for analyses of dissolved components and hydrocarbon gas.

5.2 Temperature probes

In addition to the SCIMPIs, several of the instruments comprising NEPHOS include temperature sensors. Multiple factors affect temperatures in the shallow subsurface. In the absence of local heat production, changes in bottom water temperature and advective fluid flow, the temperature in the subsurface should increase linearly as a function of the condutive heat flux from a deeply buried heat source (in this case, the subducted plate). A primary effect imprinted on this regional thermal gradient results from changes in bottom water temperature, which propagate into the seafloor to a depth that depends on the thermal conductivity of the sediments and the period of the bottom water temperature change; for example, a tidal change propagates to 20 cm for a typical sediment thermal conductivity and a seasonal change propagates to a depth of 80 cm. Superimposed on the regional gradient and on the effects due to changes in bottom water temperature are vertical and horizontal advection of heat by fluid flow. Simple calculations show that this signal should be detectable for flow rates greater than ~1 cm/yr. If seafloor temperature is also recorded, high resolution subsurface temperature profiles can be partially corrected for bottom water temperature and used to infer flow rates in the range of 1-1000 cm/yr (note: off course, we cannot correct for long-period temperature changes occurring prior to installation of the probes. However, that signal will not vary rapidly with time and can therefore be separated from signals due to rapid changes in fluid flow

The mini-CORKs will include thermal 'inserts' that will be deployed by the ROV after the mini-borehole probes are driven into the sediments and will allow measurement of the temperature profile in the upper 3-5 meters. The seafloor flow meters discussed in section 6.4 will record seafloor temperature. We also propose a relatively large number of simple, inexpensive lance-like probes, similar to the DSV ALVIN temperature probe. Each probe will contain RTDs (resistance thermal devices) at the seafloor and at ~10 cm intervals in the subsurface. We prefer RTDs to thermistors because they are more accurate, more stable over long time periods and more flexible from an engineering standpoint. A pencil-thin board will be developed that will fit into the probe and will include the 8 RTD sensors, an 8-channel 24 bit A-to-D converter, and a current source. Exciting the 8 sensors by a common current source will eliminate sensor drift among the sensors in each probe, further improving accuracy compared to probes constructure from multiple self-contained thermistors. At <$3K each, these instruments can be deployed in larger numbers to resolve the spatial scale of variations in flow rate in zones or relatively rapid fluid flow. They will be deployed around selected flow meters in regions of expected strong lateral changes in flow rate in order to define spatial variability on the scale of tens of meters. We initially have planned a 1-m length for these probes because past experience suggests that it is very difficult to insert a thin probe more than ~1 m into a sedimented seafloor with an ROV or submersible. However, with development of seafloor drilling systems, we can envisage longer temperature probes. If we maintain the 10 cm RTD spacing, the cost of longer probes will be proportional to the length..

6.SEAFLOOR INSTRUMENTATION

6.1 ***Bottom currents:*** The Torres proposal to NSF includes strategies to measure the tidal flux and hydrostatic pressure changes over the site, by deployment of standard MAVS current meters (Garcia-Berdeal, et al, 2005) and we would add upward-looking ADCP's to the observatory site to capture the currents within the water column above the area affected by the gas flux.

6.2 Bottom pressure recorders: Pressure changes due to tides are expected to be a significant parameter affecting fluid flow and gas vent. Ambient pressure will be monitored with various instruments including bottom pressure recorders (BPRs). These instruments have a wide range of applications and will be included in many ORION applications. They can accurately measure ocean tides (Mofjeld et al., 1995; Mofjeld et al., 1996), displacements of the ocean surface from tsunami waves (Eble and Gonzalez, 1991; Gonzalez et al. 1991), and vertical deformation of the seafloor (Fox, 1999; Chadwick et al., in press). Repeated ROV-based pressure measurements can be used to calibrate the long-term rate of drift of the BPRs (Nooner et al., 2004; Chadwick et al., in press) in order to measure lower rates of tectonic deformation.

6.3 Seafloor cameras:

Previous work has shown that a visual record is a viable way to check for significant in flow rate or pattern that might affect other measurements and provides a data set for analyzing sediment and biological processes to methane flux and hydrate formation (MacDonald et al. 2005). High resolution imaging of the observatory site is needed to determine the response of the seafloor / water interface to the flux of gas and the formation of shallow gas hydrate deposits. Visual indicators of this process include the gradual inflation of hydrate mounds, streams (often intermittent) of gas bubbles, and the biological response to the supply of methane (bacterial mats, bivalves, mobile consumers). A rotary time-lapse camera system will be installed near the summit vent to make quantitative population estimates of the mobile epifauna associated with hydrate deposits. This is a very understudied group, but is clearly a link in the trophic transfer from bacterial production to the benthic ecosystem. The camera system will produce striking 360° panoramas of the benthic environment that can be useful for education and public outreach.

The specifications for a visual observation component are as follows: 1) low unit cost so that multiple imaging nodes can be installed, 2) operating mode for automatic, replicated imaging, 3) operating mode for targeted surveillance of points of interest, 4) modest power and data transfer

demands, and 5) integration of scaling lasers. To meet these requirements, we will adapt a commercially available underwater camera system to the power and data transfer specifications of NEPHOS. This system (AquaPix model Seasnap 360) comprises a 5 mpixel camera mounted with a 110 watt-second strobe inside a thick-walled glass tube. Camera and strobe rotate together on a turntable driven by a stepper motor. In automatic mode, the camera takes a picture, then rotates 36 degrees and waits for a specified interval (e.g. 3 hours) before taking the next picture. NEPHOS would allow us to change this interval in real time. All illumination is provided by the on-board strobe. Ten pictures complete a rotation with 10% overlap between pictures and exact replication of imaging parameters. In targeted mode, the camera will pivot to a preset position—for example to inspect one of the NEPHOS instruments. For targeted imaging, additional illumination is required in the form of emplaced lamps or strobes. Change detection will be facilitated by including leveling lasers within the glass tube. The lasers give a scale for image subjects and an artificial horizon for detection of changes in seafloor topography.
Video images can also be recorded from the camera in the targeted inspection mode where external lamps are available. A robust operating interface will be designed for the NEPHOS array. This system will prioritize routines stored in each camera's firmware so that commands for automatic surveillance at various sampling rates and targeted inspection of specific location around each camera.

Power demands for the system are <1 watt dc current during normal automatic operations regardless of sampling rate. Targeted inspection will require additional power to drive external lamps. Estimated demand for each lamp is 100 watt during inspection. Data return will depend on image collection. Each image is approximately 1 megabyte in normal jpeg compressed mode.
Notes on connection engineering: Because of the I/O and power requirements for each camera system, robust connections will have to be established between the system components and the NEPHOS net. Deployment will be a multi-stage process. First the array with I/O and power connections will be laid out per anticipated site-specific dimensions. There will be a single command node for each camera array with all other components hard-wired to it. This system will be packaged for transport to the seafloor. The deployment vehicle will carry the package to the NEPHOS site and position the components as required. Finally the underwater mating to the command node will be established to commence system operation.
Costs for each component of the system can be summarized as follows:

Camera system with strobe, housing and connector -- $9500

Laser ranging systems -- $2000

External lighting array incl. cables and connectors -- $3500

24-channel command / power node with underwater mateable connections (will service up to 5 cameras) -- $20000

Non-recurring engineering for interface -- $35000

Project management, pre-cruise planning and at-sea participation by MacDonald -- $15000

6.4 Seafloor flow meters: Six flow meters developed by Kevin Brown will be installed in an array near the summit and on the flanks of the pinnacle to determine fluid flow rates into and out of the seafloor. A previous 45-day deployment of one of these instruments near the southern summit of HR indicated an episode of rapid outflow (~1000 cm/yr) that lasted 2 days (Tryon et al., 2002). The mechanism driving this period of rapid outflow has not been identified.

6.5 A multifrequency acoustic experiment to quantify methane flux via bubbles.

Because bubbles excited by acoustic waves vibrate at a frequency determined by the water depth and by the bubble size and composition (eg. Medwin, 1977), acoustics may provide an effective means of determining the methane flux out of the seafloor via bubbles. We propose to adapt technologies developed for monitoring particle fluxes from hydrothermal vents for this application by extending acoustic backscatter and/or scintillation instrumentation to operate over a range of frequencies and thus be sensitive to a range of bubble sizes. We plan to prepare an NSF proposal in the near future for a short-term pilot experiment to determine the appropriate range of frequencies and transmission distances. To date, we have only images bubbles from shipboard echo sounders at 12 and 18 kHz (Heeschen et al., 2003). Anticipated costs and power requirements for this component of the Hydrate Ridge observatory are expected to be similar to those for an acoustic observatory at a vent cluster in the main Endeavour hydrothermal vent field that has been proposed by Peter Rona, Daniela Di Iorio and others.

7. WATER COLUMN INSTRUMENTS

Methane reservoirs and seeps are an active component of the continental margin carbon budget and represent a poorly characterized pathway for reduced carbon cycling and methane input to the atmosphere. The input of methane to bottom water in central Cascadia is not limited to the methane discharge from HR. Indeed, Heeschen et al (2005) showed that the distribution of dissolved methane can be represented by mixtures from at least two primary source regions, which can be traced by their stable carbon isotope signature (Collier and Lilley, 2005). Methane inventories suggest that the combined vent sites on HR produce $6 \cdot 10^3$ mol h^{-1} and this is primarily released in the gas phase rather than dissolved within fluid seeps.

The NEPHOS observatory is located near the Newport Hydrographic Line (44.6ºN), occupied since the early 1960s (eg. Smith et al., 2001; Huyer et al., 2002) and it is strategically nested within the "Multi-Scale Ocean Observatory for Ocean Dynamics and Ecosystem Response along the Northeast Pacific Continental Margin (J. Barth et al., ORION proposal). This margin observatory is aimed at the long-term study of the regional fluxes and rates of physical, biological and chemical processes. We have proposed an array of methane sensors as part of the water column monitoring efforts of Barth et al. As part of NEPHOS, we propose two additional deep ocean profiler moorings be placed around the NEPHOS SHR study site to complement the nearby Newport Endurance Line mooring. In this way, near-field methane fluxes can be directly estimated by the addition of methane sensors to the profilers. We would also add an upward looking ADCP near the base of the mooring to capture higher resolution current data from the NEPHOS site to better connect the benthic transport into the regional dynamics studied by the Endurance Line and regional Pioneer Arrays. The combined contribution of methane from the hydrate and shallower thermogenic sources will be addressed through the synergy between NEPHOS's hydrate-focused observatory and the larger scale NE Pacific Margin Observatory.

8. ROV NEEDS FOR INSTALLATION AND MAINTENANCE:

Immediately after installation of sub-seafloor instruments (either IODP SCIMPI/CORKs or miniboreholes), we plan ROV visits to connect instruments to the data loggers. Following this initial trip, annual visits to the observatories will be needed to retrieve samples and data and to change batteries; however, two visits to the site may be needed during the first year of operation. A spring visit will make possible implementation during the late summer of engineering improvements and repairs. Following this initial period, annual visits would be scheduled during the duration of the experiment, which we envision to last for 5 to 10 years. All components of the water column moorings are designed to be ROV-serviceable. Although a more frequent schedule might be attractive, there are financial and logistic reasons (including a short weather window), which make it difficult to plan for more than one visit per year. Fortunately, proximity of the site to shore (50 miles from the Newport, Oregon marine facility) makes relatively rapid event-response and engineering interdiction feasible by coastal and ocean-class vessels. Additional ROV visits will be needed to install seafloor and water column sensors, but once all instruments are installed, an annual service visit should be adequate. However, if several other observatories are installed in this region and an ROV is housed locally, ROV visits could be scheduled on an as-needed basis, based on the quality of data returned via cable from the observatory.

9. DATA MANAGEMENT PLAN

After an initial time during which the PIs for a given instrumentation development project have priority, the data will be released to the public via a WWW-based data center. Support of this facility will require 1.0 FTE of time from scientists to oversee the program ($220K with benefits and overhead) and 1.0 FTE support for a data manager ($140K), who will be assisted by 2 graduate student assistants with 0.49 FTE appointments ($100K). During Year 1, an additional 0.5 FTE will be required to hire a specialist to set up the WWW site ($110K). $50K is budget in even years to cover participant support costs for a 3-day workshop for ~15 high school and middle school science teachers to provide background knowledge that will enable them to incorporate results from NEPHOS in their classrooms. Several of the PIs have experience organizing such workshops (see individual PI's vitae).

10. LONG-TERM VISION

The NEPHOS incremental, interdisciplinary and whole-system concept will allow a broad-base of earth scientists, oceanographers and microbiologists to look at inter-linked processes in new and revolutionary ways. Long-term multidisciplinary and interdisciplinary observatory studies will open up time and space domains that were previously inaccessible. This will facilitate the development of comprehensive carbon cycle models that relate the processes that control the generation and transport of methane on the formation scale to the local distribution and concentration of gas hydrate within the GHSZ, and link these factors to those that govern the release of methane at the seafloor and its ultimate fate within the hydrosphere.

11. BROADER IMPACTS

Implementation of NEPHOS has impacts that include outreach and education, future hydrocarbon resources, and astrobiology.

We actively participate in several formal and informal educational outreach efforts that bring our science to a variety of public communities (Cowles et al., 2004; Torres et al. 2004b). For instance, PIs in this ORION proposal have proposed a new COSEE center at OSU focused on adult learners in formal and informal settings. NEPHOS will use ORION-facilitated research to produce high-quality educational products and services and to provide opportunities for networking between oceanographic researchers and educators and will take advantage of the fact that the public is fascinated by "burning ice" to develop an engaging interface between the observatory and the public, taking advantage of the outreach infrastructure that we have developed through COSEE and independent programs.

The experimental protocols for identifying and studying life in extreme environments on Earth, such as the methanogens and methanotrophs found within offshore gas hydrate systems, are of substantial importance to astrobiological efforts, particularly given the discovery of contemporaneous methane (and proposed formaldehyde) venting on Mars, and the importance of gas hydrates to the early evolution of Titan. Much activity has also gone into quantification and characterization of offshore gas hydrates as a future hydrocarbon resource. The establishment of NEPHOS will be the first long-term systematic study of the *in situ* time-variability of such a system, encompassing the full range of physical, chemical and microbiological factors that govern its behavior.

12. Relationship to other ORION RFAs

NEPHOS has strong, well-developed synergies with elements needed for an observatory node to monitor hydrology of this Eastern Boundary Current region (proposed to ORION by J. Barth et al.) and with a node dedicated to monitor seismic and geodetic signals associated with the strain accumulation and release across the Juan de Fuca/North America plate boundary (proposed to ORION by A. Trehu).

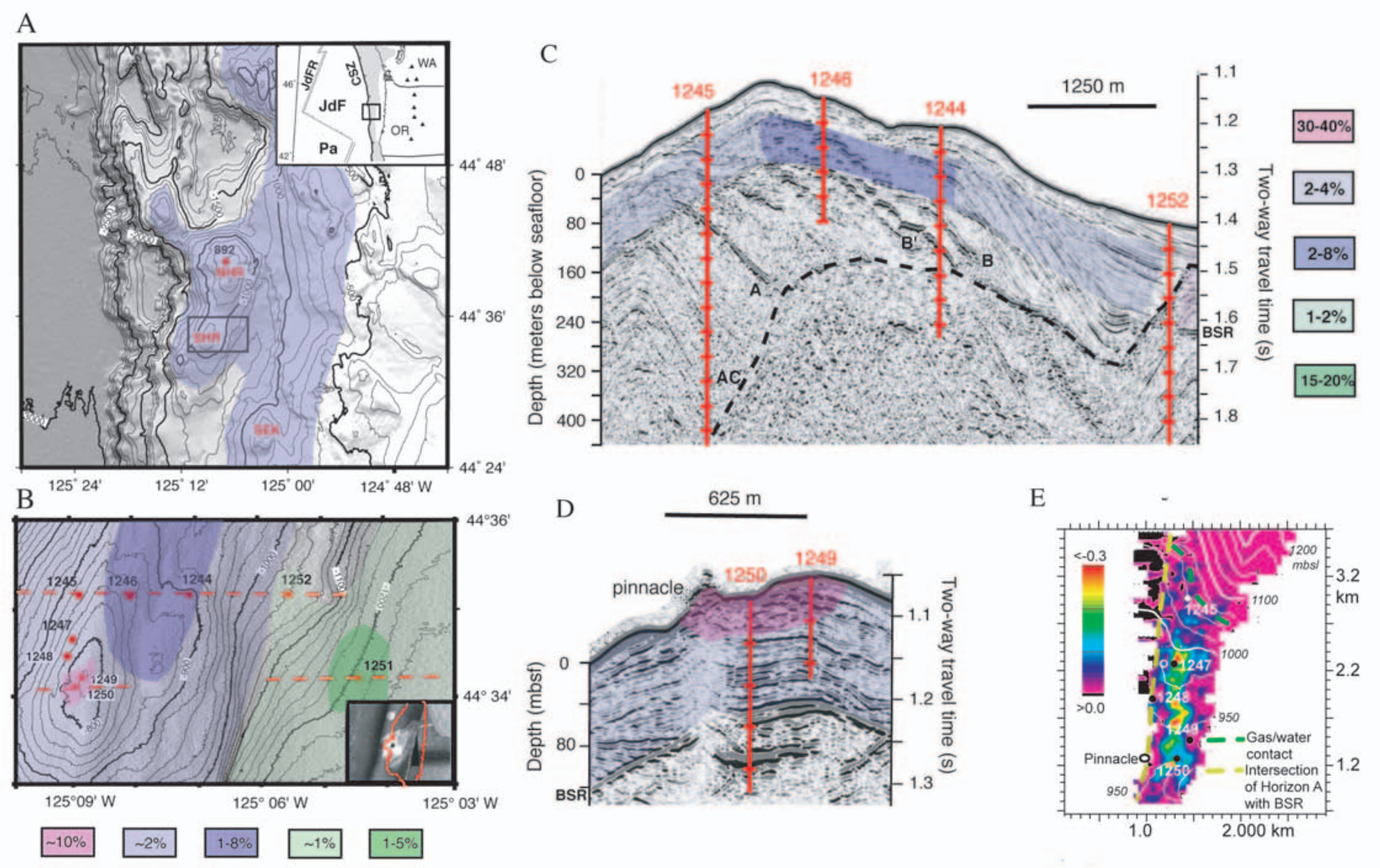


Figure 1A. Bathymetric map of the accretionary complex offshore Oregon. Contour interval is 100 m. Red dot shows the location of ODP Site 892, drilled during Leg 146. Box shows the location of Fig. 1B. Transparent violet overlay shows where a BSR is present in seismic data. Inset shows the tectonic setting of Figure 1A. Cascade volcanos are shown as triangles. SHR – South Hydrate Ridge; NHR – North Hydrate Ridge; SEK – Southeast Knoll; OR – Oregon; WA – Washington; JdF – Juan de Fuca plate; Pa – Pacific plate; JdFR – Juan de Fuca ridge; CSZ – Cascadia subduction zone. 1B. Bathymetric map of the region studied during ODP Leg 204. Contour interval is 20 m. Red dots show the location of sites drilled during Leg 204. Several holes were drilled at each site. Dashed red lines show locations of vertical slices through the 3D seismic data shown in Figure 2. Transparent color overlays show the lateral extent of zones of different gas hydrate content, estimating by averaging the data from the seafloor to the BSR. The inset shows the seafloor acoustic backscatter pattern at the summit of southern Hydrate Ridge with light colors indicating high backscatter. The 800 m depth contour is shown for reference. The dark spot in the center of the region of high backscatter is the shadow of a carbonate pinnacle. Observations made with the ROV Alvin indicate that the very strong seafloor reflectivity around the pinnacle results from carbonate pavement (possibly mixed with gas hydrate) whereas the mottled reflective pattern results from gas hydrate at or near the seafloor. 1C/D. Seismic profiles extracted from the 3D seismic data along the lines shown in 1B. Transparent overlays indicate zones of different average gas hydrate concentration estimated as discussed in the text. Although overlay colors are the same as 1B, values are larger because they represent averages over the gas hydrate occurrence zone rather than over the gas hydrate stability zone. Vertical red bars show sites drilled during Leg 204; tick marks are spaced 75 m apart. AC – top of the highly deformed sediments of the accretionary complex; B – seismic horizon B, which was found to be coarse-grained and gas hydrate-rich at Site 1246; A – seismic horizon A, interpreted as a stratigraphically-controlled zone along which methane-rich fluids migrate from the accretionary complex to the southern summit. 1E. Reflection amplitude of Horizon A. Onset of high reflectivity is interpreted to indicate onset of a free gas phase. High amplitudes near the summit correspond to regions of high gas pressure. (1A-D from Trehu et al., 2004a; 1E from Trehu et al., 2004b).

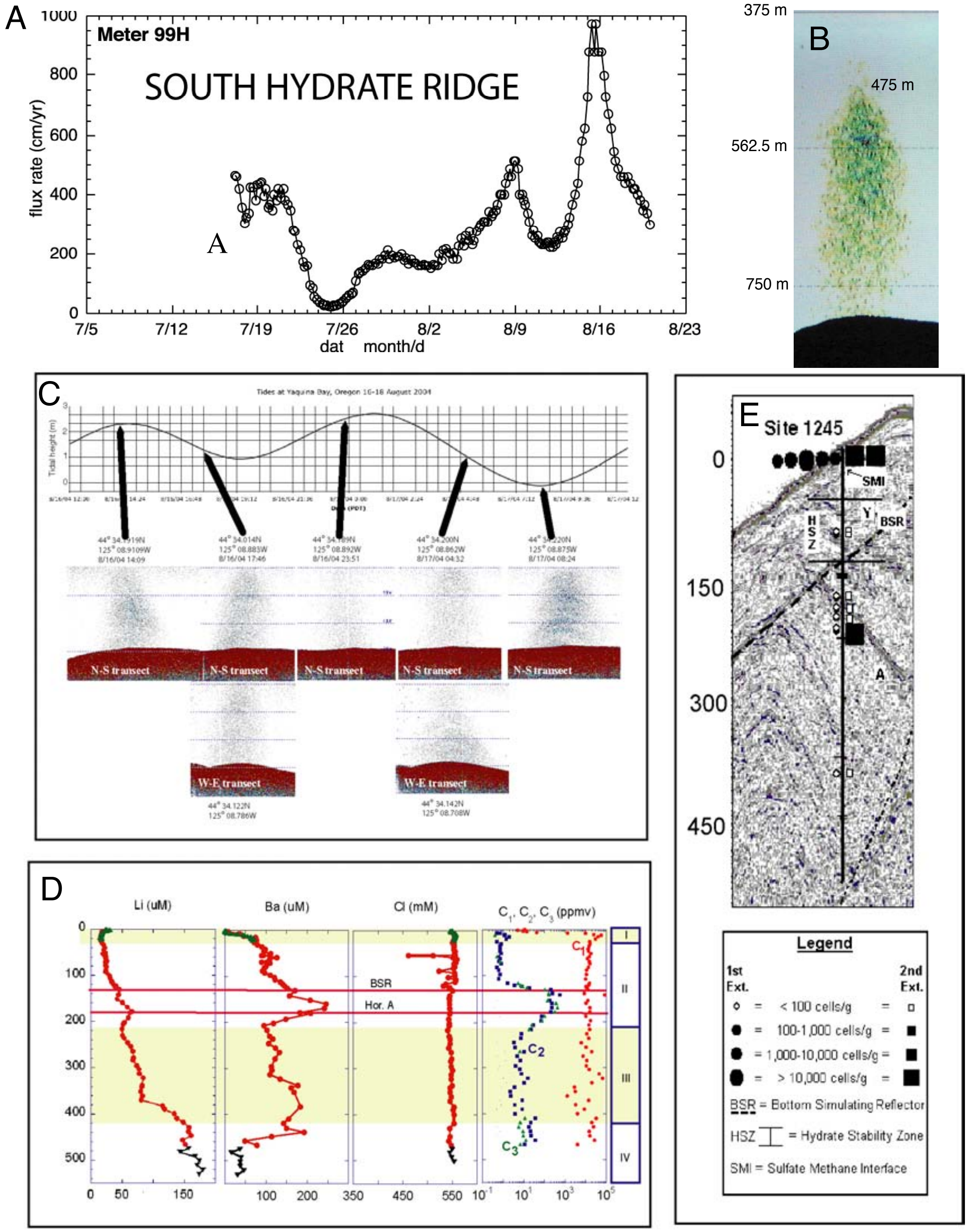


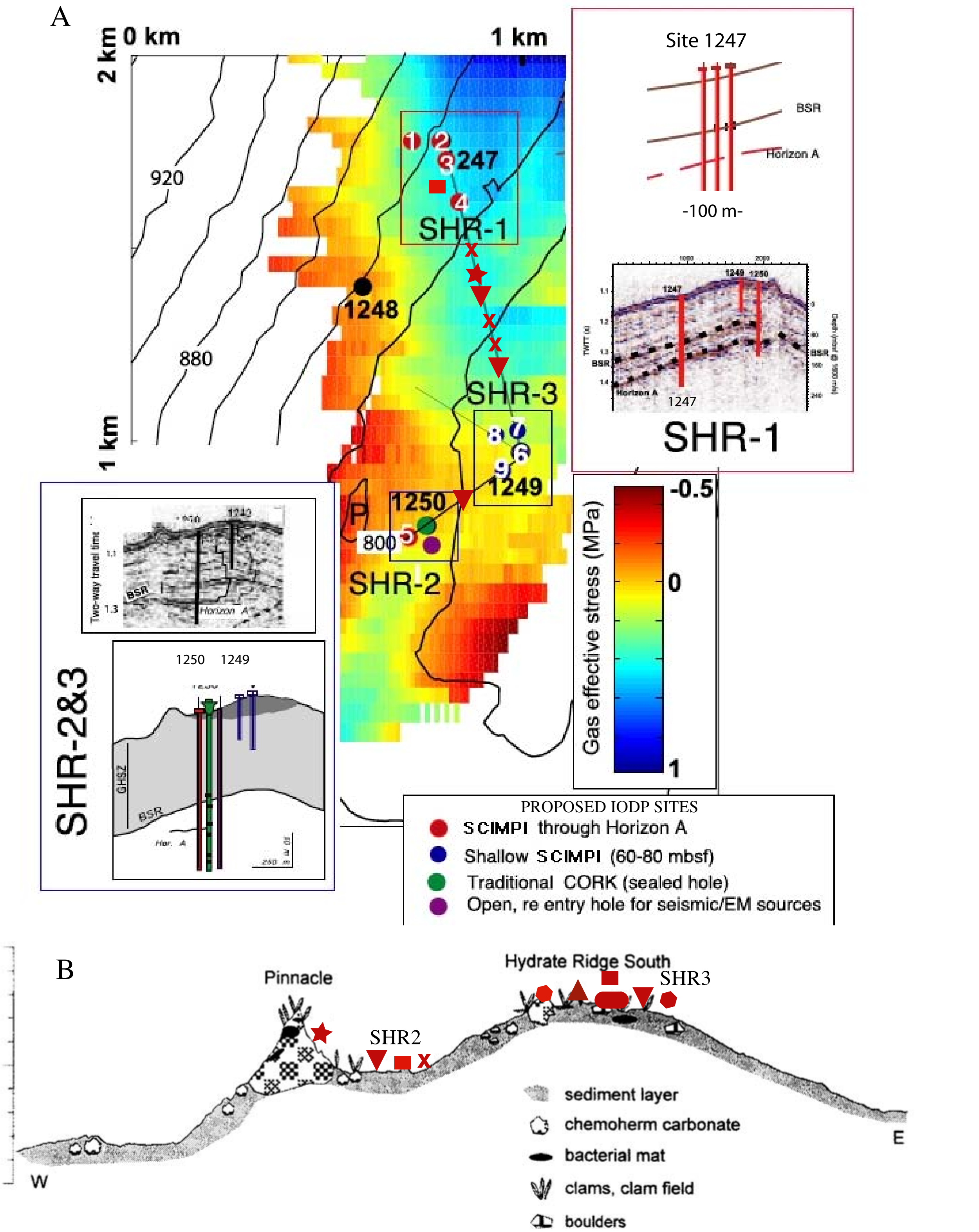
Figure 2. A. Time series of fluid flow rate out of the seafloor near the summit of SHR (from Tryon et al., 2002).

B. 12 kHz image of bubble plume observed in July, 2000, at SHR (Heeschen et al., 2003). Disappearance of plume at 475 m water depth corresponds to the top of the gas hydrate stability zone, suggesting that bubbles are armored by hydrate.

C. 12 kHz acoustic images at depths of 500-900 mbsl during a series of repeat transects across SHR on Aug. 16-17, 2004. Tidal sealevel changes are indicated by the curve at the top of the figure, referenced to Yakina Bay, OR. The width of the plume is consistantly ~200 m, as previously reported by Heeschen et al. (2003), but the intensity varies.

C. Downcore distributio nof dissolved Li,Ba, and Cl at ODP Site 1245. Different colors indicate different holes drilled at this site. Panels at the right show methane (red), ethane (blue) and propane (green) measured in headspace samples as well as a lithostratigraphic column for this site (Trehu et al. 2003).

D. Methanogen numbers present in samples acquired form ODP Leg 204 Site 1245as determined by real time QPCR directed at the methyl CoM reductase gene in DNA extracted from the samples.



OTHER INSTRUMENTATION

- ▲ Water column methane sensors and upward looking ADCP
- ⬬ Multifrequency acoustic bubble monitor
- ★ mini-CORKs
- ▼ Seafloor flow meters
- X Temperature probe
- ■ Bottom pressure recorder
- ⬢ 360 degree bottom camera

Figure 3. Schematic illustration of NEPHOS. A shows the IODP component (CORKs and SCIMPIs); B is a cross-section of the summit region constructed from a bottom camera tow (Linke and Suess, 2000). IODP instrumentation are as discussed in the IODP proposal. Additional instrumentation are not shown to scale. The greatest concentration of seafloor instrumentation is at Site SHR3, where massive hydrate occurs at the seafloor and bubbles are consistantly observed. Instruments to measure fluid flow are also located at SHR2 and along profiles linking the 3 sites.

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Table1. Sites for the SHR NEPHOS observatory. Instruments will be clustered at these 3 sites or located on profiles between sites. The whole observatory is contained within a radius of < 1 km and can therefore be considered to be a single node.

Site	Lat.	Long.	Depth (m)	Comment
SHR1	44º 34.6'N	125º 09.0'W	845	Primary target is a deep, high permeability sedimentary horizon, located below the base of gas hydrate stability here, that transports methane to the summit. Objective is to monitor and sample temporal changes in hydrology, microbiology and geochemistry and to relate changes to forcing factors such a earthquake and tides.
SHR2	44º 34.1'N	125º 09.0'W	807	Between the summit and the pinnacle. Objective is to provide power to a CORK with active fluid and microbiological sampling capabilities as well as to monitor
SHR3	44º 34.2'N	125º 08.8'W	788	Summit region where massive gas hydrate occurs at the seafloor and bubbles are streaming out of the seafloor into the ocean. Objective is to monitor transport of methane through the sediments and water column to determine mechanism and flux and to observed changes in seafloor hydrate and associated fauna; also monitor possible forcing factors. subsurface and seafloor fluid flow.

Table 2: All instruments will be deployed within 800 m of the summit of south HR and can therefore be considered as a single NEPHOS site at 44.5N and –125.17 for ORION planning purposes. This table summarizes the instruments that we are proposing for this multidisciplinary observatory. Schematic instrument layout shown in Figure 3. Additional instruments may be added as ideas develop into designs. (NA – not currently available)

Instrument	**Components**	**Development status**	**sampling rate**	**power**	**estimated cost**
SCIMPI	Phase I: temperature, pressure, resistivity to log fundamental physical properties controlling fluid flow in the subsurface	Proposal submitted to NSF to adapt CPT technology to downhole use and set up Spider web network and data logger (K. Moran and C. Paull)	1 Hz for each data stream; ~15 data streams/ SCIMPI	NA	$320K/ SCIMPI 9 SCIMPIs = $2,880K
	Phase II: geophones and/or hydrophones to detect seismic events and use for active source imaging experiments	Proposal being discussed (A. Trehu and R. Stephen)	50 Hz/ channel 6-12 chan./ SCIMPI	NA	~$50K additional/ SCIMPI x 9 = $450K
	Phase III: additional modules	No proposal yet	NA	NA	NA
CORK	pre-perforated casing for a 200 m hole; sensors for outside the casing; mechanical ROV-removable seal; bio-traps; Isosampler/DALE	Some development needed to adapt isosampler and seals for this application. Development needed for bio-traps.	NA	NA	~$1,500K (?)

mini-CORK	Sampling and temperature measurements in shallow boreholes	Proposal submitted by Torres, Schultz and Johnson	NA	NA	$500K (?)
Bottom pressure recorders	Sensor records ambient absolute pressure	Autonomous instruments exist; cable-friendly version planned. Included in several other community experiments	<10 bits/s; sample interval = 15 sec.	150 W max (probably <50W). 48VDC	$50K each 3 units proposed = $150K
Seafloor flow monitors	Measure fluid flow rate in and out of the seafloor	Design completed, including acoustic telemetry. Minimal design needed to mate to a cable	NA	NA	$20K each 6 units = $120K
Temperature probes	Measure temperature in seafloor an din shallow sediments. Proxy for fine-scale spatial variation in fluid flow.	Design is straightforward. Proposed but not initially funded.	1 s/mn/RTD ~10 MB/yr for each probe.	NA	$3K each 30 units proposed = $30K
Bottom Cameras	Panoramic views of the seafloor. Use to monitor observatory condition as well as hydrate evolution and associated fauna.	Design completed and ready for fabrication.	1 MB/image 8.7 GB/yr if an image is recorded each hour.	<1W plus intermittent draw of 100W for strobe lights	50K for 2 cameras and command/ power node (does not include engineering)
5-150kHz seafloor up-looking ACDP	Better understand the high-freq. currents coupled to estimates of the seafloor fluxes and mooring data.	Standard technology – integrate with bubble monitor or water column mooring.	NA	NA	$75K one unit at SHR3

Multifrequency acoustic bubble monitor	Quantify methane flux in bubbles by measureing bubble size distribution and rise speed.	Proposal under discussion (Trehu, Di Orio, Rona). Represents extension from single frequency instrument developed for hydrothermal vents	NA	NA	See Di Iorio, Rona et al. proposal for ballpark estimate. Detailed estimate awaits funding and completion of pilot study.
Water column mooring with methane and other sensors		Same technology proposed for NEPCM RFA. Two additional units needed for SHR.	NA	NA	$390 each/ 2 units proposed. $780K

BUDGET JUSTIFICATION:

We anticipate an initial 10 year program that should be considered for renewal for another 10-20 years. It is difficult to design a detailed year-by-year budget at this time because of uncertainties associated with IODP scheduling and funding of proposals to design, test and build some components of NEPHOS. Components that could be installed during the first year include the bottom pressure recorders, seafloor flow monitors, temperature probes, cameras, acoustic doppler current profiler and water column methane sensor ($1,200K). Phase I (and possibly Phase II) SCIMPIs could also be designed and tested in this time frame; however, we would prefer to implement the full SCIMPI suite in at 2 phases. The cost of a data center is estimate to be ~$800K in year 1 (personnel only; estimate does not include hardware and software), and is estimated to grow (by ~10%/yr) as the database grows, the number and variety of instruments increases, and the task of data integration becomes more complex. The optimal situation would be to test the design in Monterey Bay (a scenario that we anticipate for this fall when we first drafted this proposal). The mini-CORK, CORK and multifrequency acoustic bubble monitor also need to be funded, built and tested. A time-table for accomplishing this depends on many variables. The total cost of NEPHOS for 10 years, is estimated to be on the order of $14.5 million.

CUMULATIVE PROPOSAL BUDGET

FOR ORION USE ONLY

ORGANIZATION ______	PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Trehu	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets)	Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted (If Different)
1. ______	__	__	__	$______	$______
2. ______	__	__	__	______	______
3. ______	__	__	__	______	______
4. ______	__	__	__	______	______
5. ______	__	__	__	______	______
6. (___) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	__	__	__	______	______
7. (___) TOTAL SENIOR PERSONNEL (1-6)	__	__	__	______	______
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (___) POSTDOCTORAL ASSOCIATES	__	__	__	______	______
2. (___) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	__	__	__	______	______
3. (___) GRADUATE STUDENTS				______	______
4. (___) UNDERGRADUATE STUDENTS				______	______
5. (___) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				______	______
6. (___) OTHER				______	______
TOTAL SALARIES AND WAGES (A + B)				______	______
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				______	______
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				8,000,000	______
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) ______ ______ ______					
TOTAL EQUIPMENT				6,500,000	______
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				______	______
2. FOREIGN				______	______
F. PARTICIPANT SUPPORT 1. STIPENDS $ ______ 2. TRAVEL ______ 3. SUBSISTENCE ______ 4. OTHER ______					
TOTAL NUMBER OF PARTICIPANTS (_____) TOTAL PARTICIPANT COSTS				______	______
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				______	______
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				______	______
3. CONSULTANT SERVICES				______	______
4. COMPUTER SERVICES				______	______
5. SUBAWARDS				______	______
6. OTHER ______				______	______
TOTAL OTHER DIRECT COSTS				______	______
H. TOTAL DIRECT COSTS (A THROUGH G)				______	______
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) ______ ______					
TOTAL INDIRECT COSTS (F&A)				______	______
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				______	______
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				______	______
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$14,500,000	$______

M. COST SHARING: PROPOSED LEVEL $______	AGREED LEVEL IF DIFFERENT: $______			
PI/PD TYPED NAME AND SIGNATURE*	DATE	FOR ORION USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* ______	DATE ______	Date Checked	Date of Rate Sheet	Initials-ORG

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)