Project Number: 900502

Project Start: Jan 1, 2005 **Project Duration (in years): 2**

Please indicate what type of project is being proposed (mark all that apply).

Feasibility/Scoping	Development	Research	Infrastructure	Education
[ ]	[X]	[ ]	[ ]	[ ]

Project Manager/PI: Ken Smith

Project Title: An autonomous bottom-transecting instrument platform

1) ABSTRACT (new and continuing projects)

Coupling between a pelagically-derived food supply and sediment community utilization of organic matter is critical to an understanding of biogeochemical cycling in the ocean. To resolve the coupling between pelagic and benthic systems, it is important to monitor the arrival and residence of organic matter on the sea floor using instrumentation capable of making measurements with appropriate spatial and temporal resolution. It is also imperative to measure the structural heterogeneity such as burrows in the surface sediments to interpret spatial and temporal variability of fluxes across the sediment-water interface. Critical questions which must be addressed to ultimately resolve pelagic-benthic coupling in the context of biogeochemical cycling are: 1) what is the quality and quantity of phytodetritus reaching the sea floor, 2) how important is irrigation (non-diffusive transport) in measuring mineralization in sediments and 3) what responses are elicited in the sediment community by the arrival of fresh detritus on the sea floor?

To address such critical questions, we began development of a new autonomous bottom-transecting instrument, ROVER II, to make long time-series estimates of fresh phytodetritus arriving on the sea floor. Under NSF funding, we have been designing ROVER II to concurrently monitor the structural features of the sediment that influence spatial and temporal heterogeneity in sediment community activity, which ultimately affects the signal to noise ratio and resolution of measurements on biogeochemical processes in the sediments. ROVER II will be capable of conducting non-invasive time-series measurements of phytopigment fluorescence as an indicator of fresh phytodetritus on the sediment surface, while imaging the same sediments acoustically to provide 3-dimensional profiles of structural features (e.g. burrows and animals). Sediment community metabolism measurements (e.g. sediment community oxygen consumption) coupled with 2-dimensional oxygen imaging studies, will be conducted on the same sediments along transects including up to 50 sites without docking, recharging and data download.

Development of ROVER II has been stalled due to unforeseen personnel problems. This development is critical to another project I have jointly with Jim Barry in designing an acoustic link between ROVER II and the MARS network. I am requesting engineering time at MBARI to provide cross-fertilization between our current ailing engineer at SIO and a counterpart at MBARI so that the ROVER II development can proceed. Development costs in 2005 will be provided through NSF funding.

2) PROPOSAL

a) The problem addressed (new projects only)

Statement of the problem

Critical research questions, which have to be addressed to ultimately resolve pelagic-benthic coupling in the context of biogeochemical cycling in the deep sea are:

1) What is the quality and quantity of phytodetritus reaching the sea floor?
2) How important is irrigation (non-diffusive transport) in measuring mineralization in sediments?

3) What responses are elicited in the sediment community by the arrival of fresh detritus on the sea floor?

To address these critical questions, we propose to develop a new autonomous instrument (ROVER II) to measure fresh phytodetritus arriving on the sea floor while concurrently monitoring the structural features of the sediment. ROVER II will be capable of conducting non-invasive time-series measurements of phytopigment fluorescence on the sediment surface as an indicator of fresh phytodetritus, while concurrently imaging the same sediments acoustically to provide 3-dimensional profiles of structural features (e.g., burrows and animals). SCOC measurements will be conducted on the same undisturbed sediments. We propose to develop ROVER II for long-term deployments at the MARS site.

Why it is important

Long time-series monitoring of upper ocean processes associated with the production and cycling of organic matter is currently being conducted using technologies ranging from remote sampling by satellites and moored instruments (continuous sampling) to temporally intense but discontinuous sampling from surface ships (e.g., Karl and Michaels, 1996; Siegel *et al*., 2001; Smith *et al.*, 2002). However, technological and logistical constraints have limited similar long-term studies of carbon cycling in the deeper water column and sediments from shelf to abyssal depths (e.g. Biscaye *et al*., 1994; Smith *et al*., 1994; Sayles *et al*., 1994; Smith *et al*., 2001). With increasing depth and distance from the primary site of organic matter production in the euphotic zone, there is increased difficulty in resolving biogeochemical cycles, which extend throughout the entire water column and underlying sediments (e.g. Druffel *et al*., 1996). In the deep ocean, the signal to noise ratio in biogeochemical measurements are routinely low due to spatial and temporal heterogeneity, requiring long time-series monitoring for detection (e.g. Deuser, 1986; Smith *et al*., 1994; Smith *et al*., 2002).

The quantity of particulate organic matter (POM) reaching the sea floor is routinely estimated from time-series collections of sinking particles in sediment traps moored tens to hundreds of meters above the sea floor (e.g. Deuser *et al*., 1981; Honjo, 1982; Haake *et al*., 1993; Smith *et al.*, 1994*;* Deuser *et al*., 1995). However, recent studies show that sediment traps undersample the large particles in the water column (e.g. Asper *et al*., 1992; Baldwin *et al.*, 1998*;* Lampitt *et al.*, 2001). Arrival of organic matter as seasonal pulses of large detrital aggregates on the sea floor has been monitored with time-lapse cameras (e.g. Lampitt, 1985; Rice *et al*., 1986; Smith *et al*., 1993; Smith *et al*., 1994; Bett *et al.*, 2001). The response of the community to such enrichments from the surface has been inferred from analyzing sediment samples taken via remote coring from a surface ship (Lochte and Turley, 1988; Thiel *et* al., 1989; Graf, 1989; Gooday and Turley, 1990; Pfannkuche and Lochte, 1993; C. Smith *et al*., 1996; Boetius *et al.*, 2000) or autonomous vehicles (Smith *et al.*, 1994; Witbaard *et al*., 2000; Witte and Phankuche, 2000; Smith *et al.*, 2002). However, continuous monitoring of the sediment community has not been possible, preventing achievement of the resolution necessary to examine the coupling between the input of pelagically-derived food and its utilization by benthic consumer groups. Now, for the first time, measurements of one index of sediment community activity, sediment community oxygen consumption (SCOC), has been made continuously with an autonomous, bottom-transecting vehicle (ROVER) developed in our laboratory (Smith *et al*., 1997).

ROVER continuously measured SCOC for four months at a long time-series abyssal station off California. ROVER was programmed to move along the bottom for a selected distance, make SCOC measurements on an enclosed portion of the sediments for a selected period of time, and then move to a new undisturbed site for the next measurement. These continuous measurements of SCOC combined with concurrent POM flux measurements in the water column provided valuable insights into temporal relationships between water column and benthic processes (Smith *et al*., 1997; Smith *et al*., 2001). However, to resolve the processes involved in pelagic-benthic coupling it is essential to measure the arrival of organic matter directly at the sediment surface and concurrently measure the response of the benthic community. Sequential measurements of these parameters at a series of sites in close proximity (20 m apart) will allow us to examine the temporal relationship between the arrival of POM and the response of the sediment community.

Once POM reaches the sea floor, it is either metabolized at the sediment surface or some fraction is conveyed into the sediments through bioturbation. Such post-depositional processes are poorly understood from shelf to abyssal depths but are critical in interpreting biogeochemical processes in sediments (e.g. Sayles and Martin, 1995; Levin *et al*., 1997). Responses by sediment bacteria, protozoans and meiofauna to pulsed inputs of phytodetritus are reported in the deep sea (Gooday and Turley, 1990; Pfannkuche. 1993; Moodley *et al*., 2002; Smith *et al.*, 2002). Concentrations of phytopigments associated with fresh detritus in surface sediments of cores from shelf to abyssal depths are highly correlated with SCOC measurements (Pfannkuche and Thiel, 1987). Subsurface concentrations of recently deposited particles are related to burrowing infauna (J. Smith and Schafer, 1984; C. Smith *et al*., 1986; Jumars *et al*., 1990). Rapid subduction of chlorophyll-containing detritus by burrowing infauna has been demonstrated in core samples (Graf, 1989) and *in situ* tracer experiments (Levin *et al*., 1997; 1999). The age of sedimented particles, inferred from naturally occurring radiotracers, suggests rapid vertical mixing of recent material by infauna at bathyal depths (C. Smith *et al*., 1993) and rapid ingestion by mobile epibenthic megafauna at abyssal depths (Lauerman *et al*., 1997). Burrow structures are also sites of enhanced biological activity compared to the surrounding sediment (Aller and Aller, 1986; Aller, 2001).

Burrowing infauna also may influence the transport of solutes across the sediment-water interface through irrigation, a non-diffusional process (e.g. Sayles and Martin, 1995; Aller, 2001). Irrigation can be responsible for a major fraction of nutrient fluxes in shelf and slope sediments when compared to diffusion (Archer and Devol, 1992; Devol and Christensen, 1993). However, at greater slope and abyssal depths, the importance of irrigation compared to diffusion is not apparent (Archer and Devol, 1992; Sayles and Martin, 1995). Physical ventilation of persistent burrow structures can also contribute to non-diffusive exchanges (Aller and DeMaster, 1984; Ray and Aller, 1985; Aller, 2001). Structural heterogeneity affecting fluxes in sediments must be considered when evaluating spatial and temporal variability in sediment processes.

Present state of art/understanding

See above

How it relates/contributes to MBARI's mission and strategic plan

Development of ROVER II and coupling to the MARS network will permit long-time series measurements of critical benthic processes within the Monterey Bay system to understand the coupling of pelagic and benthic communities on meaningful time scales of hours to years.

b) Approach to the problem (new and continuing projects)

Status of project

We proposed to develop a new autonomous bottom-transecting instrument to make long time-series measurements of fresh phytodetritus arriving on the sea floor while concurrently monitoring structural features in the sediment that influence spatial and temporal heterogeneity in sediment community activity, ultimately affecting the signal to noise ratio and resolution of measurements on biogeochemical processes in the sediments. This NSF grant (OCE 97-32353) was partially funded for three years in 1998 to only develop an *in situ* scanning system to measure the fluorescence of the surface sediments and non-invasively image the same sediments acoustically to provide 3-dimensional profiles of structural features (burrows and animals). Our purpose was to provide proof of concept for this scanning system both in the lab and benthic environments to abyssal depths with no provision to build a second-generation bottom-transecting instrument in the budget. We developed an optical and acoustic scanning system to monitor non-invasively the surface sediments for fluorescing deposits on the surface and structural features to 10 cm depth below the sediment surface. This system was mounted on a test platform to provide short term, one site scanning capabilities to abyssal depths. The scanning system functioned well from bathyal to abyssal depths, including one deployment at Sta. M (4,100m depth). The description of the scanning system and initial results are presently being prepared for publication.

We proposed to continue this development to make long time-series measurements across the sea floor using a new generation bottom-transecting vehicle (ROVER II). Additional NSF funding was granted in 2002 to continue this development (OCE 02-42472). Development of ROVER II has been stalled due to unforeseen personnel problems. I am requesting engineering time at MBARI to provide cross-fertilization between our current ailing engineer at SIO and a counterpart at MBARI so that the ROVER II development can proceed.

Answers to questions raised by MT after submission of abstract:

1. Existing NSF funds can be used to help defray MBARI engineering costs.
2. We will work with engineering management to identify appropriate engineering collaboration.
3. When complete, the Rover II system would require no further engineering commitment from MBARI. The system would be operated by Science and/or DMO.

Results to date

We developed an optical and acoustic scanning system to monitor non-invasively the surface sediments for fluorescing deposits on the surface and structural features to 10 cm depth below the sediment surface. This system was mounted on a test platform to provide short term, one site scanning capabilities to abyssal depths. The scanning system functioned well from bathyal to abyssal depths, including one deployment at Sta. M (4,100m depth). The description of the scanning system and initial results are presently being prepared for publication.

Publications (resulting from original Rover and the new prototype scanner)

Smith, K.L., Jr., R.C. Glatts, R.J. Baldwin, A.H. Uhlman, R.C. Horn, C.E. Reimers and S.E. Beaulieu (1997) An autonomous bottom-transecting vehicle for making long time-series measurements of sediment community oxygen consumption to abyssal depths. Limnol. Oceanogr. 42: 1601-1612.

Smith, K.L., Jr., R.C. Glatts, F. Uhlman, A. Tengberg, R.J. Baldwin, R.N. Glud, P.O.J. Hall, G. Holst and B. Grunwald. High resolution acoustic and optic measurements of deep-sea sediments : *in situ* monitoring to 4100 m depth. Deep-Sea Res. (in prep).

Smith, K.L. Jr. and R.S. Kaufmann (1999) Long-term discrepancy between food supply and demand in the deep Eastern North Pacific. Science 284: 1174-1177.

Smith, K.L., Jr., R.S. Kaufmann, R.J. Baldwin and A.F. Carlucci (2001) Pelagic-benthic coupling in the abyssal eastern North Pacific: an eight-year time-series study of food supply and demand. Limnol. Oceanogr. 46: 543-556.

Plans for 2005

The majority of the Rover development will take place at Scripps using NSF funding. Technology development will involve information transfer from Scripps to MBARI.

INSTRUMENT DEVELOPMENT (Optical/acoustic imaging system w/ benthic chambers/planar optode)

We have designed and propose to build a bottom-transecting vehicle, an extensive modification of the original ROVER, with the following capabilities (proposed modifications shown with asterisks):

1. Operates on the sea floor as an autonomous free vehicle to depths of 6,000 m for periods up to 7 months without battery recharging.
2. Transits across the sea floor, minimizing the impact that a long-term free vehicle structure would have on each measurement site (~50) within a specific study area over a single deployment period.
3. Measures fluorescence of fresh phytodetritus on sediment surface using an optical scanning system to map distribution and quantity of phytopigments at each site.
4. Provides a 3-dimensional image of the top 10 cm of sediment using a high frequency acoustic scanner to map distribution, size and abundance of structures (e.g. burrows) and animals at each site.

5. Measures SCOC for a programmable duration using duplicate benthic chambers at each site.
6. Provides 2-dimensional sediment pore water oxygen concentrations to a depth of 5 cm as an independent measure of SCOC, using duplicate planar optodes at each site.
7. Monitors operation of instruments and the surrounding area with time-lapse still and video cameras.
8. Has flexibility to be used as an autonomous, programmable platform for a wide variety of measurements.
9. Provides real-time communication capability for recharging, data transmission, and programming changes through mateable port for underwater link to cabled observatories.

A. Description of instrumentation

The original ROVER resembled a small forklift (2.7 m long X 2.0 m wide X 2.2 m high) with a forward-mounted instrument assembly, current meter, double-tread propulsion system, central battery and controller electronics, flotation, acoustic releases and disposable ballast (Table 1; Fig. 1a). This instrument was developed with NSF funding (OCE91-15393) and underwent 3 successful deployments at 4,100m depth in the NE Pacific, including a 4-month deployment from January to May 1996 (Smith *et al*., 1997). On a subsequent 6-month deployment in the central N. Pacific at 4,800 m this instrument mysteriously disappeared.

We propose to develop a similar platform, ROVER II, with major modifications in the instrument assembly and payload configuration to accommodate an optical-acoustic imaging system we have just developed with NSF funding (OCE97-32353). This new scanning system and proposed *in situ* docking capability will require modification of the central controller package. A description of the original components of ROVER and the proposed modifications for ROVER II are given in Table 1.

1. Optical-acoustic imaging system

The optical-acoustic imaging system is composed of two separate and independent imaging units. Each unit has a two-axis scanning arm (Fig. 1d) and both share a low-power micro-controller, the “imaging controller.” The units are mounted below the front bumper on the port and starboard sides of ROVER II (Fig 1b, d) with each monitored by a separate video camera (Fig. 1c). Each scanning arm will move horizontally in two axes along titanium tracks using stepper-motor-driven, millimeter-pitch lead-screws. The scanning arm will be capable of moving the sensor to any position within a hypothetical box 60 cm long (X) by 35 cm wide (Y) (Fig. 1c). In the prototype instrument, the acoustic and optical sensors were mounted with a vertical Z-axis drive that maintained a constant elevation above the sediment using acoustic data. The variable elevation scheme was found to be unreliable and unnecessary in test deployments so the proposed instrument will be developed with a fixed sensor elevation of 10 cm. Modifications will be made to both the acoustic and optical sensors to make them relatively elevation insensitive. Each component of the imaging system is described in detail in Table 2.

The scanning arm will be moved incrementally along the X-axis while scanning back-and-forth along the Y-axis. The speed of the scanning arm and the scanning intervals will be controlled by a programmable routine in the imaging system controller. The scanning arms on the two identical imaging systems will be separated > 60 cm to avoid optical or acoustic interference between the two units. After imaging each rectangular area (~ 2 h), the scanning arm will return to the starting point which places the scanner arms clear of the benthic chamber/optode assembly (Fig. 1b).

The imaging controller will be housed with the central controller and connected to the scanning motors and sensors with underwater cabling. Communication with the central controller will be via RS-485 connector and data stored on the scanner controller disk drive will be offloaded via Ethernet. Power for the imaging system will come from the ROVER II main battery system via the central controller.

a. *Optical imaging system:* The optical properties of POM arriving at the sea floor, including absorption and fluorescence, are useful measurements for assessing the presence of fresh detrital material containing chlorophyll (Chl) and accessory pigments (Yentsch and Yentsch, 1979; Mitchell and Kiefer, 1988). Of these two properties, measurements of fluorescence are 5 to 10 times more sensitive than spectrophotometric measurements of absorption (Parsons *et al.*, 1984). An additional advantage to the use of the fluorometric method is that phytoplankton populations can be characterized by the use of excitation and emission spectra specific to Chl in algae and phycoerythrin (PE) in cyanobacteria, with a negligible overlap in wavelength (Yentsch and Yentsch, 1979). With the exception of PE most of the accessory pigments do not exhibit *in vivo* fluorescence (Desiderio *et al*., 1997).

We developed an *in situ* fluorometer system to scan the sediment surface. This system will scan two adjacent fields in front of ROVER II at each site (Fig. 1b). This fluorometer consists of a fiber optic lens assembly positioned vertically on the scanning arm. At every 1 cm of scanning-arm travel along the X and Y axes, the imaging system sequentially excites a 1.4 cm diameter area of the sediment directly below with light

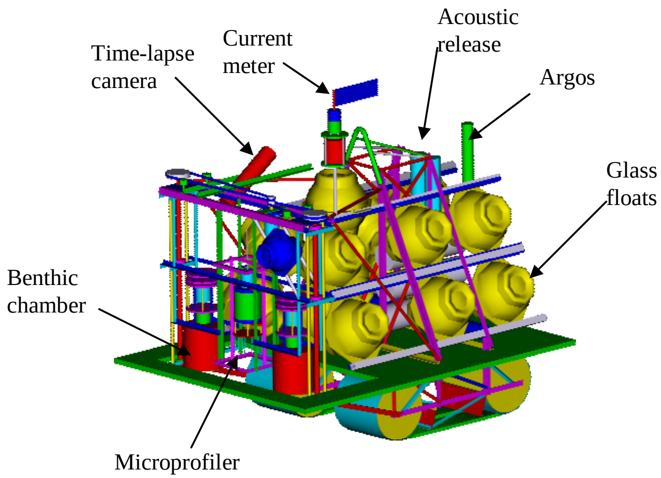

Fig. 1a. Original Rover with Instrument Rack Up

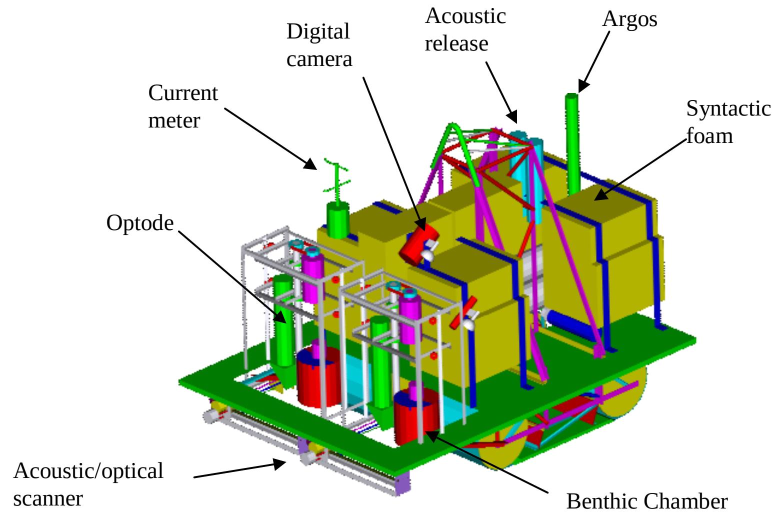

Fig. 1b. Proposed ROVER II with rack for BCPO in raised position.

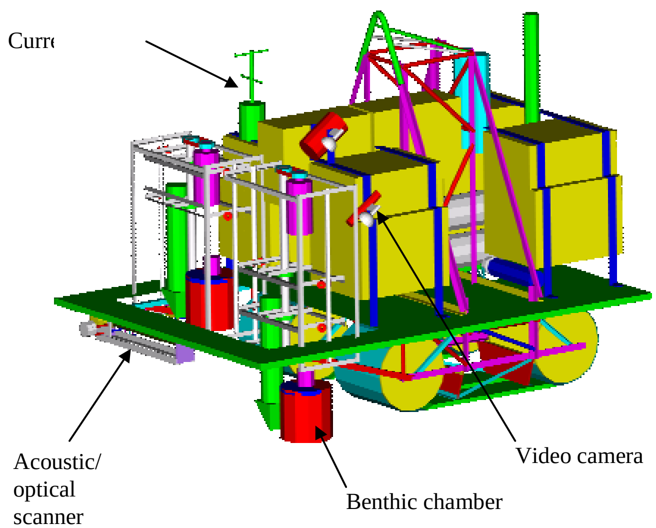

Fig. 1c. Proposed ROVER with port BCPO in lowered position.
(Port scanner removed for clarity)

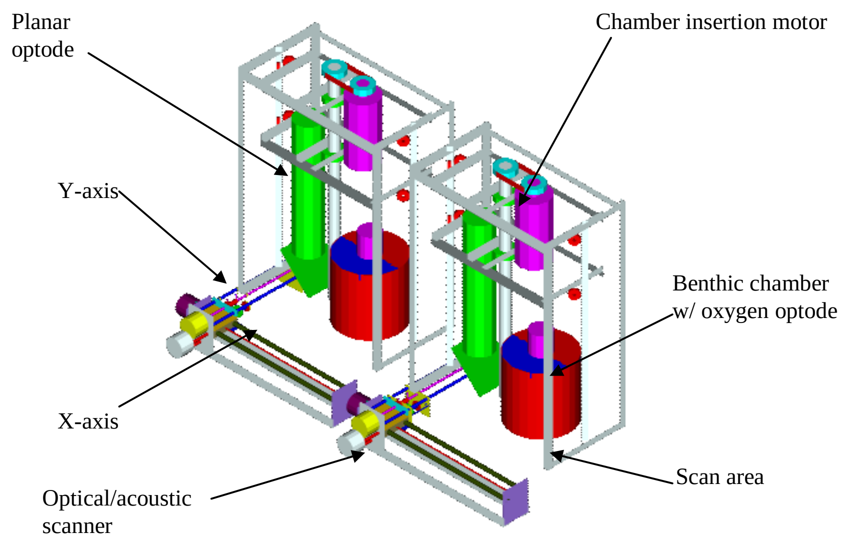

Fig. 1d. Scanner amd Benthic Chamber/Planar Optode (BCPO)

Table 1. Description of free-vehicle ROVER components

ORIGINAL ROVER COMPONENTS	ROVER II COMPONENTS
A. Structural frame: Constructed of titanium, reinforced epoxy and fiberglass with a polypropylene bumper.	Same
B. Instrument Assembly	
1. Instrument rack frame: Instrument rack raised and lowered w/ twin lead-screws driven by a DC motor.	Two independent racks for benthic chamber/planar optode systems.
2. Benthic chambers (2): Two transparent acrylic cylinders internally lined w/ polyvinylidene chloride (very low O_2 permeability = 0.6 ml/mil/100 in^2/d/20psi). Dimensions = 30.5 cm I.D. x 20 cm height w/ 6 cm penetration into sediment. Leading edge of teflon.	Same, except incorporated into benthic chamber/planar optode system.
a. stirring paddle: Crossed PVC bars driven by radial magnetic coupling to stepper motor with speed control from 1-10 rpm. Diffusive boundary layer 0.5 - 1.0 mm thick and uniform over bottom of chamber w/ paddle speed @ 9 rpm	Same
b. purge valve: Valve assembly operated by motorized lead-screw.	Same
c. polarographic oxygen sensor: Clark-type electrode w/ internal Ag/AgCl reference wire and platinum cathode (glass coated Pt wire).	Optical oxygen sensor (Aanderaa 3830 oxygen optode).
3. Oxygen microprofiler: 12 Micro-Clark-type sensors w/ internal Ag/AgCl reference wires and guard cathodes.	Replaced by planar optode system.
4. Resistivity sensors (4): Detect sediment-water interface and provide feedback to microprofiler controller electronics.	Replaced by footpad with Hall-Effect sensor.
5. Cleaning pump: Centrifugal pump and motor w/ output flow around two benthic chambers to remove adhering sediment. Activated by central controller when instrument rack is in raised position.	Same.
6. Video cameras (2): Micro-Sea Cam 2000 (Deep Sea Power and Light) w/ wide-angle ports to monitor benthic chambers and microprofiler. Each camera field illuminated by a 50 W floodlight.	Same except video stored in digital format on PC-104 micro-controller with frame grabber
7. Time-lapse camera/strobe: Benthos 372 (800 exposure) w/ 100 W-s strobe. Takes photographs at programmable intervals.	Digital camera with 30 Gbyte disk drive storage w/ RS-485 link to central controller.
C. Current Meter: Savonious rotor with vane mounted on pivoting arm.	Falmouth Scientific 2D ACM
D. Propulsion System	
1. Treads: Two fiber-reinforced PVC treads (50 cm wide) w/ external cleats to ensure traction in any sediment type and internal cleats that inter-digitate with slots in the fore and aft rollers. Treads supported between rollers by low-friction, load-bearing pressure plate.	Same
2. Motors (2): Each forward roller linked by cog belts to 1/8 HP DC motor with reduction gear in oil-compensated housings. Independent motor drives regulated by central controller.	Same

E. Central Battery and Controller w/Data Storage	
1. Batteries: Alkaline D-Cell battery packs (12 V) housed in pressure cylinders. Total capacity: 400 Ah.	Lithium D-Cell battery packs (14 V). Total capacity: 1100 Ah.
2. Central controller and data storage: Tattletale Model 7 micro-controller with real-time clock and 12-bit A/D converter to digitize sensor outputs. Data storage on 64 Mbyte IDE disk drive.	Persistor CF2 micro-controller with 512 Mbyte CompactFlash data storage.
3. Inclinometer: Dual-axis inclinometer	Current meter has inclinometer.
4. Odometer: Wheel secured on a suspension bracket with swivel and mounted between the treads in contact with sediment surface.	Use 2D ACM current meter for speed, distance measurement during transits
5. Compass: Mounted on central controller chassis	Current meter has electro/mag. Compass
6. Transponder: Acoustic transponder mounted above ROVER	Status reporting through MORS AR-6X1 acoustic release.
F. Flotation Package: Benthos glass spheres	Syntactic foam blocks.
G. Acoustic Release and Disposable Ballast	
1. Acoustic releases (2): Benthos 865A acoustic releases	MORS RT-6X1 and AR-6X1 acoustic releases
2. Back-up release: Independent programmable timer and burnwire.	Same
3. Disposable ballast: Cylinder of available scrap metal.	Same
H. Transmitter for satellite tracking: Mounted on top of ROVER for tracking via ARGOS satellite facility.	Same
I. Water sampler: Niskin bottle (5 liter) mounted vertically	Same

of a discrete wavelength of 450 nm for Chl and PE. The 1.4 cm diameter was chosen to provide overlapping images to cover the entire 60 cm by 35 cm field. Simultaneously with the excitation of phytopigments on the sediment surface, the imaging system monitors any emitted fluorescence using a photo-multiplier tube (PMT), which is essential with the expected low concentrations of phytopigments (B.G. Mitchell, pers. com.) at times of low POM fluxes (e.g. winter). The PMT (Hamamatsu H7155-01) is placed in series with a motorized filter wheel containing filters centered at 590 and 685 nm where peak fluorescence from PE and Chl occur *in vivo* (Cowles *et al*., 1993). The output of the PMT is digitized and stored in memory. Laboratory analysis of stored data will allow the construction of a false-color mosaic of each site for Chl and PE intensity and will be compared to video and still camera images of the same area of sea floor.

A scan of fluorometer data from a deployment at Station M (4100 m) is shown in Fig. 2. Due to problems with the Z-axis mechanism, only one and a half optical scans were taken. The data shows negligible Chl in Oct 2001, but there is some evidence of PE fluorescence. Review of the video mounted to the scanner showed that much of the surface detritus was washed away by a bow wave created by the lander platform. This could account for some of the lack of fluorescent activity. Photographs and video of the lander operation can be viewed at the Smith Laboratory web site (http://smithlab.ucsd.edu/scanner/). The ability of ROVER II to land and move away from the landing site eliminates the bow-wave problem associated with the lander.

An improved fluorometer design developed for a concurrent project will improve sensitivity for PE fluorescence detection and eliminate the need for a constant sensor elevation. The new instrument (Table 2; (http://www.olympusmicro.com/primer/techniques/fluorescence/filters.html) will be based upon a design used in fluorescence microscopes that employ dichroic beamsplitters to separate the outgoing excitation light from the incoming fluorescent emission. The excitation light will be derived from a bank of blue (450 nm) light emitting diodes (LED) and directed out of the fluorometer by a 45° dichroic beamsplitter through a transparent pressure window. The emission light from the sediment directed by an additional dichroic beamsplitter to PMT modules optimized for red or green light. During development, it was discovered that the red-enhanced PMT necessary to detect Chl fluorescence has a noise level five times that of a standard PMT that can detect PE fluorescence. The new design will use two separate PMT modules to eliminate this design flaw. The new fluorometer should also reduce the losses involved in coupling light to fiber optic cables with high-pressure underwater connectors and allow more LED's to be used for excitation. Together, these modifications are expected to increase PE detection sensitivity by a factor of ten and Chl sensitivity by a factor of two.

Time-series measurements of changes in quantity and composition of phytopigments will serve as a proxy for fresh phytodetritus arriving at the sea floor to address **research question 1** (see above). Fresh phytodetritus has been observed on deep-sea sediments in the NE Pacific at 4100 m depth (Sta. M; Lauerman and Kaufmann, 1998). This material included dividing cyanobacteria, autotrophs of all sizes exhibiting the characteristic red fluorescence of Chl and intact diatoms with protoplasm (Beaulieu and Smith, 1998). We expect there will be variability in the total amount of light fluoresced from different algae due to optical effects associated with the composition of the cell wall (Lorenzen, 1966) and because of differences in the physiological state of the algae (Mitchell and Kiefer, 1988). We also expect that detrital material will be high in phaeopigments but these pigments fluoresce very weakly *in vivo* (Yentsch, 1994).

To address the problem of optical sensor drift over long-term deployments, we will employ a solid standard manufactured by Turner Designs (http://www.turnerdesigns.com/t2/instruments/accessories/998_0056.html). The encapsulated standard will be mounted at the scanner starting point and a fluorescence measurement will be taken at the beginning of each scan. Any drift from window fouling should be apparent from this measurement. The solid standard remains stable for >2 years.

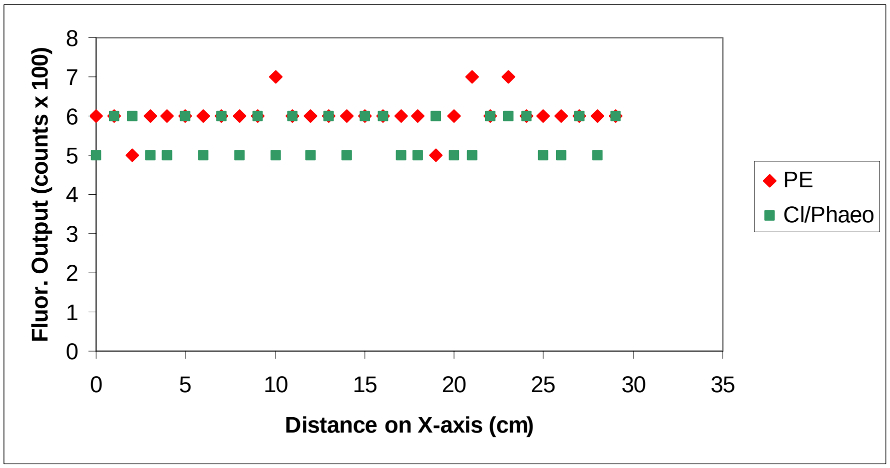

Fig. 2a. Single scan of fluorometer data from 4100 m depth. The scanner arm moves one cm per fluorometer reading.

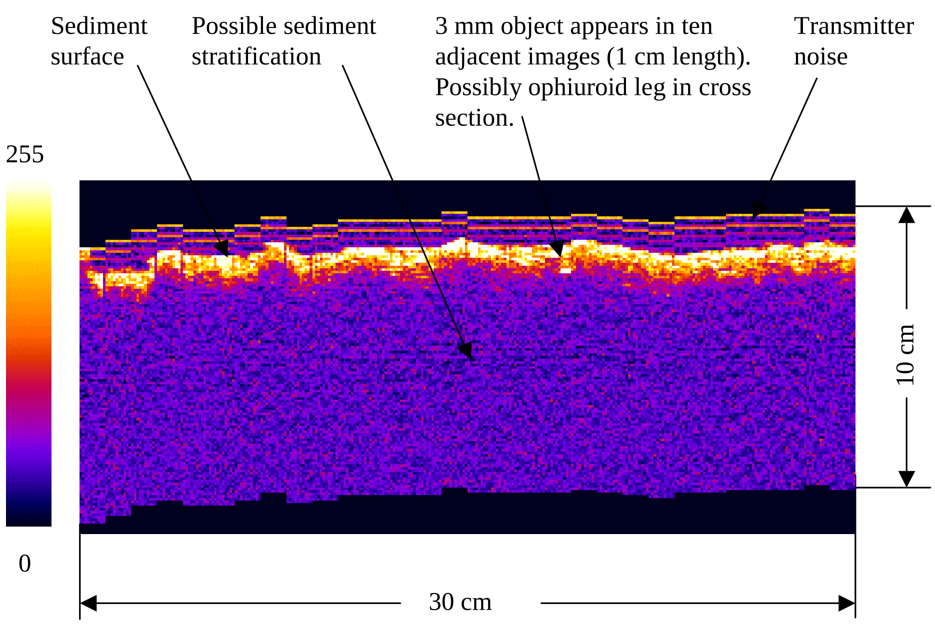

Fig. 2b. Acoustic Scanner deployment image from 4100 m depth.

Table 2. Rover II Instrument Descriptions
Optical-Acoustic Imaging System Components

Imaging system controller	PC-104 micro-controller with 30 Gbyte disk drive. Linked to central controller via RS-485. Data offload via Ethernet. Located in same pressure housing as Rover central controller.
Scanning arm system	X-Y transport mechanism to move the fluorometer and transducer assembly across survey area. Fluorometer and transducer designed to be elevation insensitive. Horizontal positioning determined by ceramic magnets and Hall-Effect sensors.
Optical excitation source	Bank of 16 blue light emitting diodes (LED) with emission wavelength of 450 nm activated by imaging system controller.
Excitation dichroic beamsplitter	Directs excitation light downward toward sediment. Beamsplitter (Omega Optical 485DRLP) also filters excitation light with cutoff shorter than emission wavelength.
Emission dichroic beamsplitter	Beamsplitter (Omega Optical 630DRLP) separates emission light into green and red components. Green light (590 nm) directed toward standard photomultiplier. Red light (685 nm) directed toward red-enhanced photomultiplier.
Photo-multiplier tube	Ruggedized, self-contained modules that convert individual photons into logic pulses. Standard version (Hamamatsu H7155) cannot detect red light (685 nm), but red-enhanced version (Hamamatsu H7155-01) has higher noise level at green light wavelength (590 nm).
Collimating lens and iris	Focuses excitation light into collimated beam 1.4 cm in diameter. Iris restricts view of emission photomultipliers to same area as excitation light. Combination of lens and iris makes the fluorometer less sensitive to elevation changes.
Pressure window	Glass window (3 cm thick) allows excitation and emission light to pass in and out of the fluorometer housing. Window faces downward toward sediment at an elevation of 10 cm. Window cleaned at beginning of scan by stationary brush.
Acoustic Transmitter	Generates 300 Volt, broadband pulse under command of imaging system controller. Coupled to transducer by T/R switch.
Acoustic transducer	Broadband 5.0 MHz transducer (Panametrics V307 SU). 25 mm diameter transducer creates narrow beam (< 1 degree at 6 dB). Specially modified at factory for operation in pressure compensated housing.
Acoustic receiver and T/R switch	T/R switch isolates transmitter receiver signals. Receiver amplifies 5.0 MHz acoustic backscatter signal with low-noise amplifier. Digitizes signal with high-speed 12-bit A/D converter. Receiver noise is reduced by averaging repeated pulses and signal processing.

Benthic chamber/Planar Optode System

Benthic chamber controller	Motor control logic and A/D converter linked to ROVER central controller via Motorola serial peripheral interface (SPI). Located in same pressure housing as central controller.
Benthic chamber	30 cm diameter acrylic cylinder with thin, Teflon-coated, titanium leading edge.
Stirring paddles	Crossed PVC rods on end of shaft supported by plastic bearings. Coupled to a

	pressure-compensated stepper motor by a ceramic magnet coupling. Speed control of 1-10 rpm.
Chamber purge valve	Geared pressure-compensated stepper motor that raises and lowers stir motor mounted on benthic chamber lid. Helps avoid bow-wave during chamber insertion.
Chamber/ Optode insertion motor	Inserts benthic chamber and planar optode slowly into sediment after chamber purge valve has been opened. The penetration depth is determined by a light-weight footpad with Hall-Effect sensor linked to central controller.
Planar Optode	Optical oxygen sensor that produces an image of oxygen concentration in sediment using an oxygen sensitive membrane. Linked to central controller via RS-485. Data offload via Ethernet. Housed in same pressure housing as central controller.

b. *Acoustic imaging system*: High frequency acoustic imaging systems (ultrasound or sonography) are used extensively in medical applications to view structures inside the human body (Zagzebski, 1996). These imaging systems are highly sophisticated and require considerable computing and electrical power to render an image in real-time. The same principles with far less complex equipment can be used to produce a three-dimensional image of structure in deep-sea sediments. A relatively simple system incorporating a 1.5 MHz transducer was used to image an aquarium-maintained simulated shallow-water sediment community in the laboratory (Orr and Rhoads, 1982). This preliminary study established the effectiveness of acoustics for non-invasive imaging of sediment structure and associated infauna. *In situ* placement of an obliquely aimed 40 kHz acoustic transducer, as part of a bottom roughness profiling system, was used to image changes in backscatter presumed to be movements of benthopelagic and epibenthic animals (Jumars *et al*., 1996). However, this system was not capable of resolving individual fauna or structures on or within the sediments.

We have developed a high-frequency acoustic imaging system similar in principal to the laboratory system of Orr and Rhoads (1982) to discriminate fine structure and animals within the sediment. After experimenting in the lab with a variety of transducers ranging in frequency from 1 to 7 MHz on cores containing undisturbed, silty-clay sediments, we selected an optimum frequency of 5 MHz. This frequency can penetrate the sediment to a depth of ~10 cm and detect animals and structures such as burrows with a spatial resolution of 1 mm to address **research question 2** (see above). The acoustic transducer is mounted on the scanning arm adjacent to the optical lens assembly (see above). The acoustic system is activated every 1 mm of travel on the X and Y axes while the optical system is activated every 1 cm of travel. The components of the acoustic imaging system are described in detail in Table 2. The acoustic backscatter data from each insonification will be stored on the imaging-system controller disk drive. The scanning arm will be programmed to scan the sediment along the X and Y axes to produce a three-dimensional acoustic image for each site. After the final optical and acoustic swath on the X-axis of the scanned grid, the scanning arm will reposition to the starting point of the grid opposite the associated benthic chamber.

A Panametrics V310 transducer was used in the prototype instrument and functioned well on deployments to 4100 m showing that Panametrics transducers can be operated at high pressure. A variant of the Panametrics transducer will be used in the proposed instrument that produces a very narrow beam (Table 2). This narrow beam will provide finer resolution (1 mm to be resolved at a sediment depth of 10 cm) and be insensitive to changes in transducer elevation.

We have extensively tested the acoustic imaging system in the laboratory and *in situ* deployments to 4100 m (Fig. 2b). The acoustic image from 4100 m does not show much detail below about 2 cm due either to lack of suitable targets or insufficient receiver sensitivity. To insure better performance in the proposed acoustic scanner, large data storage will allow all receiver data to be recorded so that weak returns can be extracted from background noise using autocorrelation digital signal processing (Proakis and Manolakis, 1988) in the laboratory.

2. Benthic chamber/optical O_2 sensor and planar optode

Duplicate, independent benthic chamber/optical O_2 sensor and planar optode (BCPO) systems each consisting of an acrylic benthic chamber/optical oxygen sensor and an adjacent planar optode will be mounted side-by-side on the front rack of ROVER II within the protective bounds of the bumper (Fig. 1; Table 1; Table 2). The planar optode will be inserted into the sediment simultaneously with the benthic chambers and will provide 2-dimentional mapping of O_2 concentration in the sediment using an O_2 sensitive membrane (see Glud *et al*., 1996, for full description of optodes). The sensor of the optode is wedge shaped with the sensor membrane mounted to the vertical side of the wedge. When the membrane has equilibrated (~15 min) the membrane is excited with modulated light from a bank of blue LED's. At the same time, a series of digital photographs are taken that can be converted into an image of oxygen concentration based on the lifetime of the membrane's fluorescent emissions. Data from the planar optode is stored on a disk drive integral to the planar optode controller. The optode controller communicates with the ROVER central controller via RS-485 and its data will be offloaded via Ethernet. Power for the planar optode is derived from the ROVER II main battery system via the central controller

Each BCPO will be attached to a vertically movable rack driven by a DC gear motor and lead-screw. The insertion motors lower each BCPO vertically into the sediment (Table 2) to a depth of ~ 5 cm determined by a footpad mounted between the benthic chamber and planar optode. The penetration and enclosed sediment surface for each instrument will be monitored with a video camera (Table 1). The lid of each benthic chamber has a combined stir motor/purge valve that is held open during insertion to allow the chamber to purge, minimizing any bow-wave effect. After penetration, a geared stepper motor (chamber purge valve motor) slowly lowers the stir motor, which seals on a facing O-ring. After each incubation and prior to removal of the chamber from the sediment, the stir motor/purge valve is opened to allow the benthic chamber to be easily raised from the sediment. A pump will direct a stream of water over the chamber walls to remove residual sediment prior to transit to the next site. The oxygen sensing system for each chamber consists of an optical oxygen sensor (Aanderaa 3830 oxygen optode) mounted in the lid and connected via cabling to the benthic chamber controller (Table 2). A stirring paddle attached to the stir motor shaft will circulate the water in the chamber, maintaining the thickness of the diffusive boundary layer at natural conditions (Smith *et* al., 1997) during the programmed length of the incubation (e.g., 1 to 10 days depending on the estimated fluxes across the interface). The SCOC measured with the duplicate BCPO systems will be used to address research **question 3** above. To check for sensor drift of the optical O_2 sensor between incubations, measurements will be taken in transit with ambient bottom water.

4. Central controller and data storage

The optical/acoustic imaging system, BCPO, cameras, acoustic current meter, and propulsion system all are controlled directly or indirectly by the central controller and data storage unit mounted on the main frame of ROVER II (Fig. 1b; Table 1). Direction and magnitude of local water currents will be determined by the current meter (Table 1) and transferred to the central controller via RS-485 data link. An inclinometer and magnetic compass, located in the current meter, will provide information to the central controller on the orientation and heading of ROVER II. Transit distance will be calculated using data collected by the current meter. These data will be compared with current direction and speed data just before the transit to calculate the vehicle's actual distance traveled. The basic operation of the central controller will be similar to that used on the original ROVER (Smith *et al*., 1997).

Status monitoring of ROVER II will be accomplished using acoustic communication via one of the two vehicle's acoustic releases (Table 1). These releases have a simple data transmission mode that will provide a "status report" after deployment to determine if all vehicle systems are functioning properly at depth.

Power for ROVER II and its instrumentation is provided by lithium battery packs (360 D-cells, total power: 1100 Ah @ 14 V) housed in an aluminum pressure cylinder and mounted alongside the central controller. The power requirement is sufficient for a 7-month deployment with 50 measurement sites (http://smithlab.ucsd.edu/scanner/).

We plan to develop an acousticlink between ROVER II and MARS as originally proposed in collaboration with Jim Barry last year.

5. Flotation and ballast release

To increase the reliability of the flotation over the original ROVER, we will use syntactic foam blocks on ROVER II (Table 1, Fig. 1b). The disposable ballast will consist of a cylindrical steel bar held between the two treads by a cable and tandem release mechanism (Table 1; Smith *et al*., 1997). The ballast will be adjusted to maintain a weight in water of ~35 to 40 kg. This weight has proven effective in allowing the original ROVER to perform efficiently on the sea floor while minimizing disturbance to the sediments and measurement sites (Smith *et al*., 1997).

Field programs

We currently have four cruises funded by NSF in 2005 and 2006 to test Rover II components and the final instrument.

2005

15-27 February (New Horizon) S.D. to S.D.

15-27 June (New Horizon) S.D. to S.D.

4-18 November (10 days on station with Thompson and Jason II)

2006

Spring (10 days on station with Melville and Jason II)

Data reduction and analysis

NA

Significant changes from previous project proposal (continuing projects only)

NA

Specific deliverables (new and continuing projects)

Scientific results will ultimately be published in peer-reviewed journals

Transfer of knowledge from SIO engineering to MBARI engineering

c) Project team (new and continuing projects)

Ken Smith: principal investigator/project manager

Electronic engineer: Paul McGill

Bruce Robison: collaborator

d) Project lab space (new and continuing projects)

No space is needed for this project in 2005

3) BUDGET JUSTIFICATION (new and continuing projects)

1. Four months of electrical engineering time requested to provide cross-fertilization between our current ailing engineer at SIO and a counterpart at MBARI to develop the instrumentation assembly and controller with interface to the propulsion system.

2. Four round-trip airfares from S.D. to Monterey for collaboration between engineering staffs at SIO and MBARI (including per diem).

4) MILESTONES (new and continuing projects)

	Milestone 1	**Milestone 2**	**Milestone 3**	**Milestone 4**	**Milestone 5**	**Total Resources**[1] for each resource category for all milestones listed here
Milestone Date	1 June 2005	1 September 2005	31 December 2005			
Milestone Description	Structural frame/propulsion system	Instrumentation assembly	Controller/ acoustic link			
EE	0.5 months	1.5 months	2months			4 months
SE						
ME						
Machine Shop						

[1] This number should be the same number you entered on the resource requests for this particular resource.