Project Number: 901101

Project Start: Jan. 1, **2011** **Project Duration (in years):** **5**

Please indicate what type of project is being proposed (mark only one).

[ ]	[X]	[ ]	[ ]	[ ]
Feasibility/Scoping [Less than 100 days effort]	**Development[1]**	**Research**	**Infrastructure[1]**	**Education**
	[ ]	[ ]		
	Time Series	**Institute Initiative**		

Project Manager[2]: David Caress

Principal Investigator:

Lead Scientist: Charlie Paull

Lead Engineer: David Caress

Project Title: Ocean Imaging

[1] Development and infrastructure projects must complete the risk matrix (see item #5 at the end of the proposal form).
[2] Not all projects will require all four titles to be filled in. Please indicate individuals only for those titles that are appropriate for your project.

1) ABSTRACT (new projects only)

We propose to initiate a five year project focused on developing new capabilities to map and image the deep ocean seafloor using our existing ROV and AUV platforms. This will bridge the gap between optical and acoustic sensing, allow 4D observations, and involve integrating data from sonar and cameras. The goal is to obtain spatially quantitative, repeatable renderings of the seafloor with fidelity at scales of 5 cm. The sonar, camera, and navigational technologies required to achieve this resolution and accuracy all exist, but have not yet been integrated and applied to deep ocean exploration.

The relevant sonar and camera sensors are COTS. This project will involve integrating these sensors with the platforms, including both sensor control and data logging, and developing new software tools to use the data. In particular, mapping and imaging at sub-meter scales will require representing structures as 3D objects rather than the 2D grids of traditional seafloor mapping. Another important aspect of our approach will be collecting similar-scale bathymetry and stereo still imaging data simultaneously, allowing these data to be intrinsically collocated in space and time.

Real-time terrain and vision aiding of navigation have been demonstrated on our ROVs and AUVs. The proposed development will allow the implementation of the existing navigation aiding tools for routine operations, and facilitate the further development of these very promising approaches to subsea navigation.

We view this project as proceeding incrementally. During the first year, we propose to acquire a current generation, high frequency multibeam and dual (stereo) still cameras that can be integrated as a single package with *ROV Ricketts* (or *ROV Ventana*) for interactive operation. We will be able to simultaneously collect optical images and seafloor topography without substantial modification to the existing platform. In subsequent years we will focus on refining the data quality, aided-vehicle navigation, improvements in camera systems and data processing. We will also ultimately implement this mapping and imaging capability in an autonomous context, most likely on the Benthic Imaging AUV. We expect that the higher frequency sonar will have utility to image and quantify midwater animal populations, and we also intend to explore this capability.

2) PROPOSAL

a) <u>New Projects</u>

Statement of the problem, why it is important

Seafloor mapping and imaging is one of the fundamental types of observation used in marine geological research, and it provides important supporting information for most other oceanographic work involving the seafloor. MBARI needs to be able to obtain bathymetry data and seafloor imagery at appropriate scales and resolutions to support its research and development programs. We propose to develop a combined acoustic and optical mapping and imaging capability that achieves 5-cm lateral resolution bathymetry collocated with stereo photographic imagery. This capability will be initially operated in an interactive, ROV context, and will later be integrated with an AUV for autonomous operations in the deep sea.

Video and still imagery of ever increasing quality and resolution have been crucial MBARI ROV capabilities throughout the institution's history. Recently, the development of the Benthic Imaging AUV has allowed autonomous high resolution photography of the seafloor (Figure 1). Since 2006, the multibeam, sidescan, and subbottom equipped Mapping AUV has achieved efficient 1 to 1.5-m lateral resolution bathymetry surveys (e.g. Figure 2), allowing the discovery of new seafloor features and the investigation of geologic processes associated with phenomena such as submarine volcanism, formation of methane hydrate deposits, and sediment transport in submarine canyons.

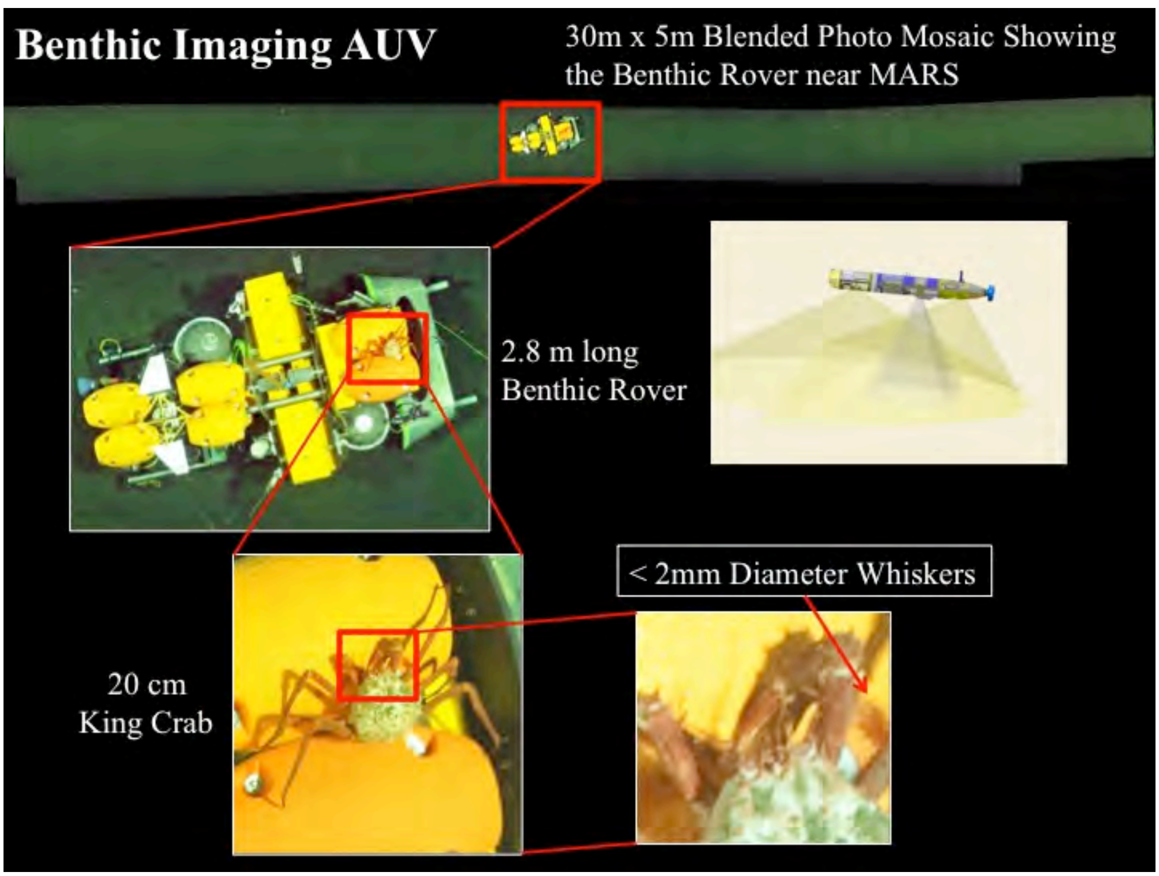

Figure 1: Example images from Benthic Imaging AUV showing the pixel resolution achieved from a 3 m altitude with a single camera and dual strobes.

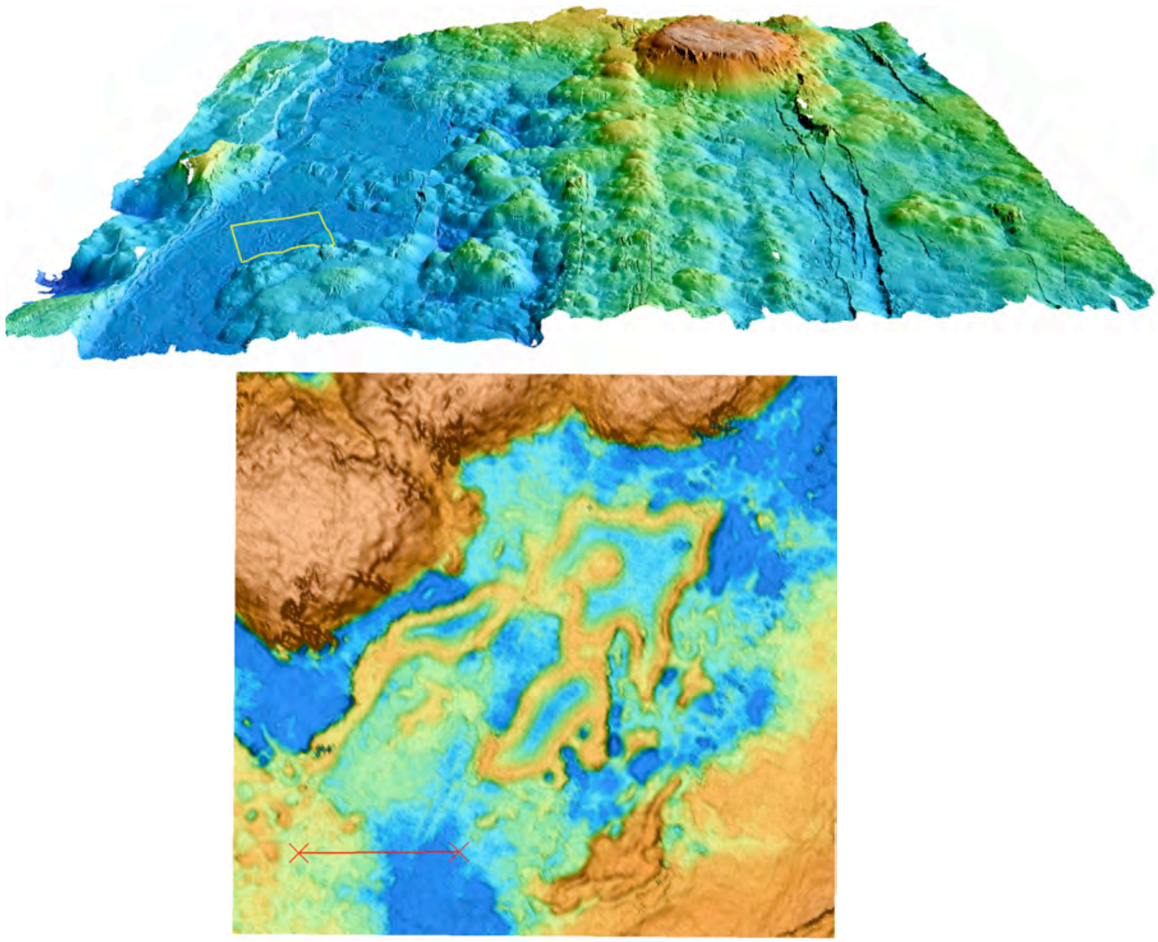

Figure 2: (Top) Perspective view of Mapping AUV survey on Coaxial Segment, Juan de Fuca Ridge in 2009. The AUV surveyed from a 75 m altitude, producing 1.5 resolution bathymetry. The yellow box is about 30 m across. (Bottom) Map view of the region outlined in yellow above; the scale bar is 10 m across.

Although the Mapping AUV development and operations have been very successful, there remains a significant scale gap between the bathymetric (≥1 m) and image (<0.002 m) resolutions. The consequence is that there are structures of interest at submeter scales that are currently below our capability to map; examples (Figure 3) include the detailed topography of benthic habitats, the variable lithologies along submarine canyon axes, and the finescale textures and cracks found at hydrate outcrops and gas seeps. In all these cases, there are important biological and/or geological processes that cannot be understood without quantitative observations of the topography at scales of a few cm.

Useful mapping at any scale requires positioning, and arguably the most difficult aspect of mapping at submeter scales is achieving repeatable navigation at that same scale. The 1-m precision navigation of Mapping AUV surveys is achieved in post-processing by correlating matching features in overlapping swaths. Recent demonstrations of terrain-aided and vision aided navigation by Steve Rock's group indicate that MBARI is now capable of implementing real-time navigation systems applying correlation of matching features in bathymetry and photographic imagery (this class of technique is often known as Simultaneous Localization and Minimization, or SLAM). The higher the resolution of the input data, the greater the precision of the resulting aided navigation (Figure 4). Consequently, the use of terrain and vision aiding can support seafloor mapping as scales of 5 cm, and perhaps even less.

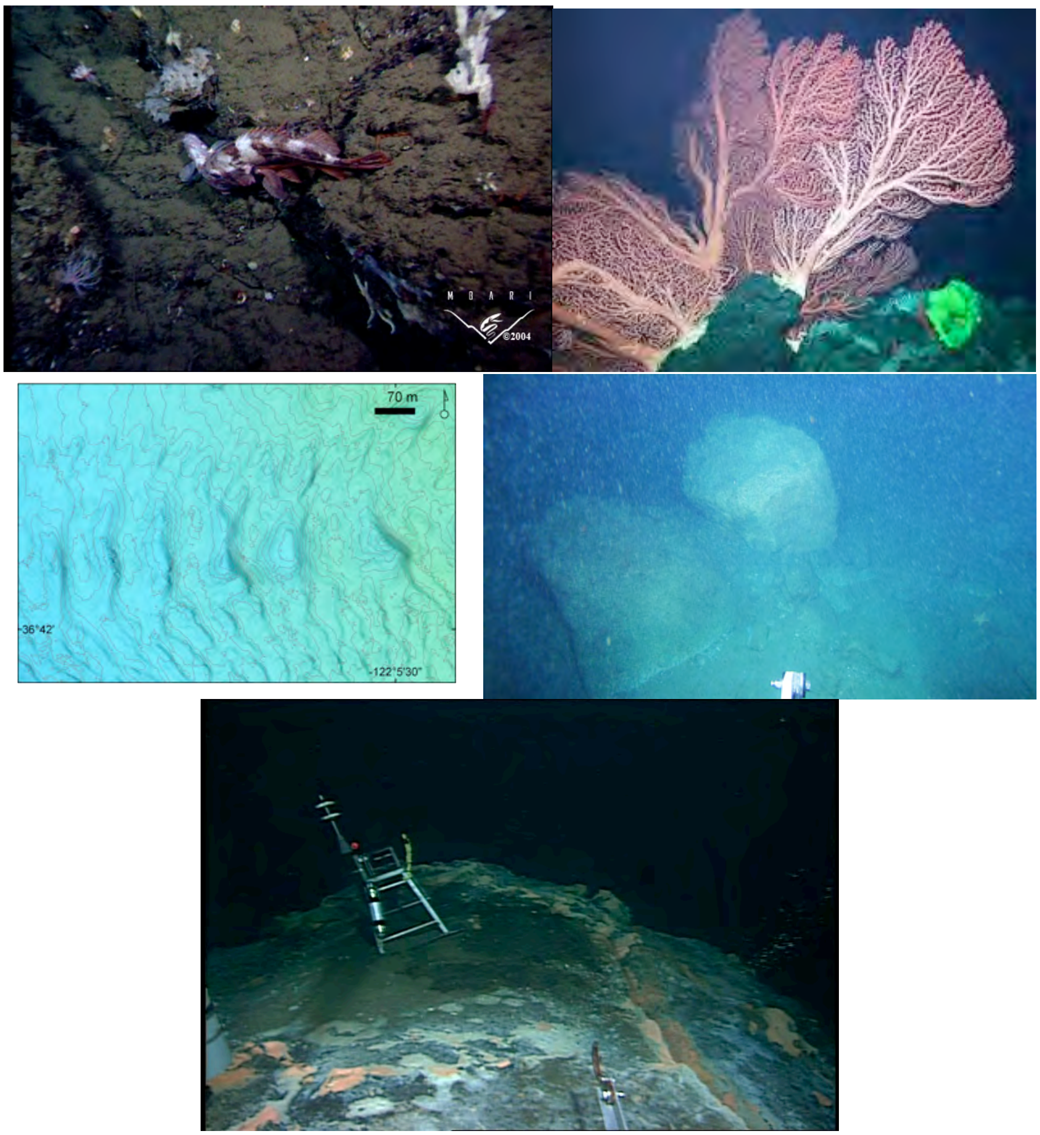

Figure 3: Examples of seafloor features with submeter topography that cannot be mapped using MBARI's current capabilities. (Top) Benthic habitats. (Middle left) 1 m resolution Mapping AUV bathymetry showing huge bedforms (1 m contours) on Monterey Canyon's floor at ~1,850 m water depths. (Middle right) The bedform field at 1,850 m water depth is composed of 0.5-1 m boulders such as those shown here. (Bottom) Summit of Santa Monica Basin gas seep mound showing some of the cracks that control where bubbles escape the subsurface.

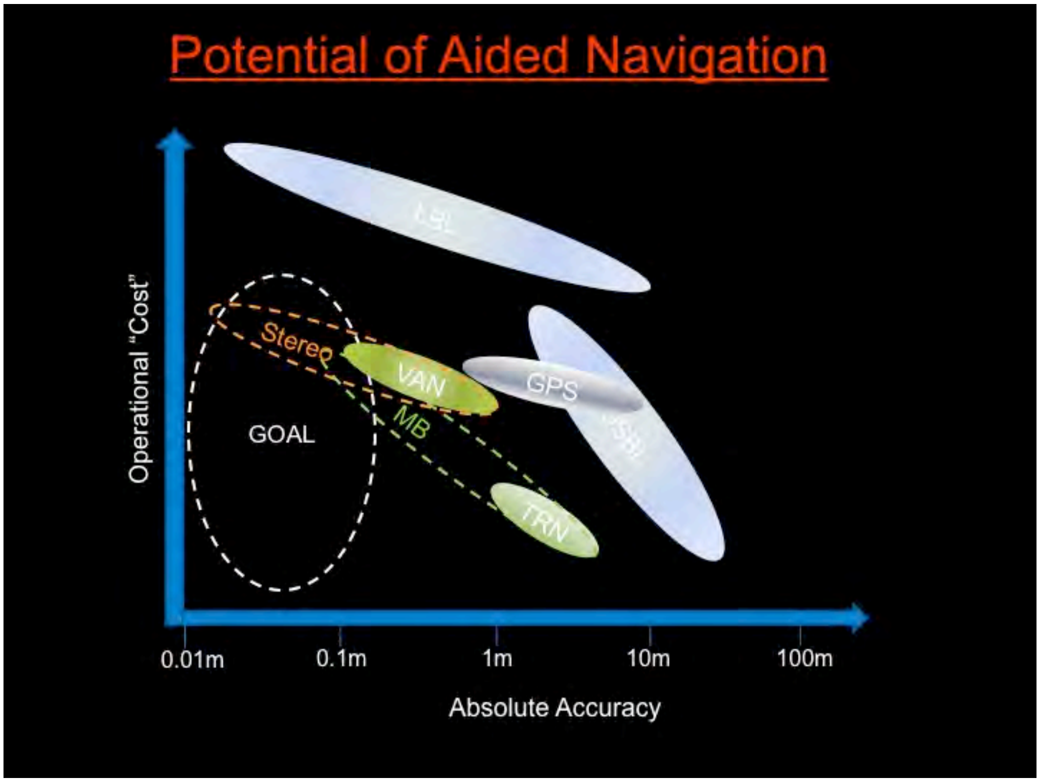

Figure 4: Potential "cost" and accuracy of real-time aided navigation compared with other navigation sources. Terrain Aided Navigation (TRN) achieves an accuracy equivalent to the input bathymetry resolution, which can be less than 0.1 m using a high frequency (>= 400 kHz) multibeam at low altitudes (<5 m). Vision aided navigation (VRN) can achieve cm-scale accuracy when based on stereo imagery.

How does it relate/contribute to MBARI's mission and strategic plan?

The first two of four primary themes in the draft strategic plan are "Exploration and Discovery" and "Ocean Visualization and Characterization". This proposal directly addresses the stated need to achieve "four-dimensional renderings" of the seafloor as part of Ocean Visualization. Moreover, exploration and discovery is really about making new observations, and the proposed 5 cm resolution bathymetric surveying, combined with optical imaging, will truly comprise a new sort of observational capability.

Approach to the problem

The proposed combined acoustic and optical mapping and imaging capability will be developed incrementally over a period of five years. As stated above, the long-term intent is to obtain spatially quantitative, repeatable renderings of the seafloor with fidelity at scales of 5 cm from both ROV and AUV platforms.

The first year goal is to design, construct, and test a combined multibeam sonar and stereo camera rig for ROV operations. The mechanical design will use sonar and camera spacings consistent with a later integration into a Dorado AUV. Although some effort will be required for refinement and integration, all of the essential software components required to operate the sonars and cameras, log the data, calculate aided realtime navigation, and perform basic processing of the multibeam and imagery data exist and are in use. Steve Rock's Precision Controls project will undertake the implementation and integration of real-time aided navigation using both terrain (sonar) and vision (camera imagery) data sufficient to insure that surveys from 2-5 m altitudes achieve >100% coverage of the target seafloor; Steve Rock and Mike Risi plan to complete this work by May. The initial test surveys in June-July and September-October will be at locations of high interest along the Monterey Canyon axis that are convenient to Moss Landing.

The test data will be used for development of algorithms and software that merge that acoustic and optical data into three-dimensional representations of the seafloor combining morphology and imagery. This will include photogrammetric extraction of topography from the stereo imagery (using the known geometry to calculate the 3D position of points observed in both camera images), followed by an exploration of approaches to usefully combining the more-or-less uniformly sampling multibeam bathymetry with highly variable photogrammetric topography. Given the best possible topographic model, the final component of new processing development in year 1 will address the problem of collocating the photographic imagery with the topography. We anticipate defining and using true 3D objects with texture mapping rather than the 2D grids currently used to represent seafloor topography and imagery. The test data will also be used by the Precision Controls project to improve the aided navigation implementation.

In subsequent years we expect to improve the real-time navigation aiding to achieve precisions approaching the target topographic resolution of 5 cm. Ultimately, we intend to integrate this combined acoustical and optical imaging system onto an autonomous platform capable of performing near-bottom surveys. At the present time, the likely target vehicle is the Benthic Imaging Vehicle, but the specifics will depend greatly on how MBARI's AUV's evolve over the next year or two.

The combination of acoustic and optical sensing, or just the acoustic sensing alone, is likely to prove useful for mapping the distribution of some animals in the midwater. We expect to explore this usage of the system in subsequent years.

Publications (from other projects over the last 5 years)

Bird, L. E., Paull, C. K., and Hobson, B., Instrumentation for investigating submarine canyons: The development of a self-triggering event detector to investigate sediment transport events, Sea Technology, 48, 17-21. 2007.

Caress, D.W., H. Thomas, W. J. Kirkwood, R. McEwen, R. Henthorn, E. A. Clague, C. K. Paull, J. Paduan, and K. L. Maier, "High-Resolution Multibeam, Sidescan, and Subbottom Surveys Using the MBARI AUV D. Allan B.", Marine Habitat Mapping Technology for Alaska, J.R. Reynolds and H.G. Greene (eds.) Alaska Sea Grant College Program, University of Alaska Fairbanks. doi:10.4027/mhmta.2008.04

McGill, P., Sherman, A. D., Hobson, B., Henthorn, R., and Smith, Jr, Initial deployments of the Rover: An autonomous bottom-transecting instrument platform, Journal of Ocean Technology, 4, 54-70. 2009.

McNutt, M., Caress, D. W., Hotspots and Hotspot Swells, in Seismology and the Structure of the Earth, Treatise on Geophysics, Vol. I, ed. B. Romanawicz and A. Dziewonski, Elsevier, 2007.

Normark, W., C.K. Paull, D.W. Caress, W. Ussler, R. Sliter, "Fine-scale relief related to late Holocene channel shifting within the floor of upper Redondo Fan, offshore southern California", Sedimentology, doi:10.1111/j.1365-3091.2009.01052.x, 2009.

Paduan, J., Caress, D. W., Clague, D. A., Paull, C. K., and Thomas, H., High-resolution mapping of erosional, tectonic, and volcanic hazards using the MBARI mapping AUV, Rendiconti Online Società Geologica Italiana, 7, 181-186. 2009.

Paull, C.K., W. Ussler III, P. J. Mitts, D. W. Caress, G. J.. West, Discordant ^{14}C-stratigraphies in Upper Monterey Canyon: A signal of anthropogenic disturbance?, *Mar. Geol.*, 233, 21-36, 2006.

Paull, C.K, Normark, W.R., Ussler III, W., Caress, D.W., Keaten, R., "Association among active seafloor deformation, mound formation, and gas hydrate growth and accumulation within the seafloor of the Santa Monica Basin, offshore California", *Marine Geology*, 250, 258-275, 2008.

Paull, C.K., B. Schlining, W. Ussler III, E. Lundsten, J.P. Barry, D.W. Caress, "Submarine Mass Transport Within Monterey Canyon: Benthic Disturbance Controls on the Distribution of Chemosynthetic Biological Communities", D. Mosher et al. (eds.), Submarine Mass Movements and Their Consequences, Advances in Natural and Technological Hazards Research, Vol. 28, 2009.

Stakes, D.S., M.R. Perfit, M.A. Tivey, D.W. Caress, T.M. Ramirez, N. Maher, "The Cleft Revealed: Geologic, magnetic and morphologic evidence for construction of upper oceanic crust along the southern Juan de Fuca Ridge", Geochemistry, Geophysics, Geosystems, 7:4, Q04003, 2006.

b) Continuing Projects

N/A

c) New and Continuing Projects: Plans for 2011

Research Activities

2011 will be devoted to the development of these new instrument systems. Figures 1-3 above illustrate the diversity of potential uses for this technology. Once available, we envision considerable project interest in using this capability.

Engineering/technology development

The initial Engineering effort will largely consist of purchasing and integrating a multibeam sonar, stereo still cameras, and lights into a package that can in turn be integrated with *ROV Ricketts* and *R/V Western Flyer* (note: if necessary or convenient, the target platform for year 1 can be *ROV Ventana* / *R/V Point Lobos* without compromising this project).

We currently envision mounting the cameras, lights, and sonar arrays onto a common frame to ensure consistent collocation. In the ROV context, the sonars and cameras will be interactively operated from computers in the ROV control room. However, we will purchase the multibeam electronics in an “AUV-ready” form including a subsea pressure housing. The data bandwidth of this system will likely require dedicated use of one spare fiber in the ROV tether. The attitude and heading data from ROV Ricketts’ existing Octans gyrocompass/motion sensor will be used. The real-time navigation data will be provided by an updated implementation of the terrain and vision aided algorithms tested successfully last year by Steve Rock’s group.

There will be three separate software development efforts during year 1:
- Realtime implementation of terrain and vision aided navigation (Rock + Risi through the Precision Controls Project).
- Implementation of data logging for navigation, attitude, sonar, and camera data (Henthorn + Thomas)
- Integrated processing of multibeam bathymetry and stereo imagery into three-dimensional models of the seafloor (Caress + Henthorn)

Following the at-sea tests, the new survey data and data products will need to be integrated with the relevant core databases and query systems (McCann) and with the VARS database and software (Schlining). These efforts can be postponed to year 2, if necessary or convenient.

Field programs (detail ship requirements/deployments)

We request three days of ROV Ricketts dives in June or July, to be followed by a second three-day sequence in September-November. A number of sites along the

Monterey Canyon axis would be suitable for tests of a 5 cm lateral resolution bathymetry survey;

The initial test surveys proposed to be conducted along the Monterey Canyon axis at the "Narrows" and the 1850 m bend will have relevance to the Continental Margins Processes project. These are likely to be the first of many repeated surveys that will be used to monitor change at these sites of interest. The seafloor imaging system is also envisioned as playing a major role in a coordinated field experiment that will utilize multiple MBARI technologies in 2012 to track movements within the canyon floor sediments Continental Margins project (90123).

Specific deliverables

During year 1 we will develop a working ROV-based seafloor imaging system capable of achieving 5 cm scale surveys combining topography and stereo imagery.

The sonar and image data processing software will be developed as part of the open source MB-System software package, and thus will be rapidly available to the external community through the frequent MB-System distribution updates.

Milestones (see last page for personnel classification list)

We expect to follow the usual MBARI Engineering practices, including holding preliminary and critical design reviews before assembling the system.

	Milestone 1	**Milestone 2**	**Milestone 3**	**Milestone 4**	**Milestone 5**	**Total Resources**[3] for each resource category for all milestones listed here
Milestone Date	**2/1/2011**	**3/15/2011**	**6/1/2011**	**9/1/2011**	**12/1/2011**	
Milestone Description	**PDR**	**CDR**	**Initial ROV test surveys**	**2nd ROV test surveys**	**Presentation of year 1 results**	
EE						
SE	**10**	**10**	**25**	**10**	**15**	**70**
ME	**5**	**5**	**15**	**5**		**30**
EE Tech			**10**			**10**

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

SE Tech						
ME Tech			**10**			**10**
Machine Shop						

Budget justification

The sensor costs, particularly the multibeam sonar and the dual still cameras, dominate the expense budget.

Multibeam Sonar:
Several existing high frequency multibeam sonars meet the requirement of 5 cm lateral resolution from altitudes of <5 m and are known to produce appropriate quality data. We have tentatively concluded that a 0.5°X 1.0° 400 kHz Reson SeaBat 7125 is the best choice because:

- It is compatible in hardware spares, logging software, and processing software with the 200 kHz Reson 7125 we currently operate on the Mapping AUV.
- It is currently available with a short lead time (six weeks), making it possible to purchase and take early delivery of a unit during 2010 if funds are available during the Fall.

The cost of this sonar, including a support contract and onsite integration assistance, is $329K. There is a $15K discount if the PO is received prior to September 27, 2010. Also, this multibeam can, with a lower resolution projector, function as a forward looking scanning sonar. If there is interest amongst the ROV pilots, the scanning sonar capability can be tested using a projector loaned by Reson.

Camera and Lighting System:

- Two SSC Ti flat port camera housings @ $5K each
- Two ProSilica GC1380 cameras with 8mm lens @ $4K each
- One, three head LED light array @ $11.5K
- Ethernet fiber modem @ $3K estimated
- Gig-E switch, cables, wet cabling and connectors @ $5K estimated
- Total camera & lighting system: $27.5K

Structural hardware, additional cables, connecters, etc

- Hardware for mounting frame @ $3K estimated
- Additional connectors and cabling @ $5K estimated

Ancillary sensors:
We will make use of existing DVL and heading/motion sensors.

<u>Engineering Time Requests:</u>

- David Caress (50 days SE) for project management, system design, software development, at-sea testing, and data processing.
- Brett Hobson (30 days ME) for system design, fabrication, and at-sea testing.
- Rich Henthorn (20 days SE) for software development.
- ME tech (10 days) and EE tech (10 days) time for fabrication.
- Mike Risi is requested for the requisite aided navigation software development as part of the 600034 Precision Control Technologies proposal.

Project team

Core Team:

- David Caress (Lead Engineer, Project Manager)
- Brett Hobson
- Hans Thomas
- Steve Rock
- Charlie Paull (Lead Scientist)

Likely to participate in Year 1

- ROV Pilot(s)
- Rich Henthorn
- Mike McCann
- Brian Schlining
- ME & EE techs

Responsibilities:

- David Caress
    - Project management
    - Sonar requirements and operation
    - Software development for data processing and display
    - 50 days
- Brett Hobson
    - Mechanical design
    - Camera system design
    - 30 days
- Hans Thomas
    - Electrical and software integration
- Steve Rock (+ Mike Risi + students)
    - Aided navigation algorithms
    - Implementation budgeted as part of Precision Controls project
- Charlie Paull
    - Survey specification and interpretation

- ROV Pilot(s)
  - Assist with mechanical, electrical, and software integration onto ROV
- Rich Henthorn
  - Modification of existing multibeam logging software
  - 20 days
- Mike McCann
  - Integrate new data into core databases (could be 2012)
  - 10 days
- Brian Schlining
  - Integrate new data into VARS (could be 2012)
  - 10 days

Project lab space

Temporary access to a dedicated lab space for this project would be advantageous.

Data availability outside project team, uniqueness

The test survey data will be used by Charlie Paull's group as part of their continuing research into sediment transport in submarine canyons. These data will be available generally within MBARI.

The sonar and camera data processing software developed by Caress will be rapidly available to the external community through MB-System distribution updates.

Risk matrix (development and infrastructure projects only)

	Technical Risk	Organizational Risk	Tech Transfer Risk	Labor Estimate Risk
High				
Medium	X	X		X
Low			X	