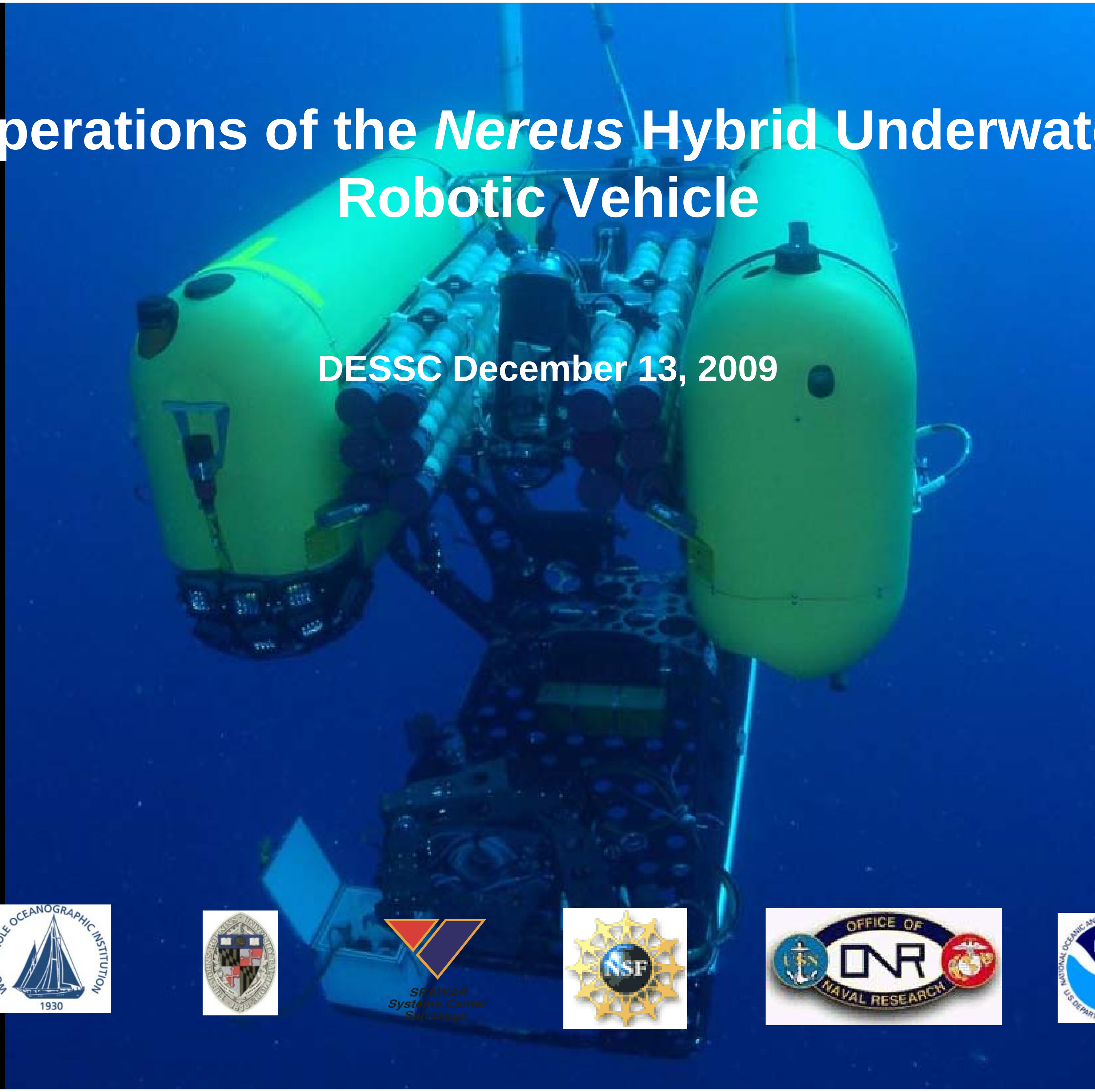
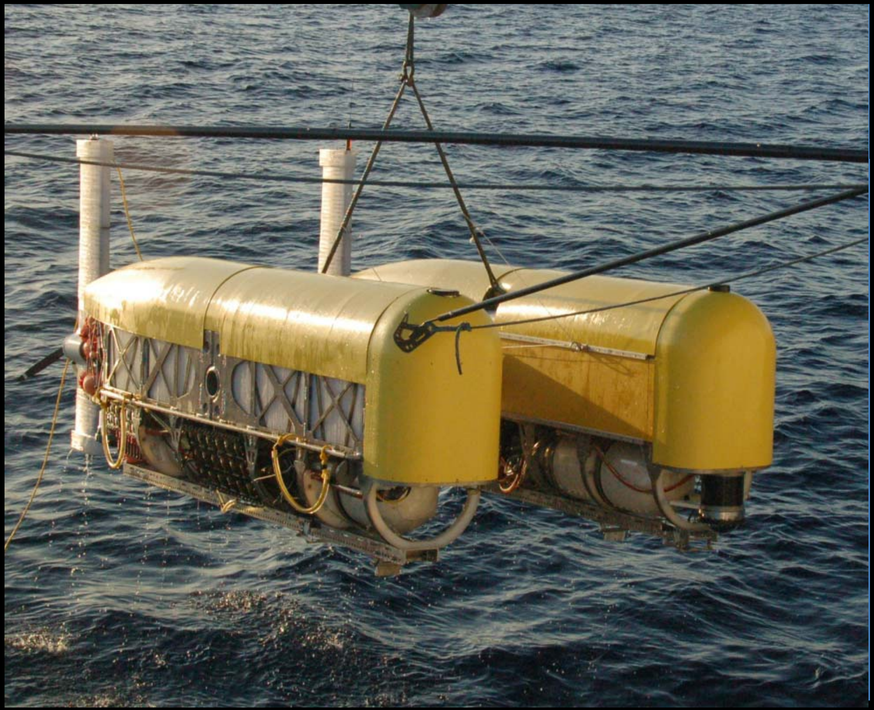
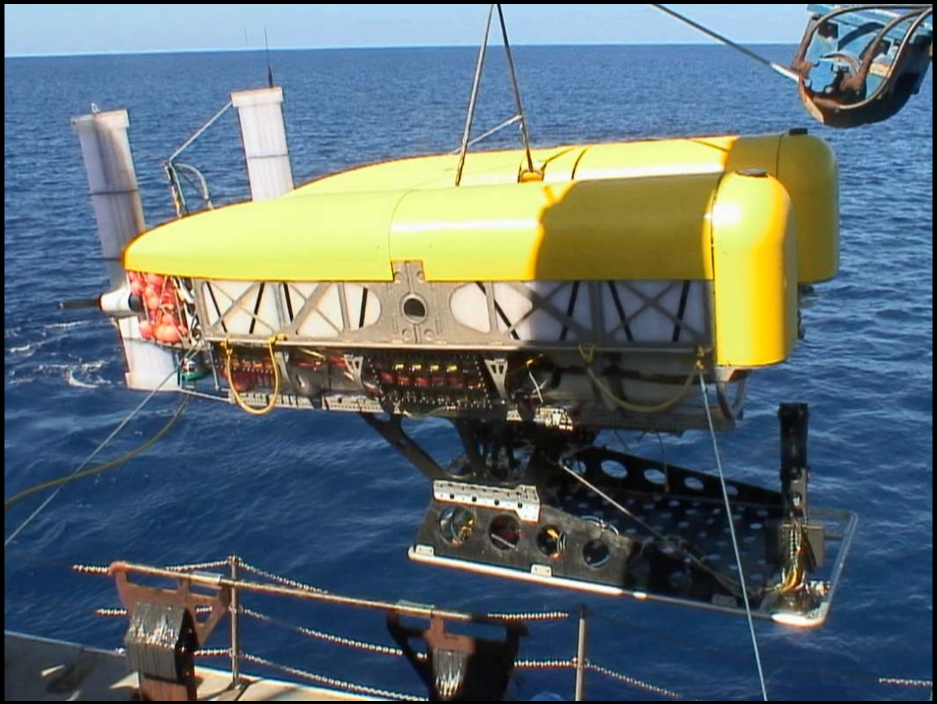
Operations of the *Nereus* Hybrid Underwater Robotic Vehicle

DESSC December 13, 2009







<u>Untethered AUV Mode</u>

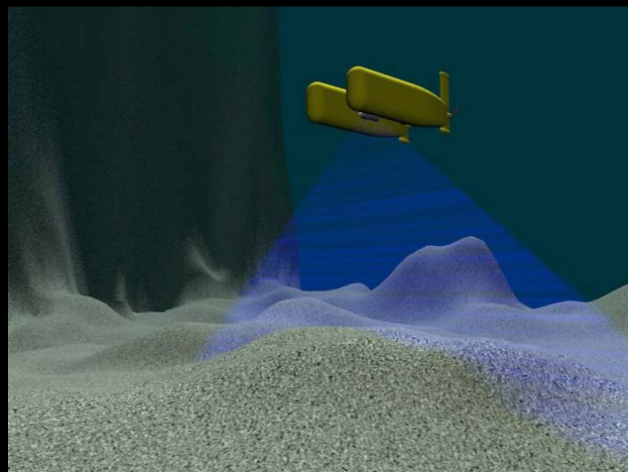
- 2625 kg
- 1472 ceramic spheres
- 30 kg (wet wt) payload

<u>Tethered ROV Mode</u>

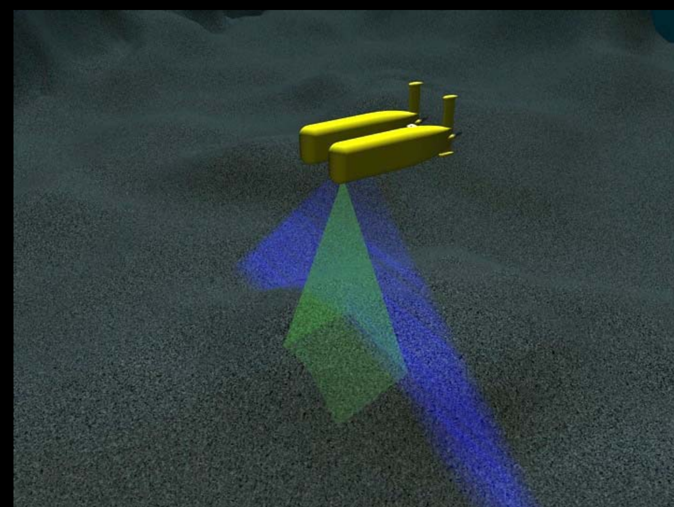
- 2920 kg
- 1680 ceramic spheres
- 30 kg (wet wt) payload

AUV Mode Operation

High altitude (50-100M) sonar mapping

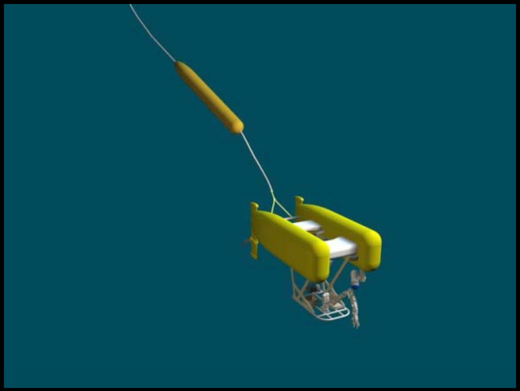


low altitude (5-10M) digital photograph collection

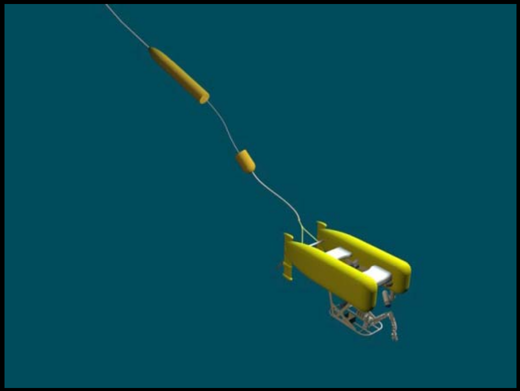


ROV Mode Operation

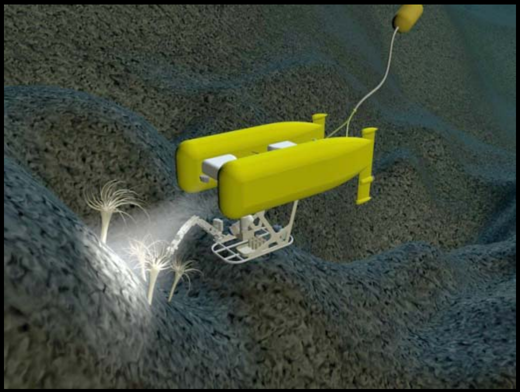
Descent with Depressor and Armored Cable



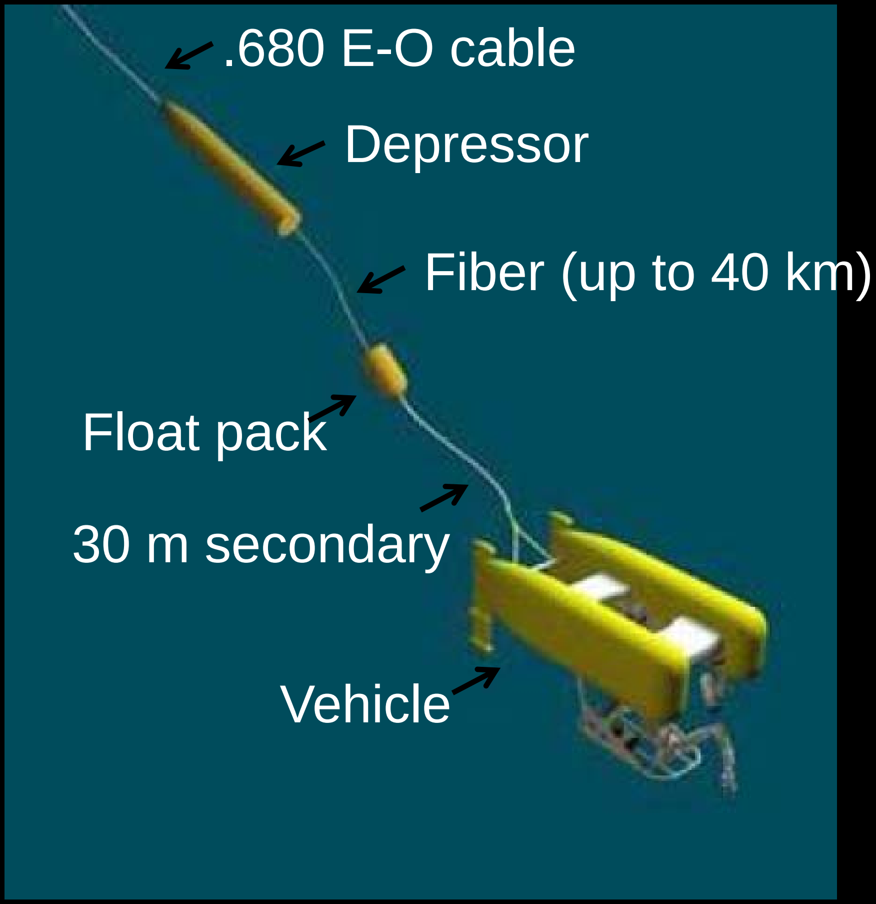
Release from Depressor
Micro-fiber tether payout



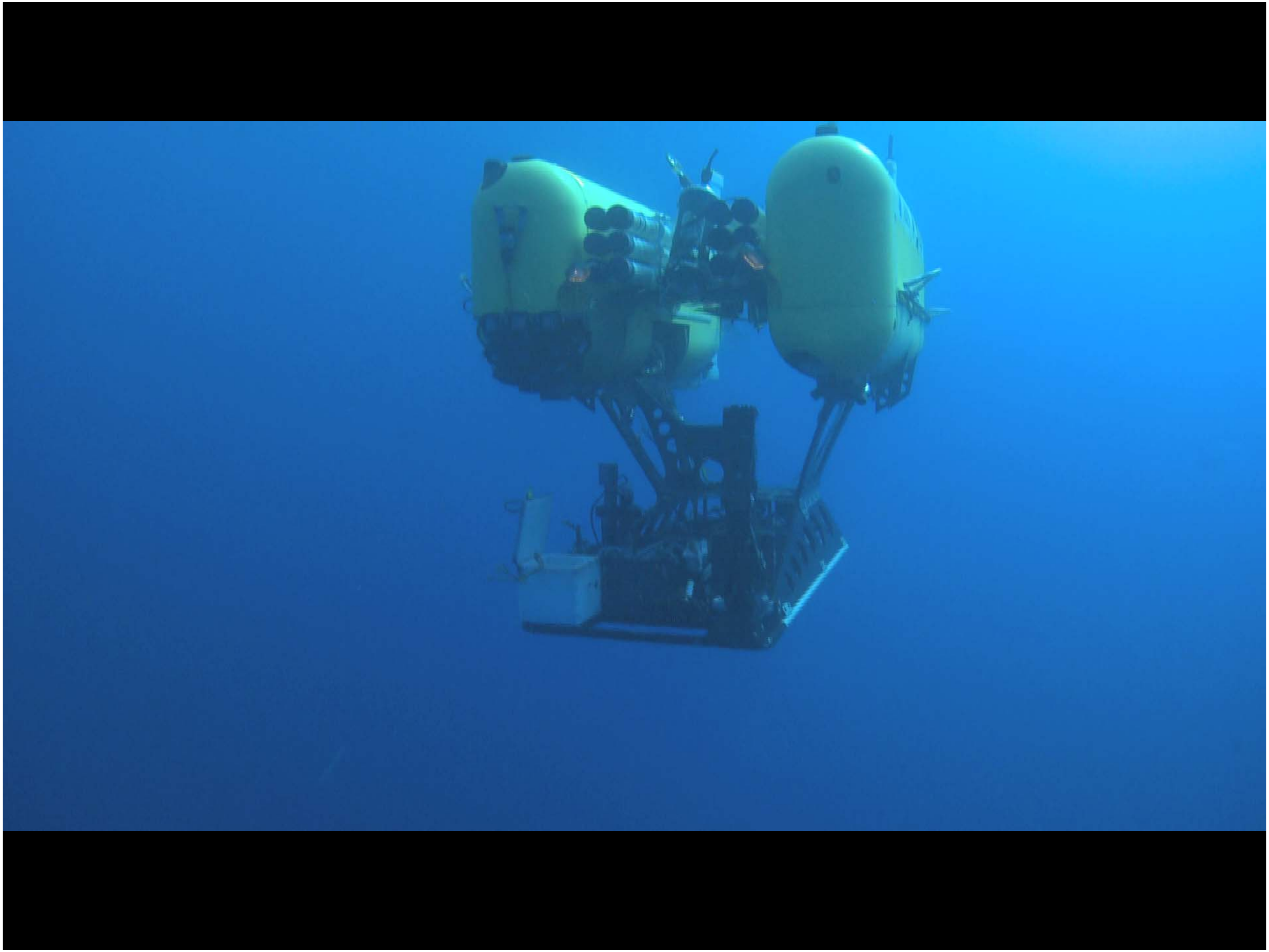
On Bottom collecting samples



Light Fiber Tether Concept



- High bandwidth (GigE) communications
- Unconstrained by surface ship
- Operable from non-DP vessels

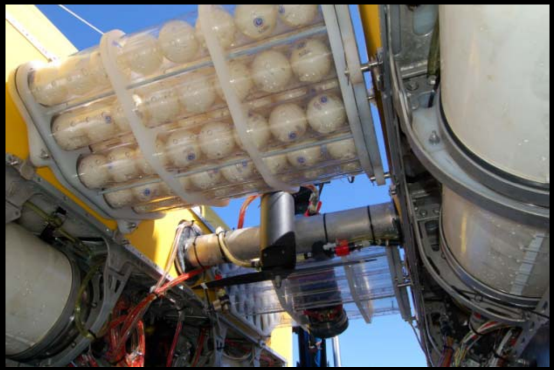


Science Interfaces

- 6 RS-232 direct to onboard main CPU
- 2 sci bus ethernet ports 4 wire at 10mbit, available in ROV mode direct through ethernet or in AUV mode from main CPU
- 6 sci bus power ports individually switchable:
    - three 12V/15W
    - three 24V/15W,
    - one 24V/50W
- NO analog inputs (external A-D now available)
- Power and serial ports split between various jboxes on the vehicle, not available all in one location
- Bio boxes, cores, grabs, small suction sampler
- Similar workspace to Jason I
- 35 kg of payload
- Careful pre-cruise and pre-dive planning critical (payload/power)
- 2 RS-232 channels available via Moxa port in ROV mode

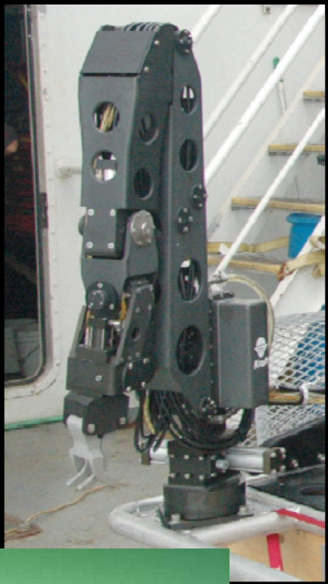
New Technologies
Enabling the Nereus System Design

Ceramic Buoyancy
and Pressure Housings



Low Power
High Quality Imaging/Lighting

Low Power
Capable Manipulators



Micro-Fiber Tether
System

Energy
Storage

Nereus Control Room

Main Electronics and Battery Housings

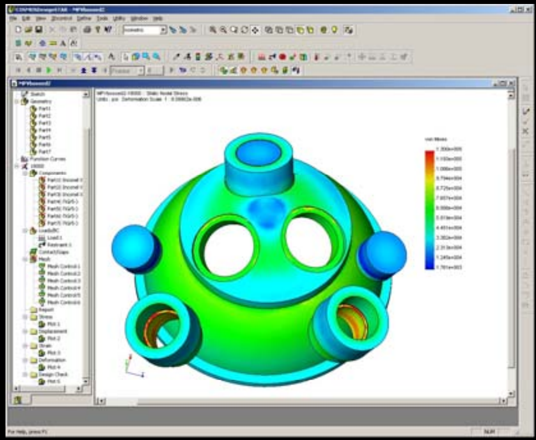
<u>Mechanical Characteristics</u>

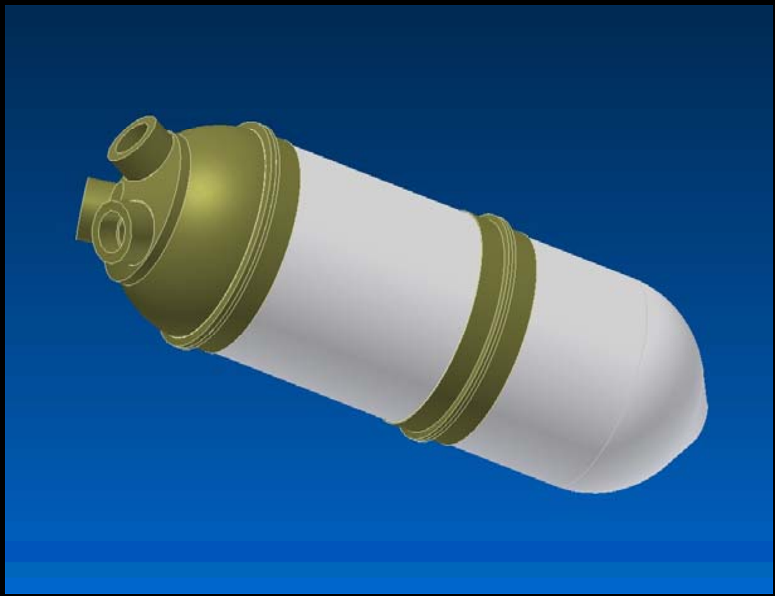
Ceramic/ Grade 5 titanium construction

Titanium hemispherical endcap

Ceramic/Titanium Design:
- 90 lbs air weight
- 135 lbs buoyant water weight

Comparable All-Titanium Design:
- 300 lbs air weight
- 80 lbs water weight





Seamless 3.6” Ceramic Buoyancy Spheres

Deep Sea Power and Light, San Diego, CA

Ceramic Sphere Technical Specifications

• Material:	Alumina Al_2O_3
• OD	9.14cm +/- 0.13cm (3.6in +/- .050in)
• Wall thickness	1.5mm (0.060”)
• Weight	140g +/- 1g (4.94oz +/- 0.04oz)
• Net Buoyancy	290g (10.23oz)
• Specific Gravity	0.32

• Pressure tested to 30,000 PSI

Nereus 2009 Mariana Expedition

RV Kilo Moana

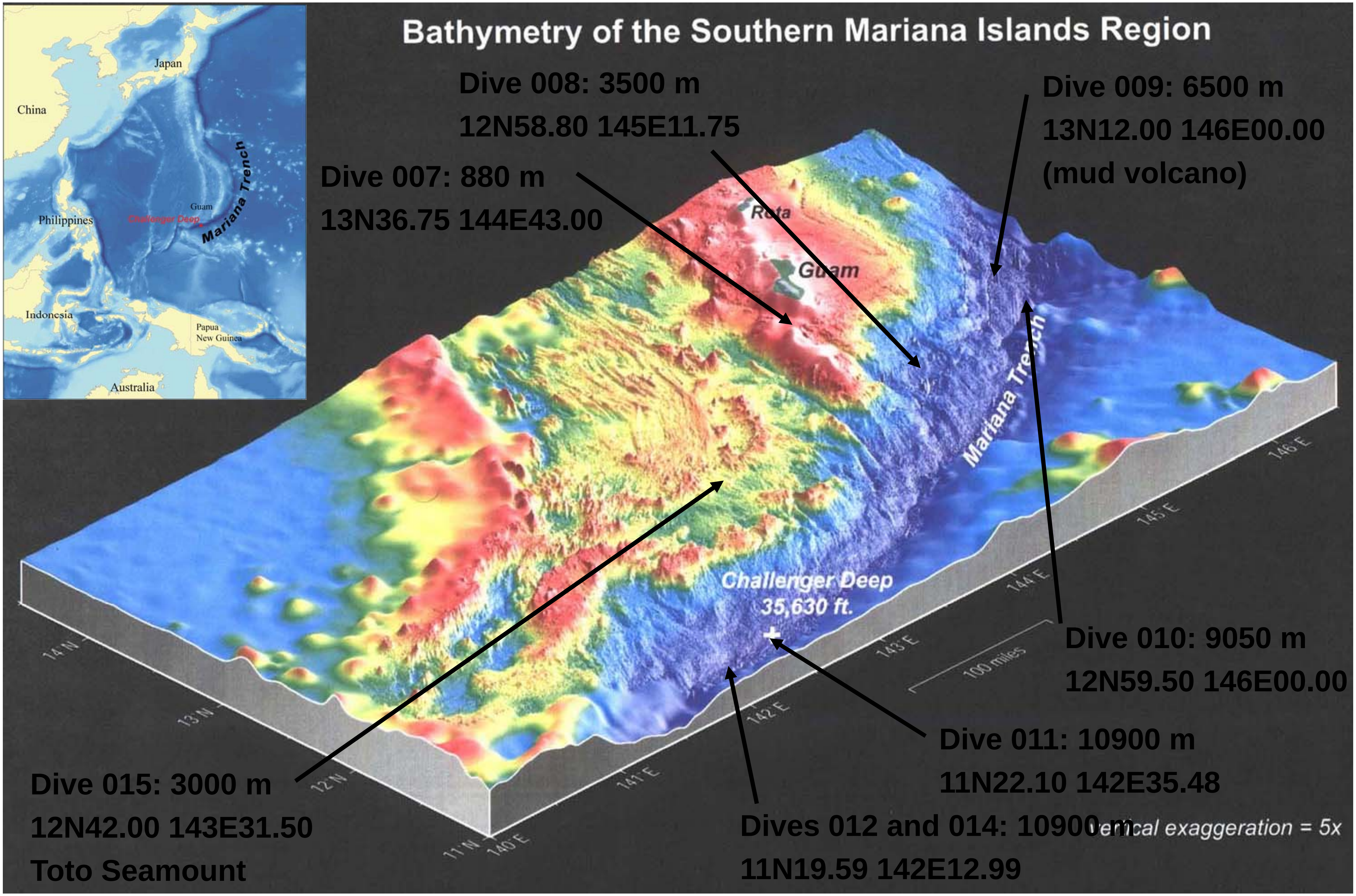
- Guam – Guam 14 days of deep engineering trials
- P. Fryer and T. Shank as science observers

HROV Project Team

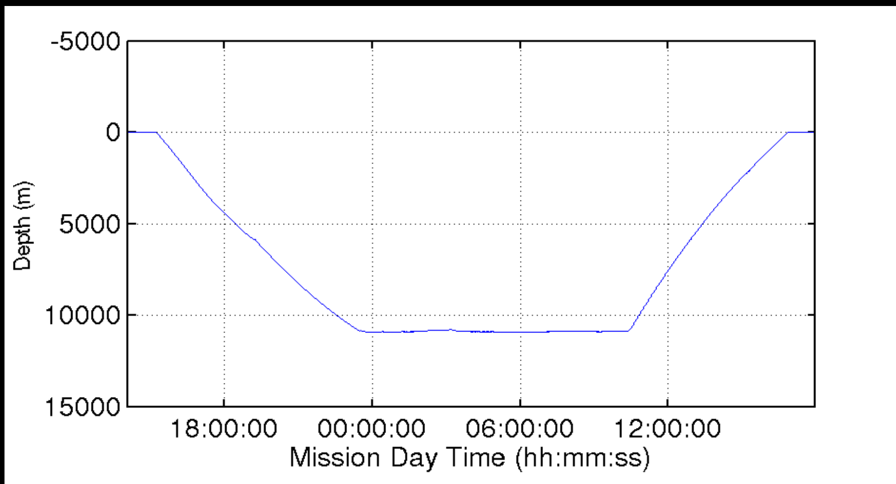
Mr. Andy Bowen	Principal Investigator
Dr. Dana Yoerger	Co-Principal Investigator
Dr. Louis Whitcomb	Co-Principal Investigator
Mr. Jonathan Howland	Lighting and Imaging
Mr. Chris Taylor	Overall Electrical System Design
Mr. Don Peters	Overall Mechanical System Design
Dr. Mike Jakuba	Flight Control
Dr. Al Bradley	Propulsion and Energy Storage
Mr. Matt Heintz	Manipulator
Mr. Daniel Gomez-Ibanez	Propulsion and Energy Storage
Mr. Chris Young	Fiber
Mr. Stephen Martin	Mission Control
Ms. Barbara Fletcher	Project Manager
Mr. James Buescher	Fiber
Mr. Jerry Stachiw	Ceramics

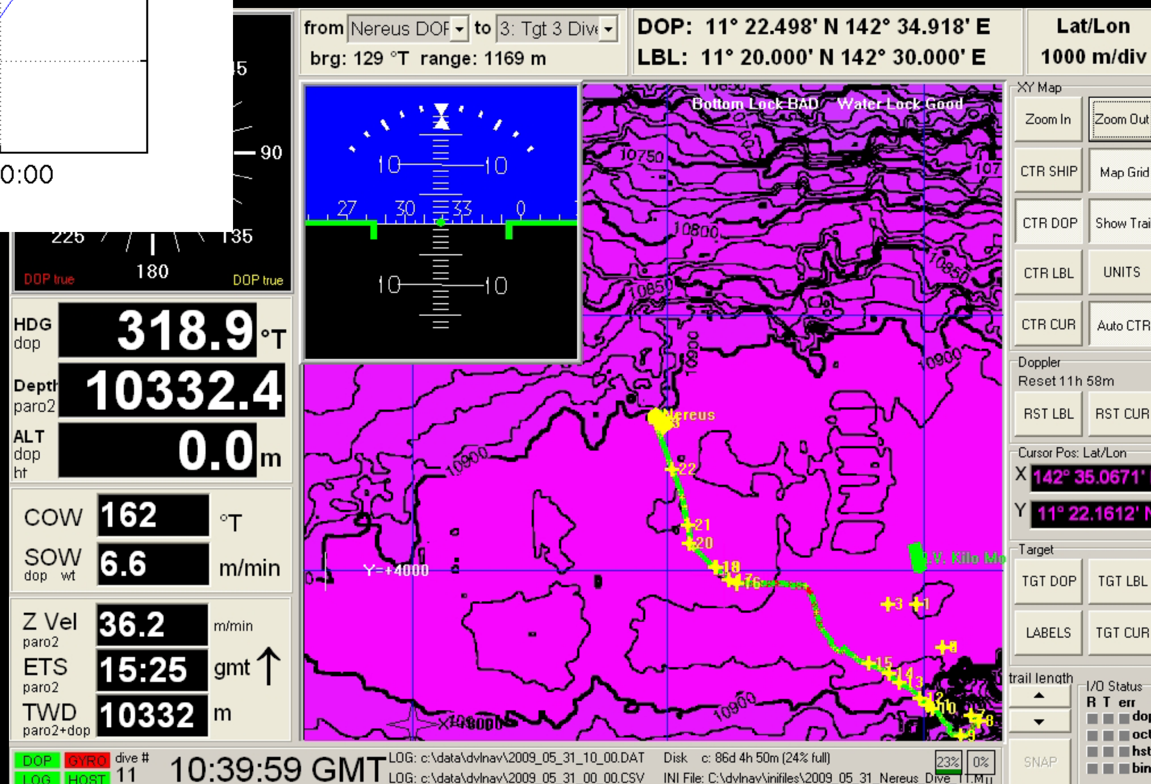
- WHOI Design Staff as required (approx. 15 eng & tech staff)

Nereus 2009 Mariana Expedition

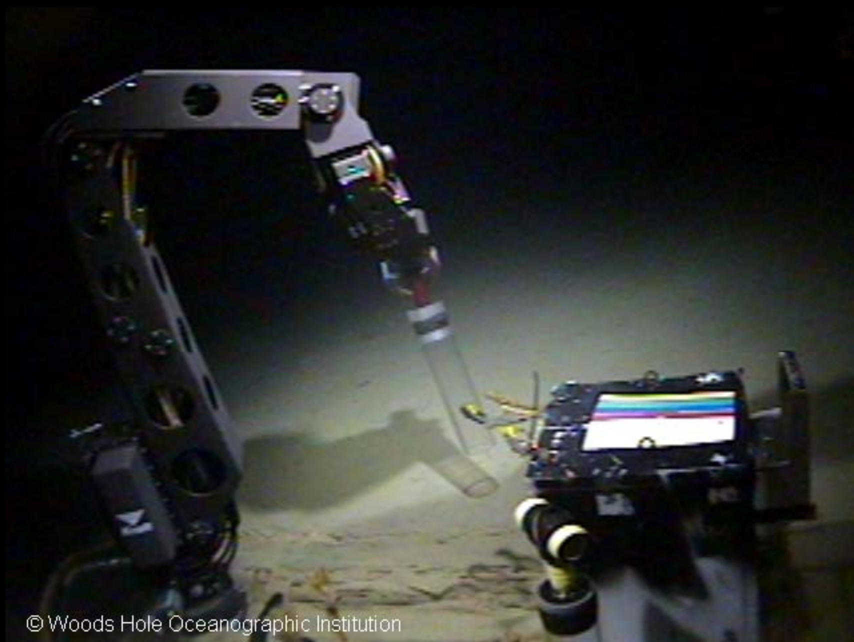


Nereus 011: Dive to 10,903 m Depth





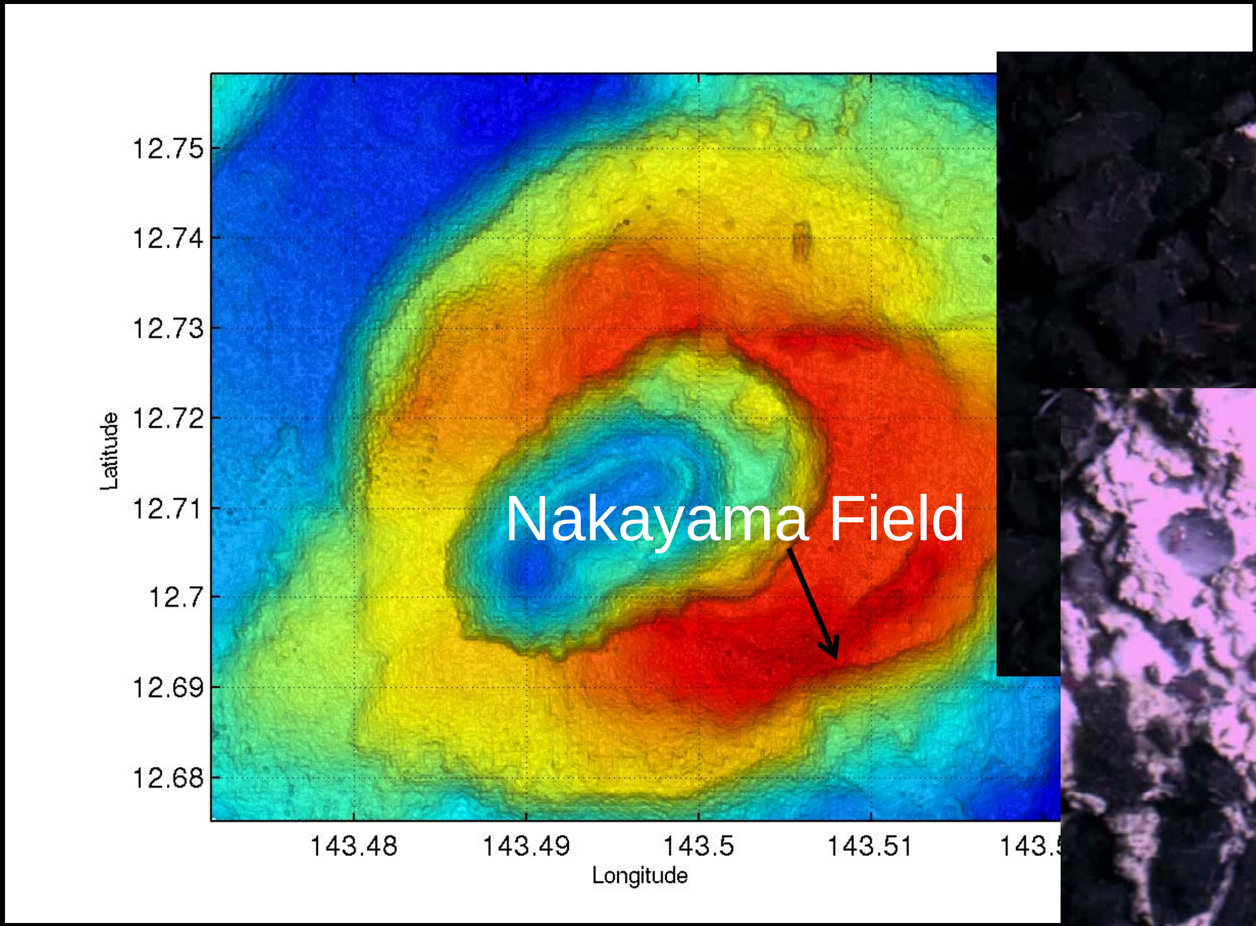
Nereus Sampling

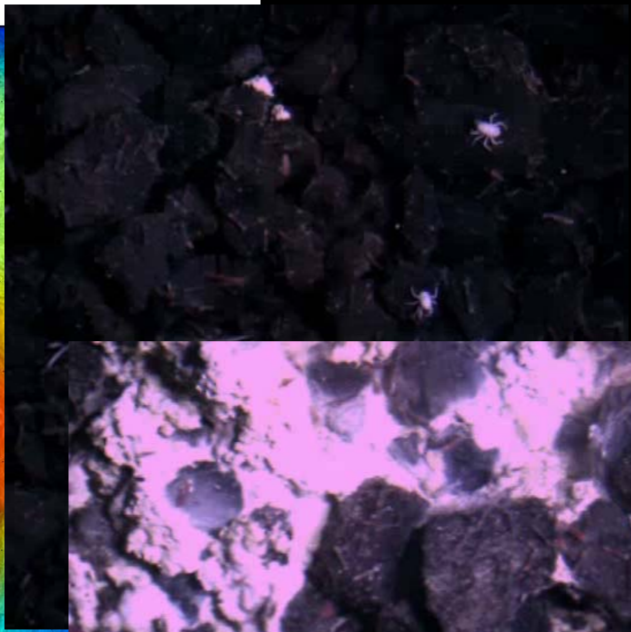


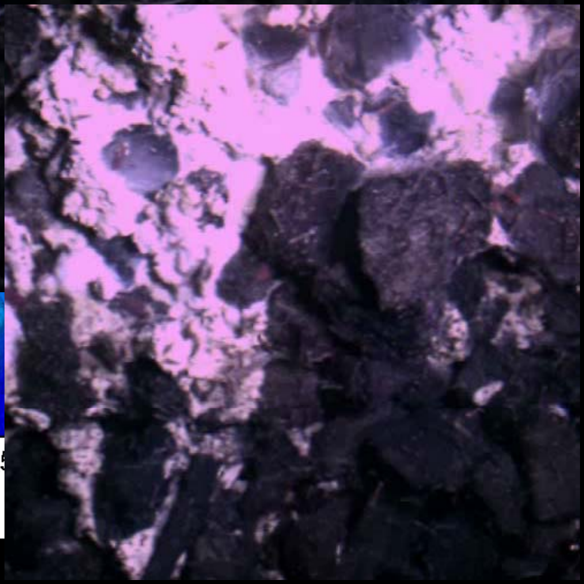
Dive Statistics

Dive	Depth (m)	Duration (hr)	Distance (m)	Termination
007ROV	911	8.4	1045	Deliberate
008ROV	3511	11.1	670	Aborted (oil leak)
009ROV	6430	13.8	70	Fiber severed (bottom)
010ROV	9039	18.5	1160	Deliberate
011ROV	10902	27.8	2835	Deliberate
012ROV	10899	19.3	735	Fiber severed (bottom)
014ROV	10176	14.1	0	Fiber severed (descent)
015ROV	2963	11.6	1560	Deliberate
Total: 8				

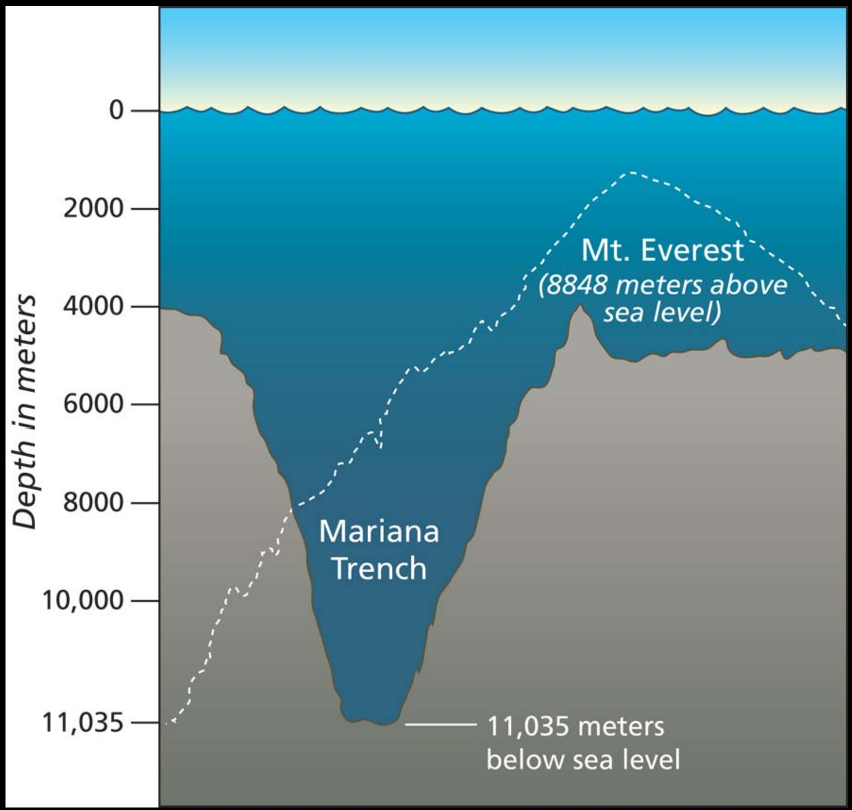
TOTO Caldera







Nereus Reaches 10902 meters in Challenger Deep, May 31 2009



The Washington Post

"*Robot on a Tether Targets The Mysteries of the Deep*"

U.S.News & WORLD REPORT usnews.com

"*Sub Explores Ocean's Deepest Trench*: *An ocean vehicle called Nereus has just made the deepest ocean dive to date*"

naturenews

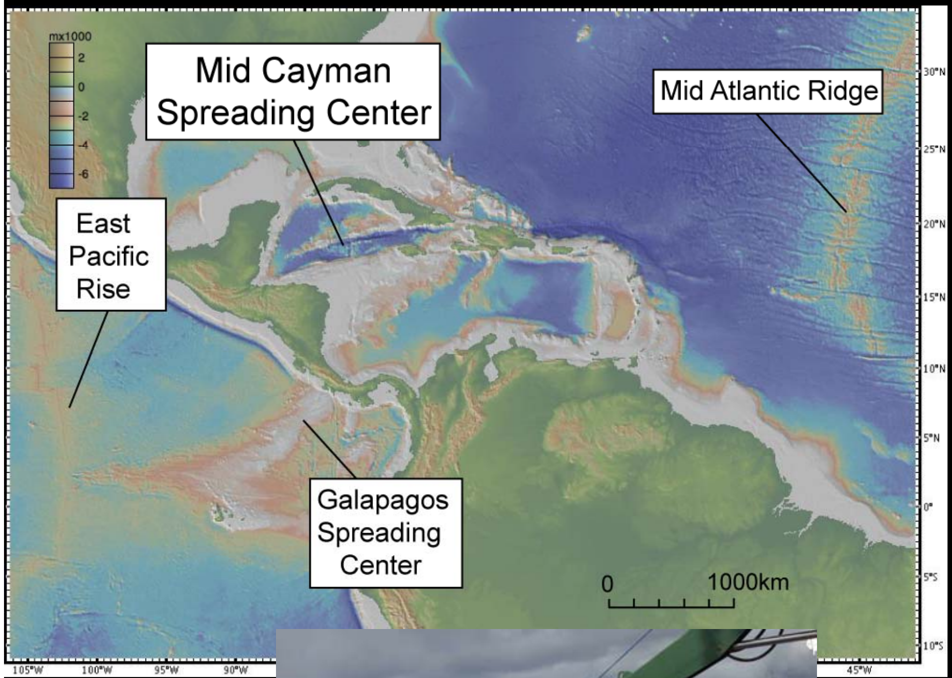
"*Submersible plumbs the depths*"

FOX NEWS .com Fair & Balanced

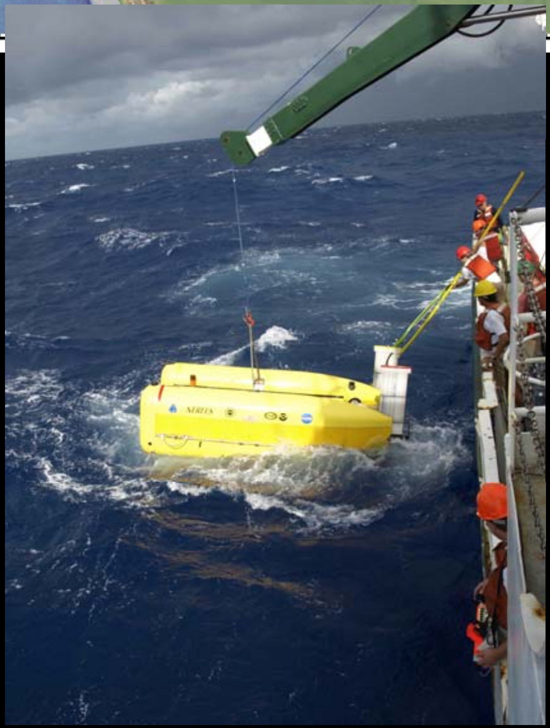
"*Hair-Thin Fiber Guides Robot Sub to Record Depth*"

BBC

"*Robot sub reaches deepest ocean*"



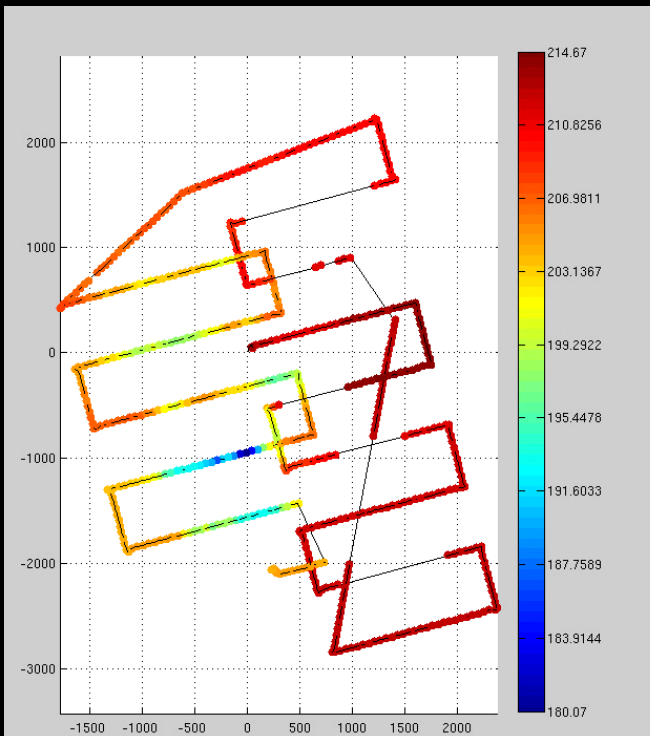
Cayman Trough 2009

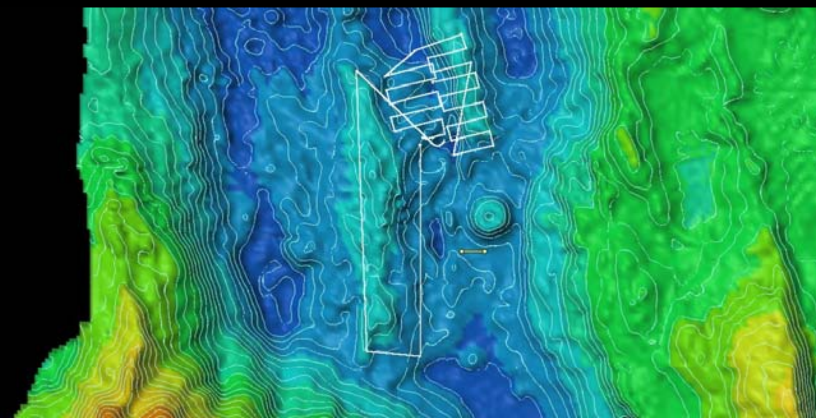


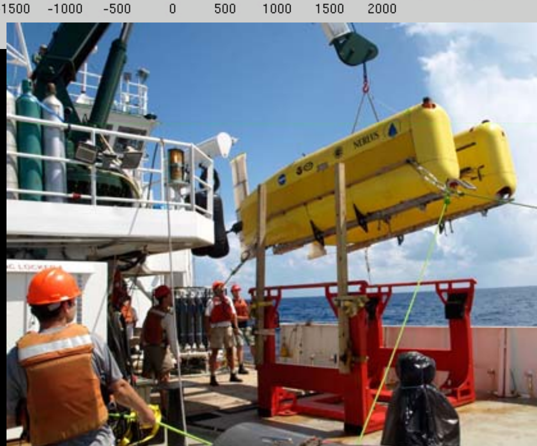
RV Cape Hatteras

- NASA ASTEP funding
- 2 legs
    - CTD & AUV for search
    - ROV for Sampling

Cayman Trough 2009







AUV Leg

- 7 AUV dives
- 115 KM surveyed
- CTD, EH, OBS sensors
- Scanning sonar
- USBL
- AComms

Cayman Trough 2009

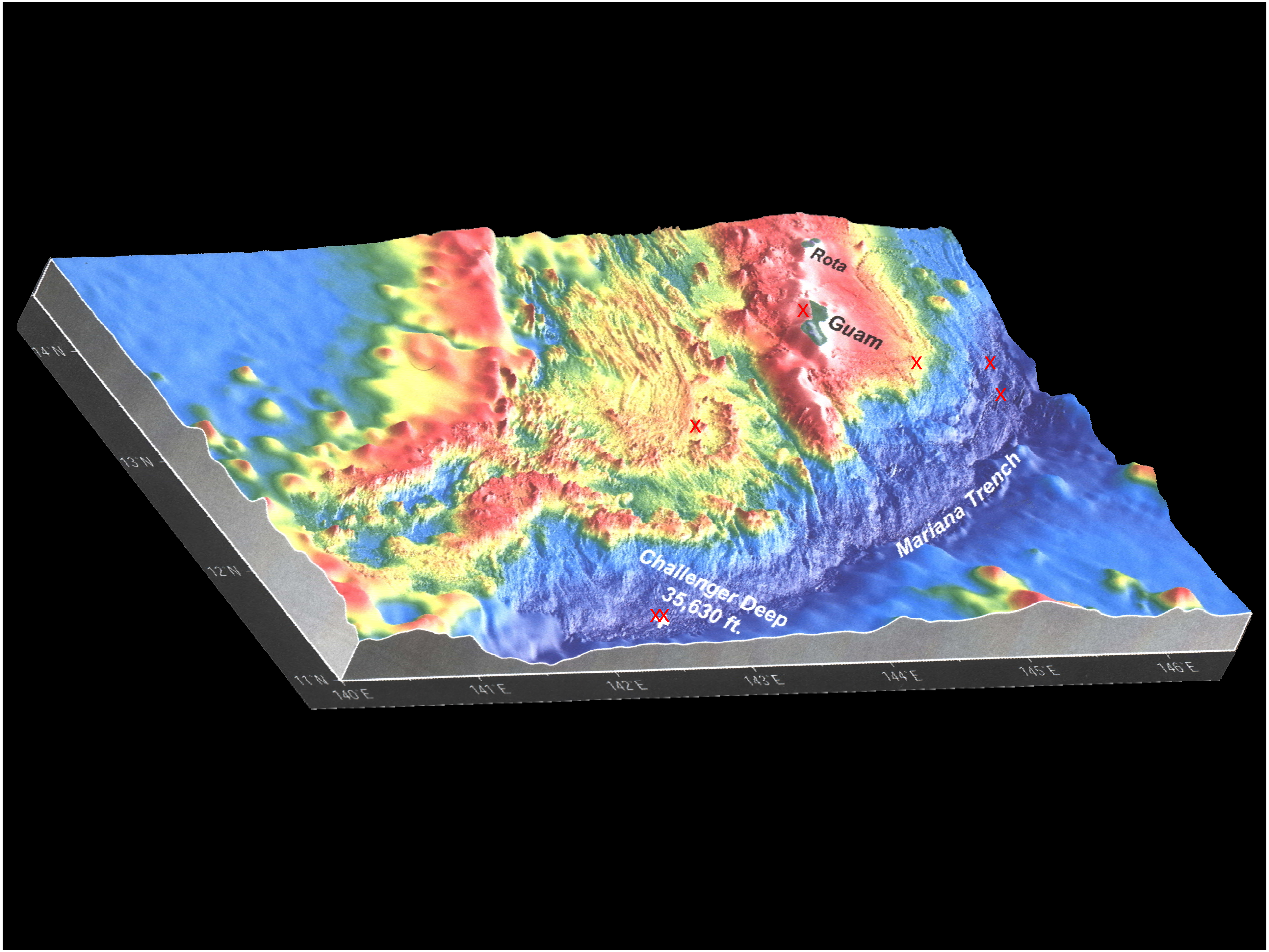
ROV Leg

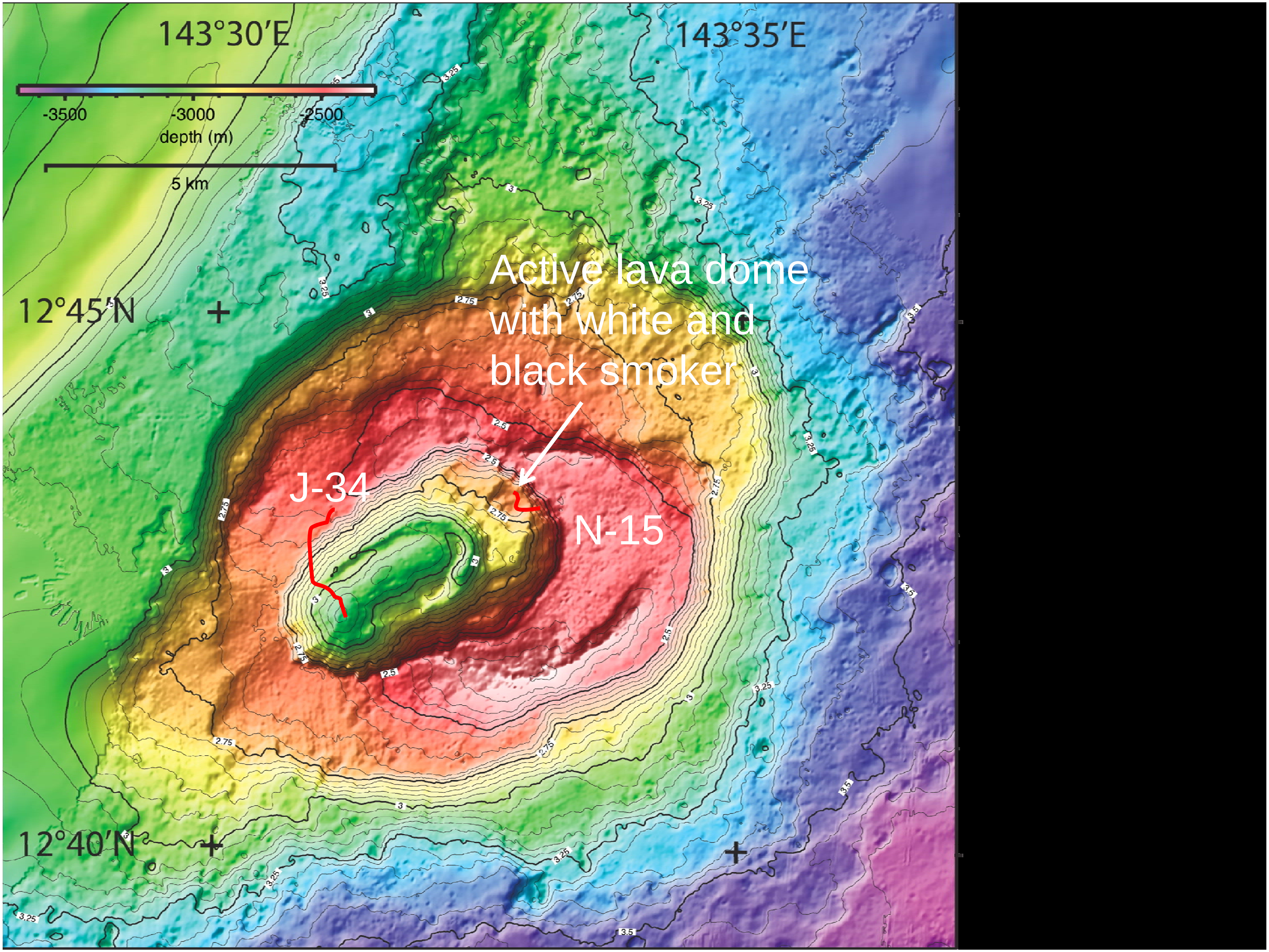
- 3 dives to 5km
- 9 km covered on bottom
- 24 hours on bottom

Conclusions

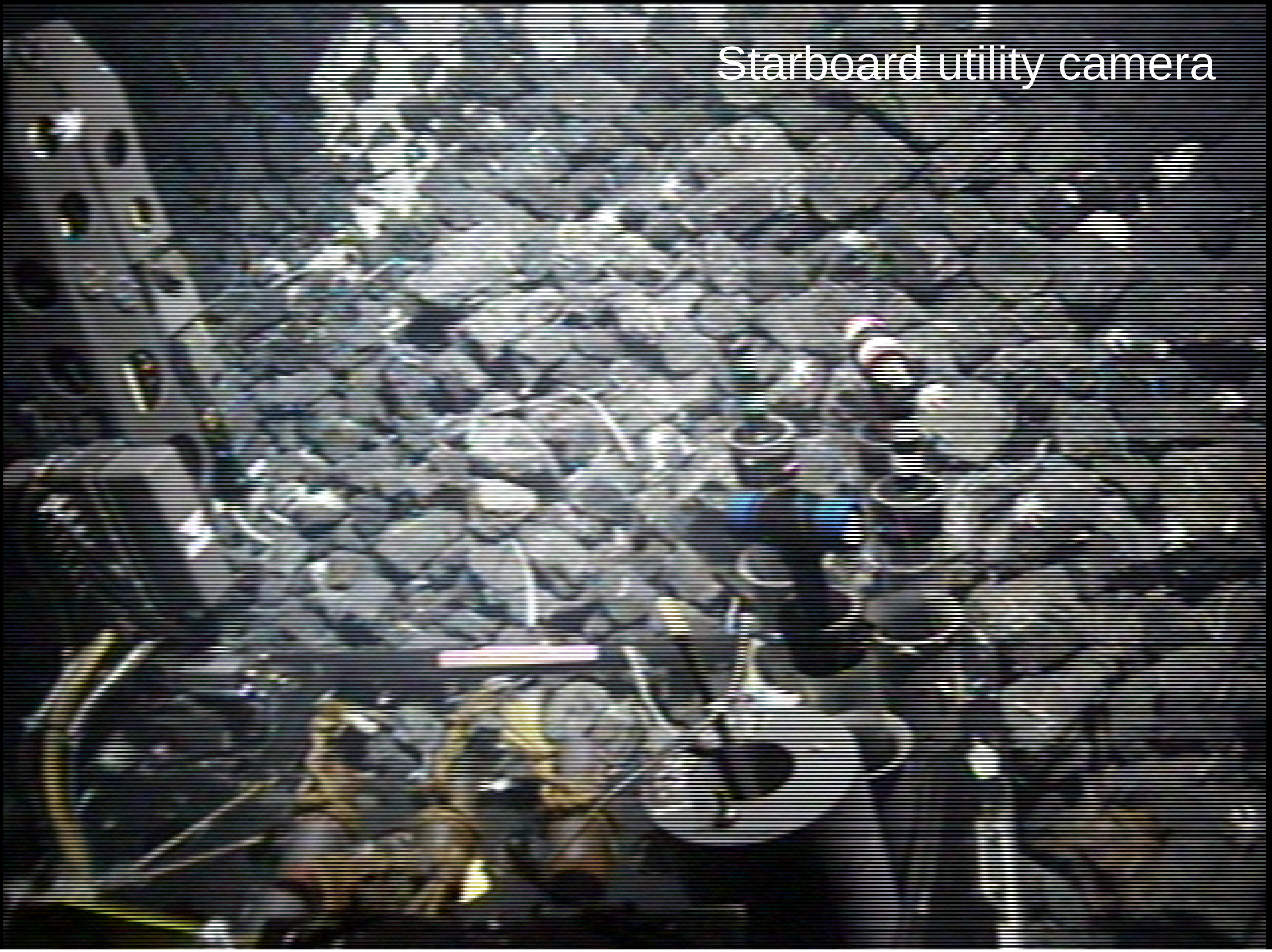
- HROV *Nereus* is becoming a proven platform for conducting oceanographic science in the world's deepest oceans.
  - Full ocean depth capability
  - High bandwidth (GigE) communications with AUV-like horizontal mobility (kilometers)
  - Deployable from regional and ocean class oceanographic vessels
- Technologies developed for the Nereus vehicle may enable a new generation of light-tethered semi-autonomous intervention vehicles.

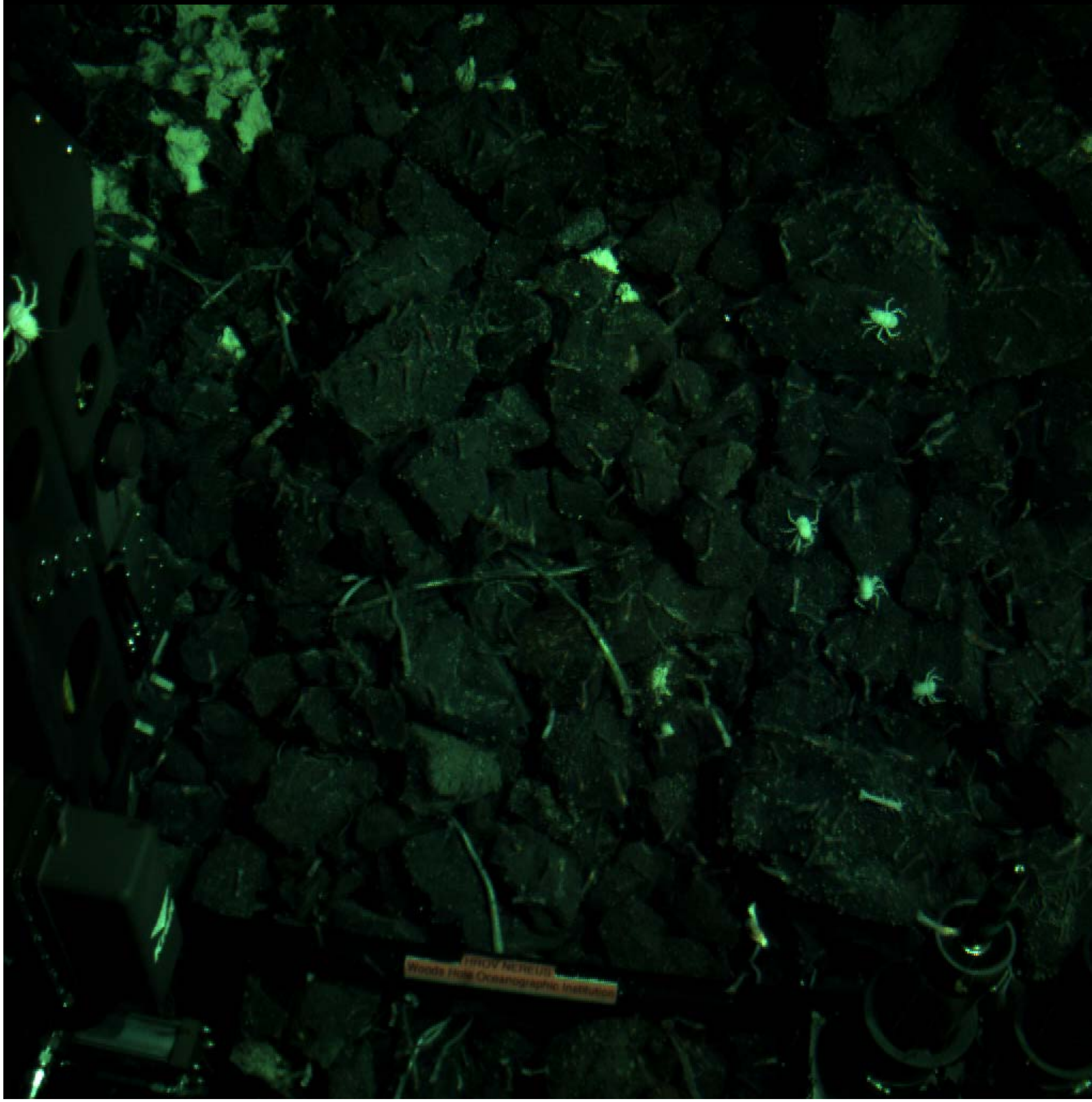
Questions?


Rota
Guam
Mariana Trench
Challenger Deep
35,630 ft.
14°N
13°N
12°N
11°N
140°E
141°E
142°E
143°E
144°E
145°E
146°E


143°30'E
143°35'E
-3500
-3000
-2500
depth (m)
5 km
12°45'N
12°40'N
Active lava dome
with white and
black smoker
J-34
N-15


Port utility camera


Starboard utility camera



Shrimp:
*Chorocaris vandoverae**

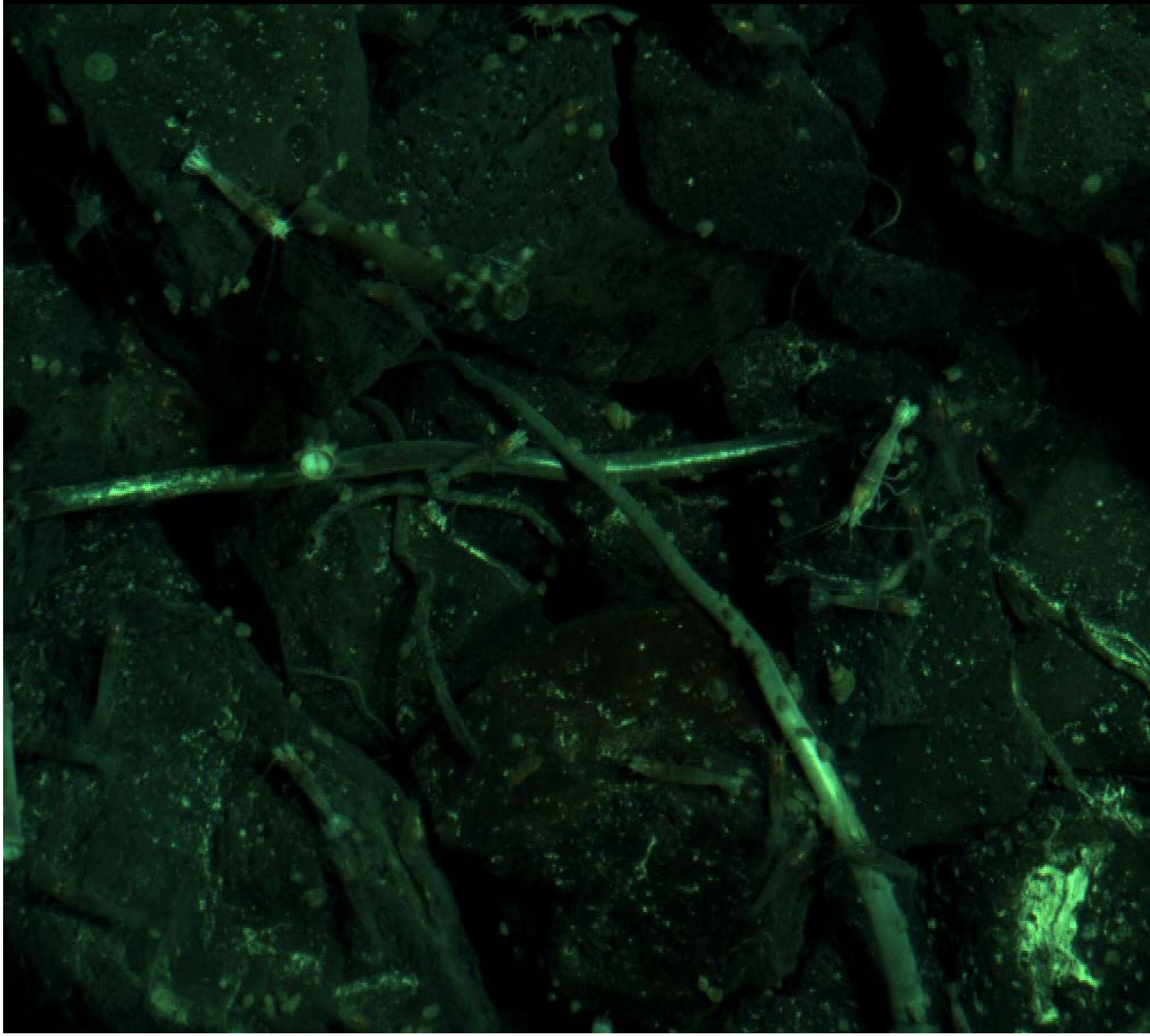
Anemones, galatheids

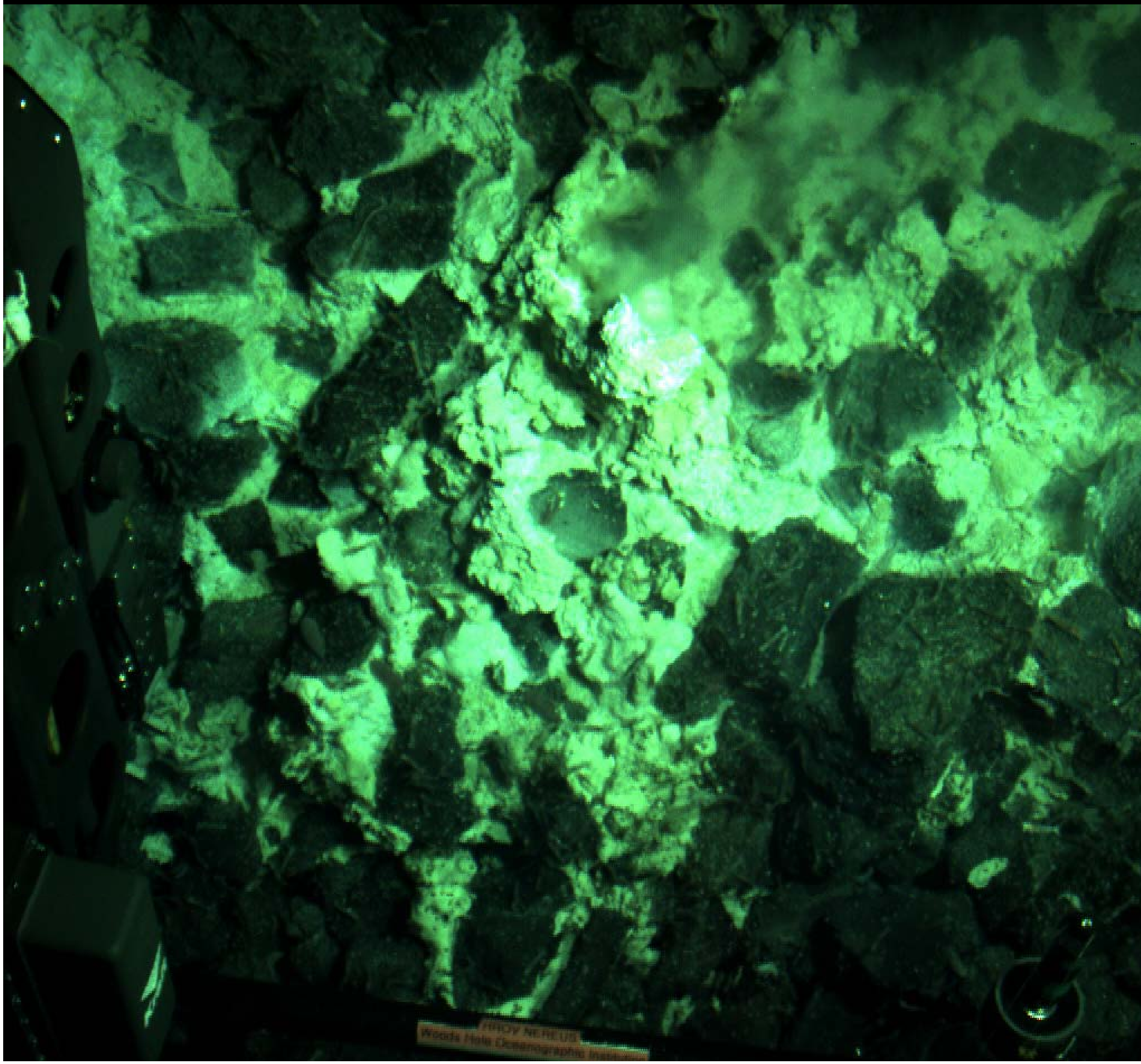
Stalked barnacles:
Neolepadids, 2 species

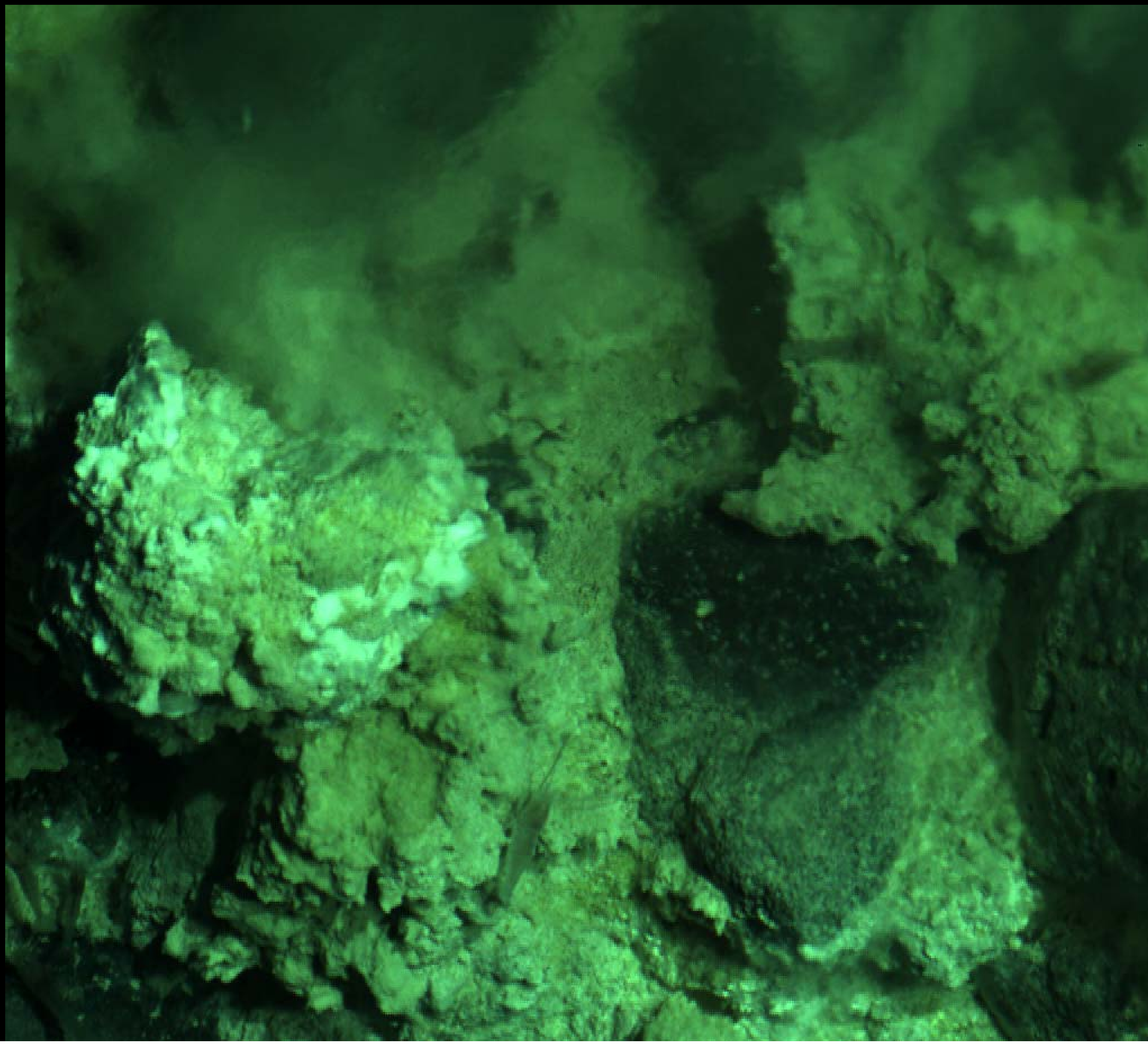
Tubeworms:
Lamellibrachia juni
(chemosynthetic
vestimentiferan)

Microbial mats:

(*Nakagawa et al. 2006)




HROV NEREUS
Woods Hole Oceanographic



AUV Configuration Trials 2009, Woods Hole

- ✓ Closed-loop speed control
- ✓ Obstacle avoidance
- ✓ Combined bottom-following/obstacle avoidance
- ✗ Operating envelope
- ✗ Autonomous descent

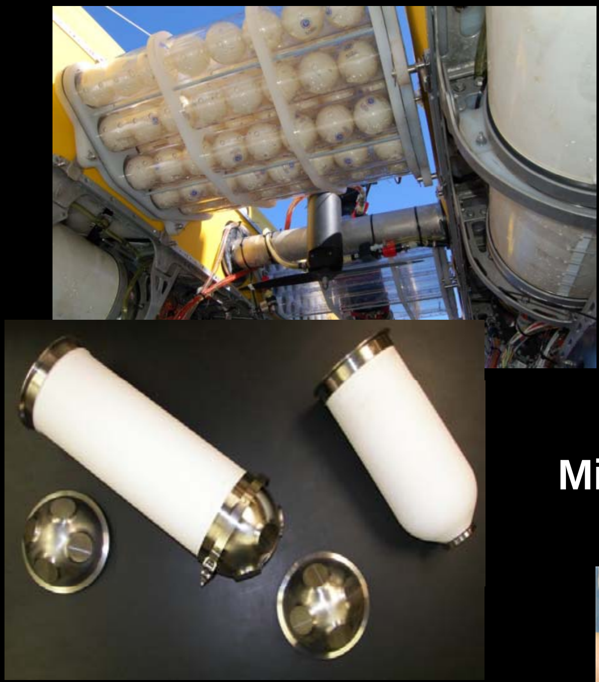
- HROV *Nereus* is a proven platform for conducting oceanographic science in the world's deepest oceans.
  - Full ocean depth capability
  - High bandwidth (GigE) communications with AUV-like horizontal mobility (kilometers)

- Technologies embodied in the Nereus vehicle may herald a new generation of light-tethered semi-autonomous intervention vehicles.

Dive	Mean Depth	Total Time Hours:Minutes	Survey Time Hours: Minutes	Distance Travelled	Notes
Nereus 016	1053m	5:48	2:56	0.95 km	AUV Engineering Dive
Nereus 017	2087m	9:24	6:05	9.72 km	AUV Engineering Dive
Nereus 018	4076m	20:18	14:25	25.3 km	AUV Water Column Survey
Nereus 019	4449m	9:30	3:12	4.94 km	AUV Near-Bottom Mapping
Nereus 020	4665m	23:55	18:07	15.34 km	AUV Near-Bottom Mapping
Nereus 021	4250m	17:24	11:56	35.3 km	AUV Water Column Survey
Nereus 022	4900m	20:12	13:45	25.5 km	AUV Near-Bottom Mapping
Nereus 023	N/A	N/A	N/A	N/A	ROV Harbor Dunk
Nereus 024	4966m	10:08	2:20	0.52 km	ROV Dive
Nereus 025	4908m	18:06	9:17	2.3 km	ROV Dive
Nereus 026	2114m	16:48	12:05	6.75 km	ROV Dive

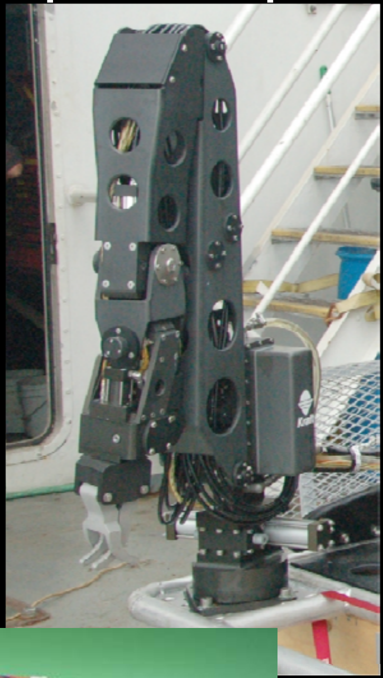
New Technologies of the Nereus Project:
How will they Impact Oceanography?

Ceramic Buoyancy and Pressure Housings



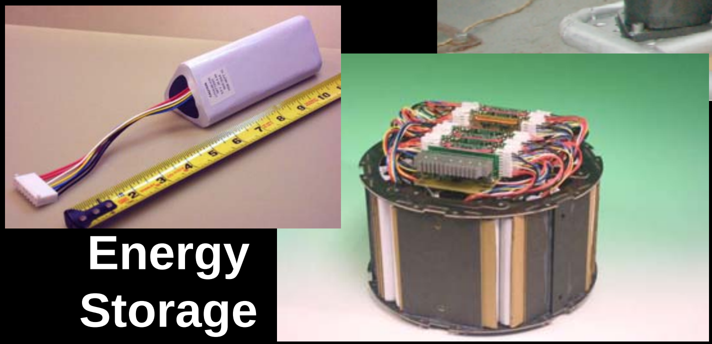
Low Power High Quality Imaging/Lighting

Low Power Capable Manipulators



Micro-Fiber Tether System

Energy Storage



HROV Control and Navigation Highlights

- Control: *Michael Jakuba Ph.D.*
  - ROV Mode Control: Auto-heading, auto-depth, auto-XY.
  - AUV Mode Flight-Control: Hover, Level Flight, Pitching Flight.
  - Terrain following: low altitude (5m +/- 1m) and high altitude (e.g. 50m +/- 5m)
  - Hydrodynamic Performance Characterization of vehicle, control surfaces, and propulsors.

- Navigation: 300 kHz Doppler, Optical gyrocompass, and pressure depth. *James Kinsey Ph.D.*
  - Autonomous Doppler navigation in AUV-mode.
  - Interactive Doppler navigation in ROV mode.

- Acoustic Communication: *Sarah Webster*
  - Real-time uplink of of navigation data, vehicle health data, and sensor data.
  - Real-time downlink of commands (e.g. “abort”, start mission X, etc.).
  - Interrogation of standard Benthos LBL transponders for LBL navigation.

- Mission Control, Waypoint, and Trackline Control: *Stephen Martin*
  - Executes pre-programmed high-level missions and responds to sensor input.
  - Launch new missions on command or in response to sensed condition. In ROV-mode monitors fiber tether, executes pre-programmed mission on loss of fiber telemetry.

[redacted]

Missions Enabled:

- Deployable on Ship-of-Opportunity
- Rapid Event Response
- Full ocean depth
- Under Ice Operations

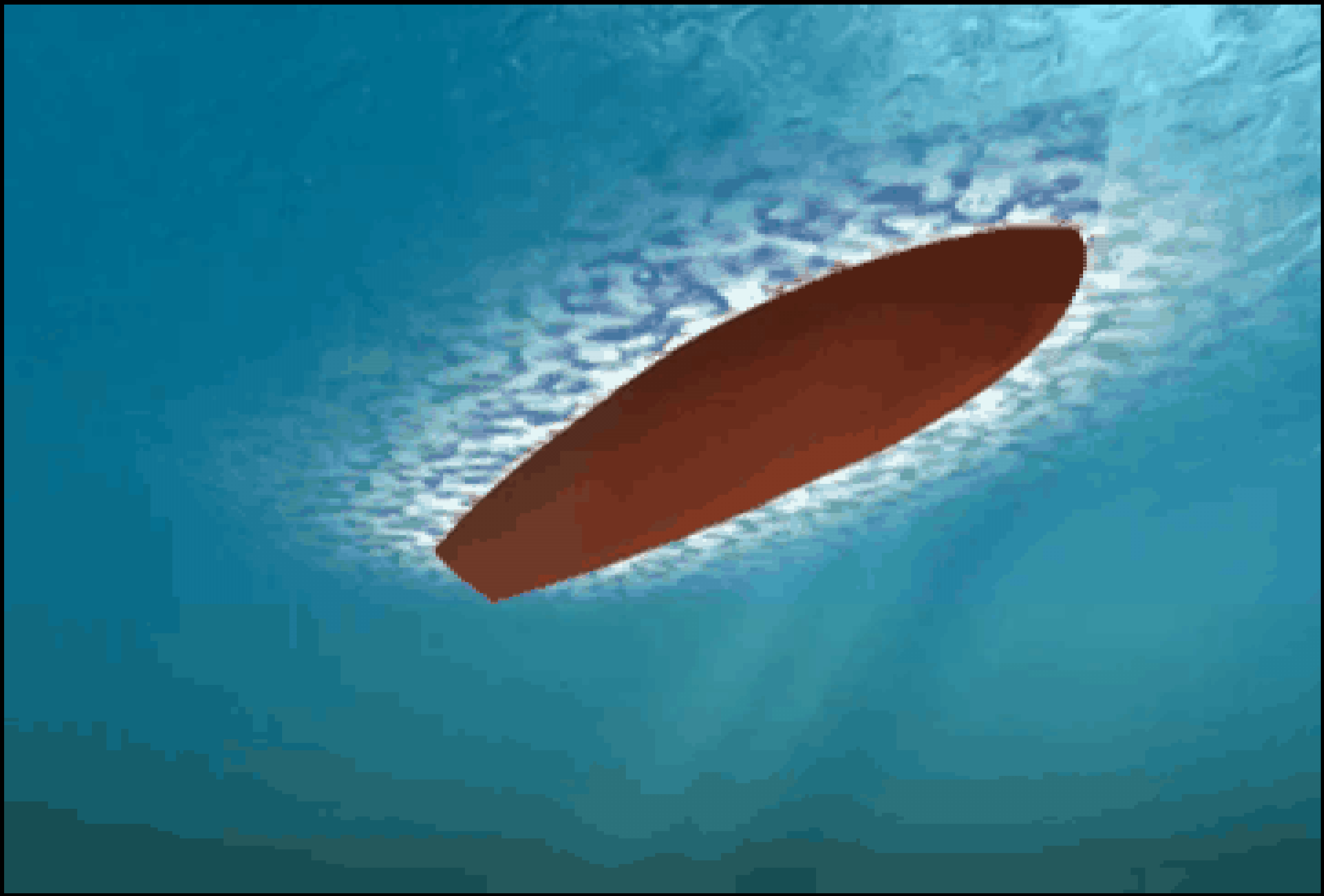
Comparison to State-of-the-Art:

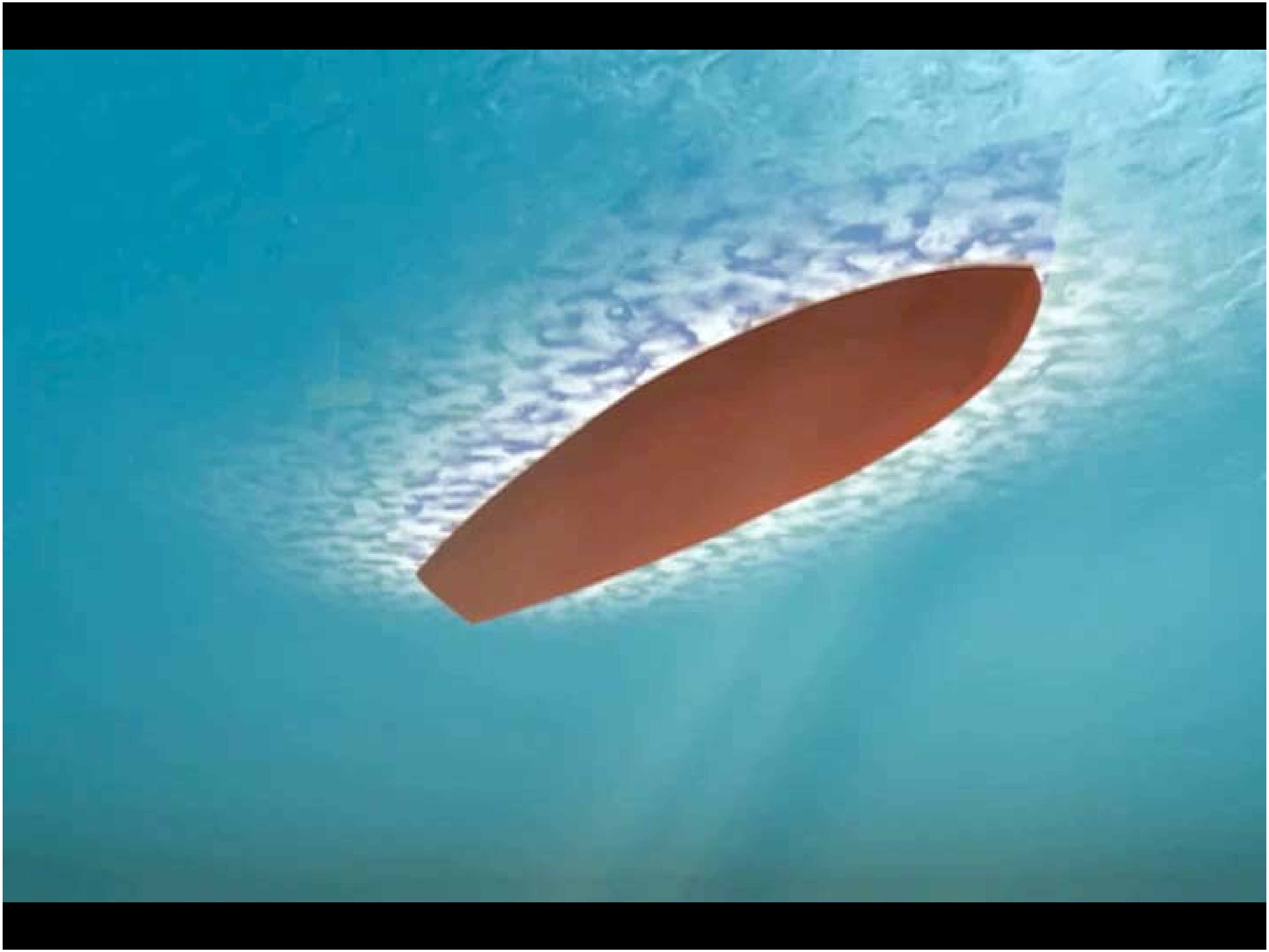
- 25,000 lbs vs. 90,000 lbs “system” weight for Nereus compared to Jason
- 5-6 Operational personnel vs. 10 for Jason
- No requirement for Dynamic Positioning
- Simultaneous deployment of AUV and ROV systems on a single cruise

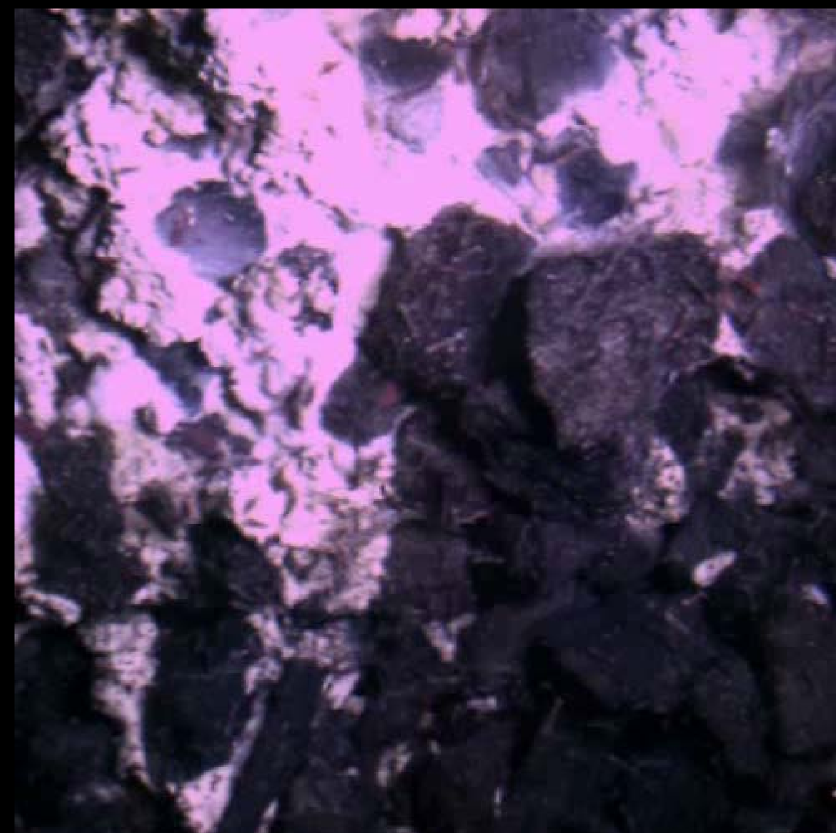
Project Notes

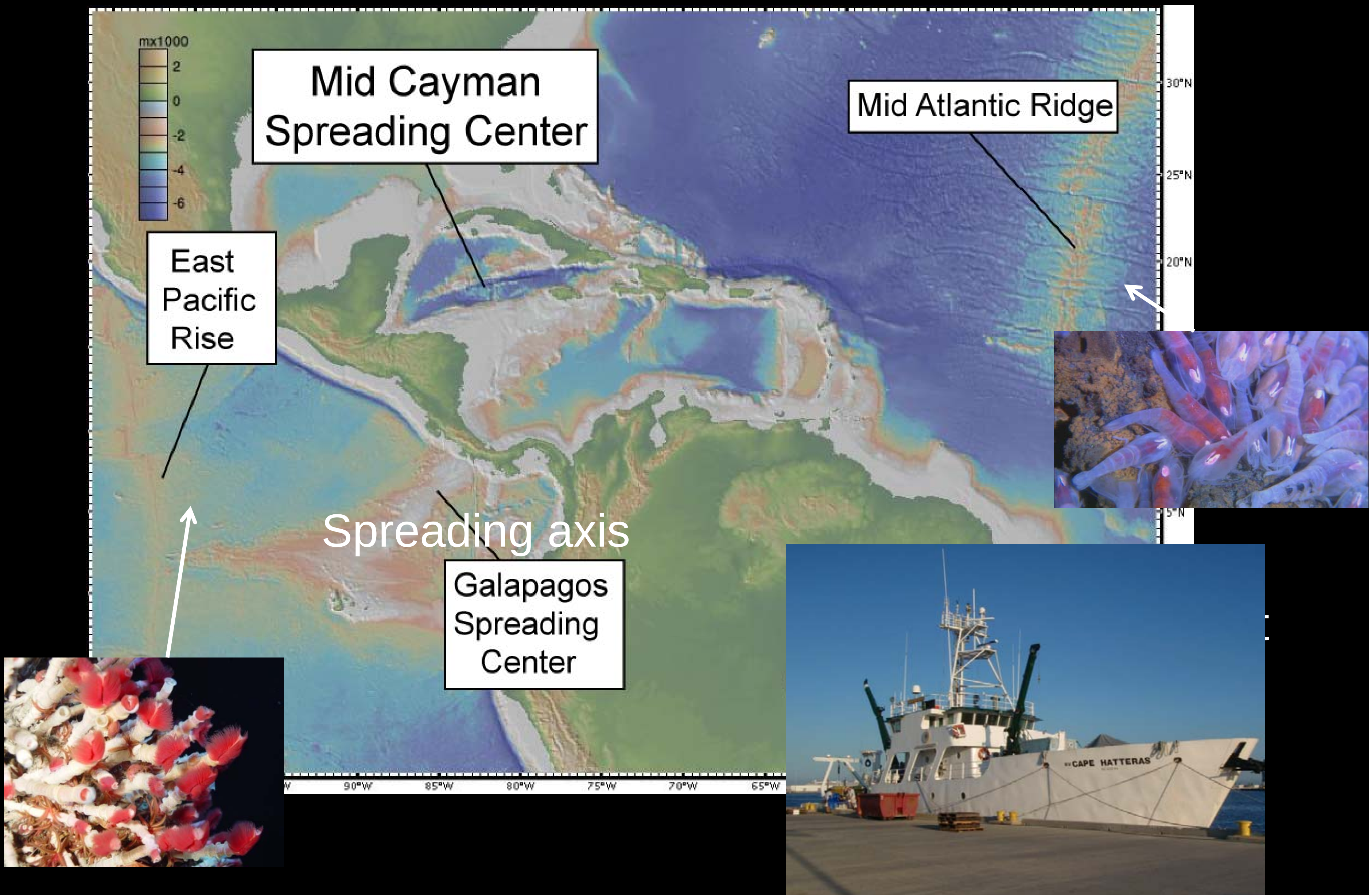
- HROV is an original mapping and sampling vehicle expanding technology and science to 11,000 meters
- HROV- 60% reduction in shipping cost compared to Jason II
- HROV- 40% reduction in estimated day rate compared to Jason II
- HROV technology transfer- Thin Fiber Communication Link, LEDs, batteries, etc. to other submergence systems/applications
- HROV can be effectively operated from non-DP ships (lowering cost)
- Synergistic approaches using two (lightweight/fly away) deep vehicles
- Educational opportunities and broadening experiences for diverse interactions amongst engineers and scientists
- Informal education capability focused on discovery in the most extreme environments on earth

- Operations with extreme horizontal and vertical mobility:
    - real-time hi-resolution remote inspection
    - instrument deployment and recovery
    - sample recovery
    - manipulation
- Operation from vessel of opportunity (no DP required):
  - Surface ship
  - Submarine
  - Air deployed
- Remote control and autonomous missions.
- Rapid event response
- Docking for launch and recovery
- Global reach






mx1000
2
0
-2
-4
-6
Mid Cayman Spreading Center
Mid Atlantic Ridge
East Pacific Rise
Spreading axis
Galapagos Spreading Center
30°N
25°N
20°N
5°N
90°W
85°W
80°W
75°W
70°W
65°W
CAPE HATTERAS