Development of a Hybrid Remotely Operated Vehicle (HROV) for Oceanographic Operations to 11,000m Depth

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UNOLS Arctic Icebreaker Coordinating Committee
March 31, 2005

HROV Project Team

Mr. Andy Bowen	Principal Investigator
Prof. Louis Whticomb	Co- Principal Investigator
Dr. Dana Yoerger	Co- Principal Investigator
Mr. Jonathan Howland	Lighting and Imaging
Mr. Chris Young	SPAWAR Light Fiber
Ms. Barbara Fletcher	SPAWAR Project Manager
Mr. Chris Taylor	Overall Electrical System Design
Mr. Don Peters	Overall Mechanical System Design
Dr. Al Bradley	Propusion and Energy Storage

- AOPE/DSL Design Staff as required (approx. 15 eng & tech staff)

HROV Advisory Committee

A panel of six oceanographic research scientists and engineers is providing guidance on how the HROV will best serve the scientific community's research needs

Melanie Holland	Arizona State University
Lawrence Lawver	University of Texas at Austin
Chuck Fisher	Pennsylvania State University
Deborah Kelley	University of Washington
Keir Becker	University of Miami
Jim McFarlane	International Submarine Engineering Ltd, British Columbia, Canada

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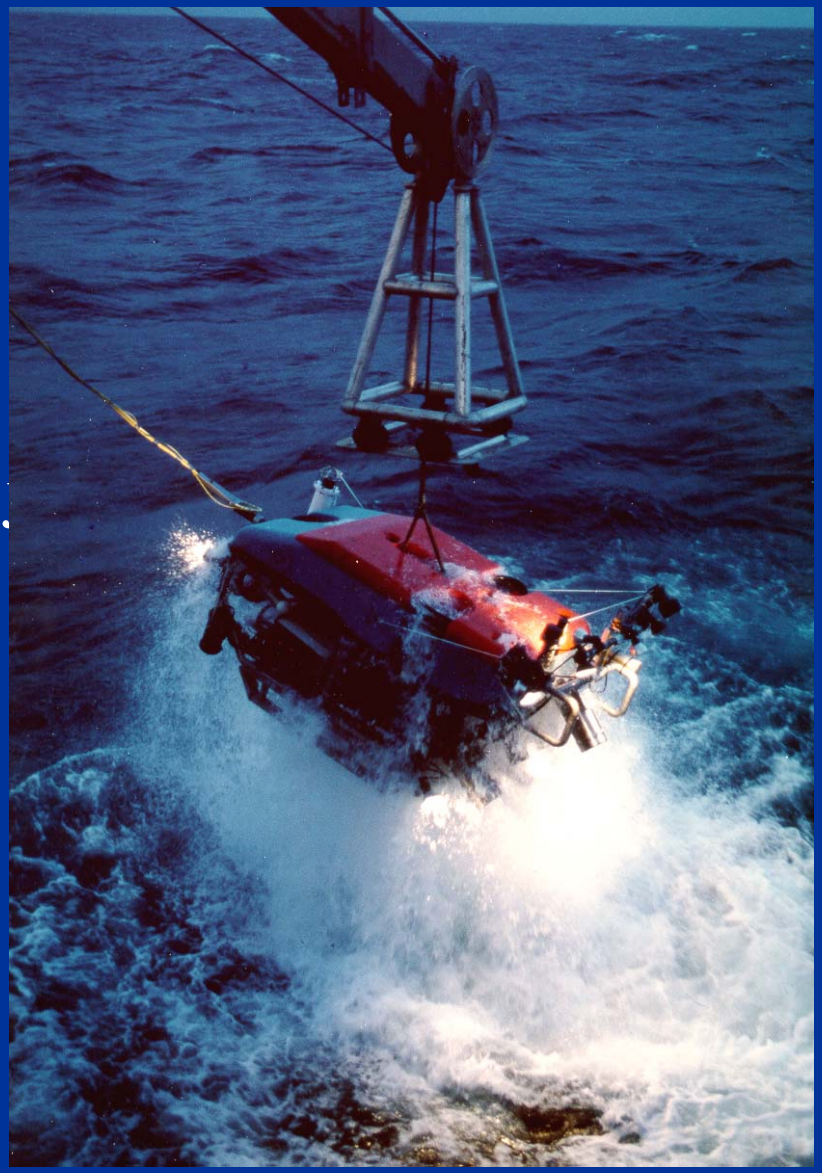
Jason I

- Development 1986
- First Dive: 1988
- Retired: 2001
- 253 dives
- 4700 hours of operation

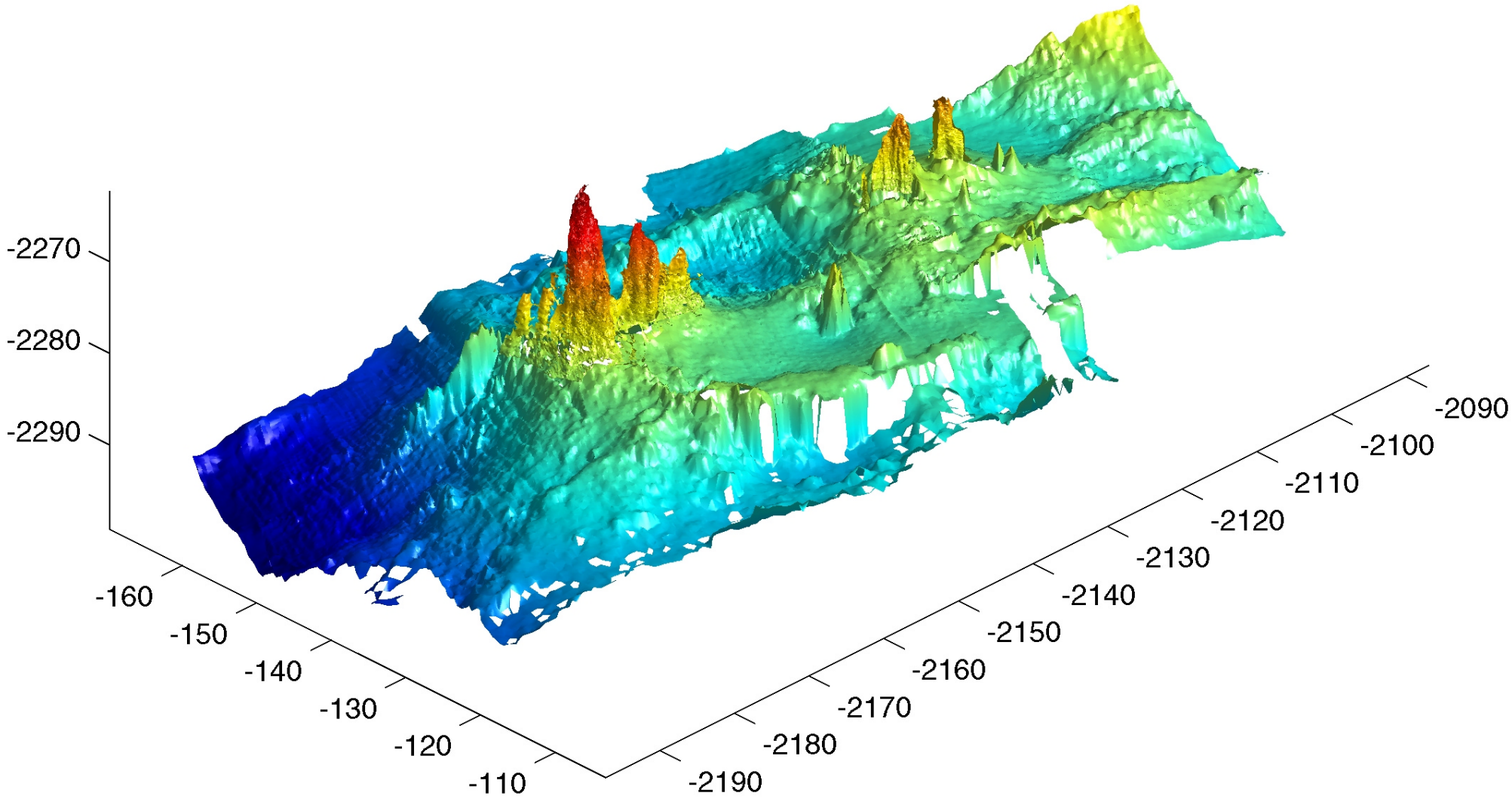


Jason II

250 lbs. of payload, with 300 lb. tool sled (Jason I had about 75 pounds)

Two spatially correspondent master-slave manipulators that can lift a person at full reach -- one is “force reflective”

- 500 lbs. of thrust in each axis (Jason I had 150 pounds)
- Proven operations to 6,500 meters (deepest diving operational ROV worldwide)
- Heavy lift capability 1.5 ton at maximum operational depth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-2280
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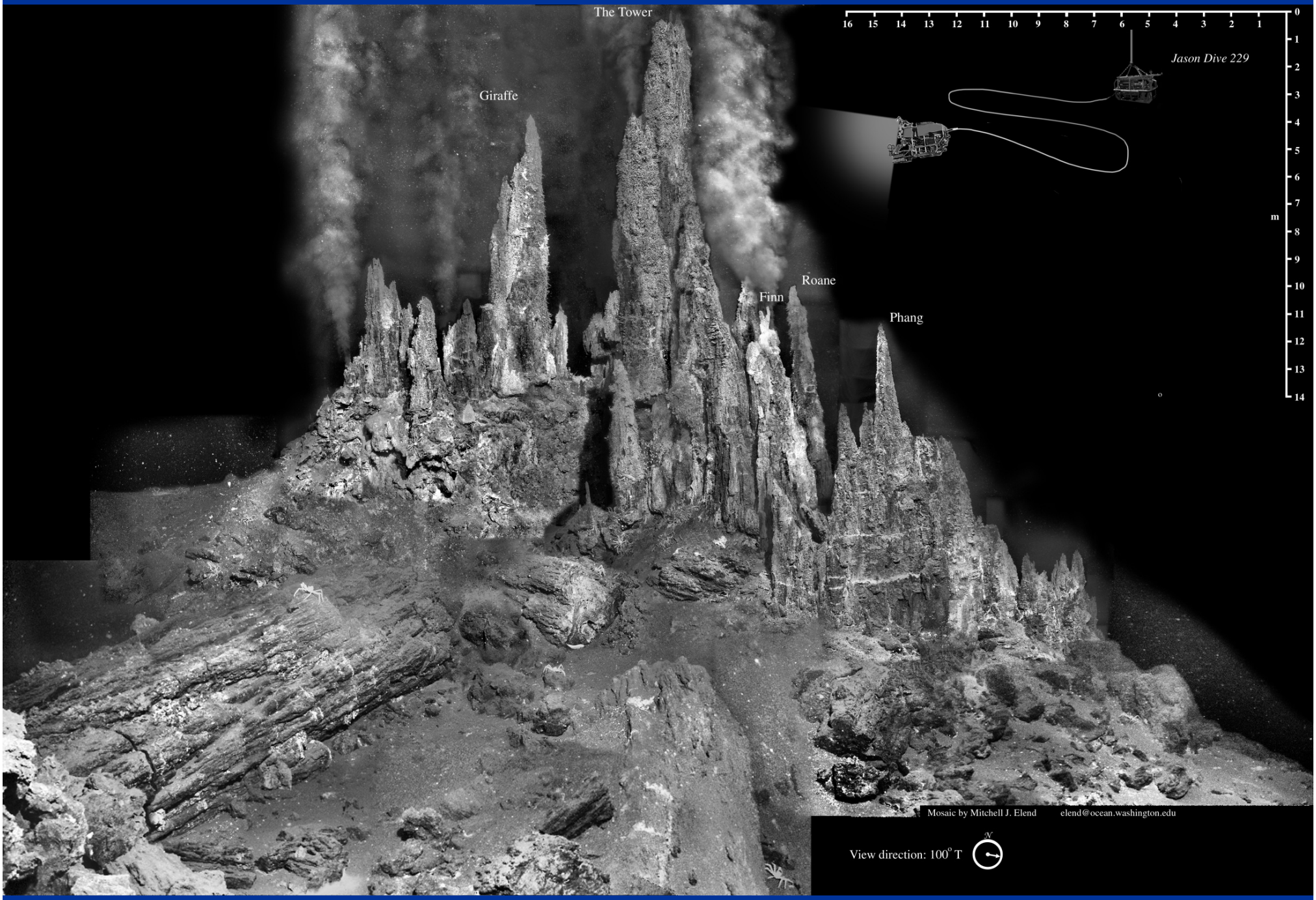
-2110
-2100
-2090


The Tower
Giraffe
Roane
Finn
Phang
16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
m
Jason Dive 229
Mosaic by Mitchell J. Elend elend@ocean.washington.edu
View direction: 100° T
N

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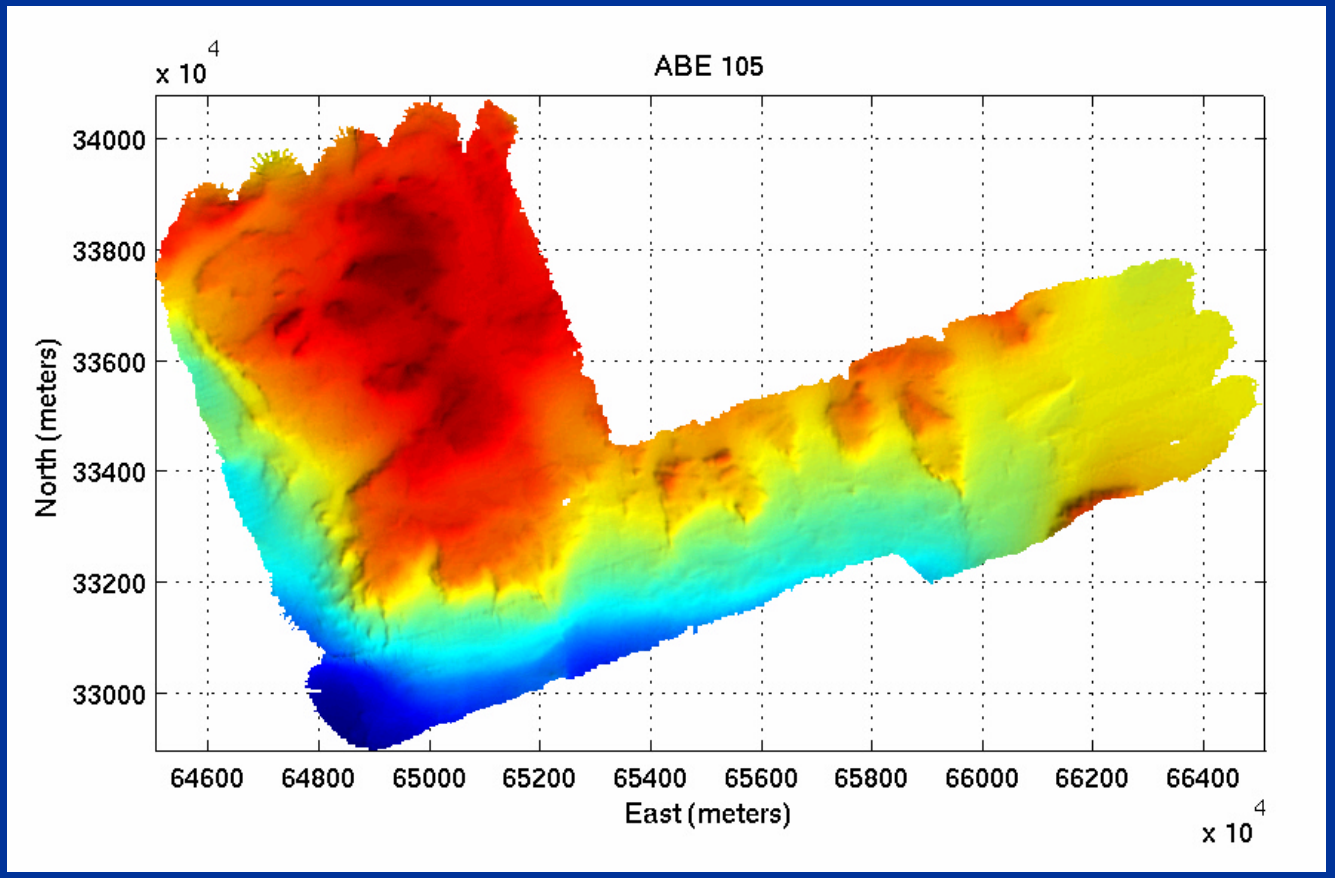
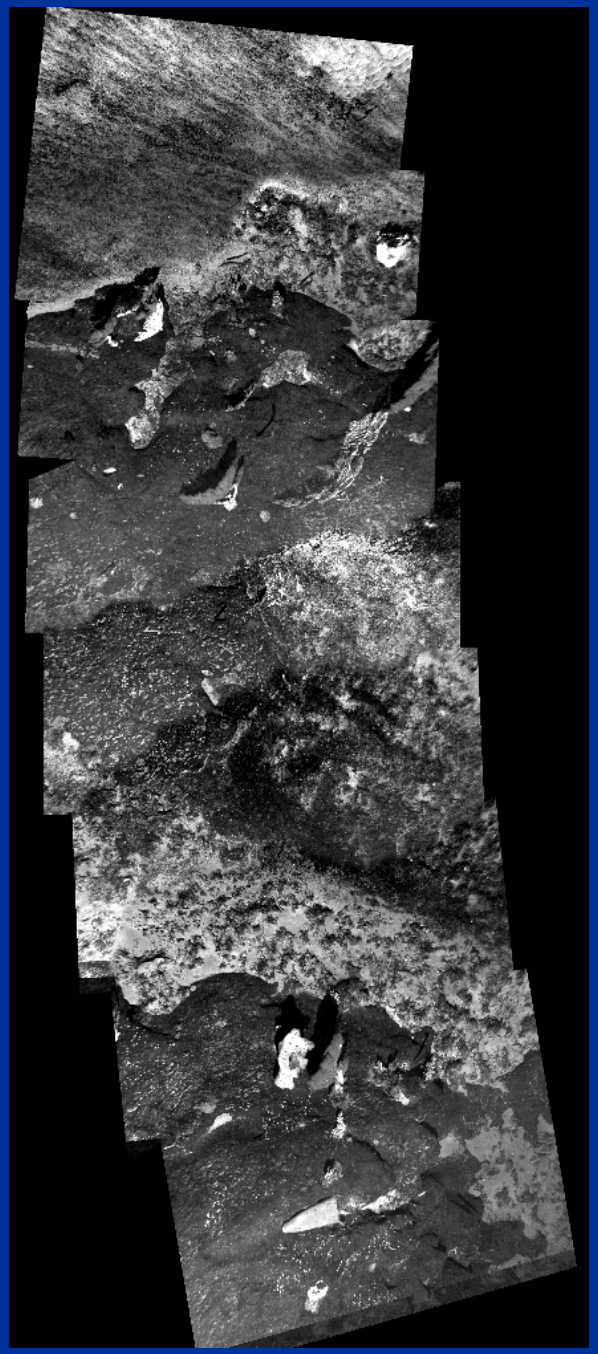
Autonomous Benthic Explorer (*ABE*)





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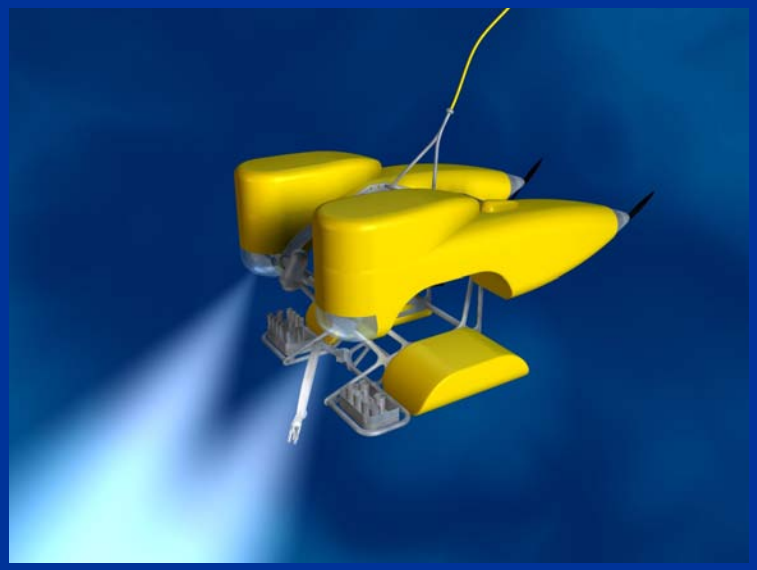
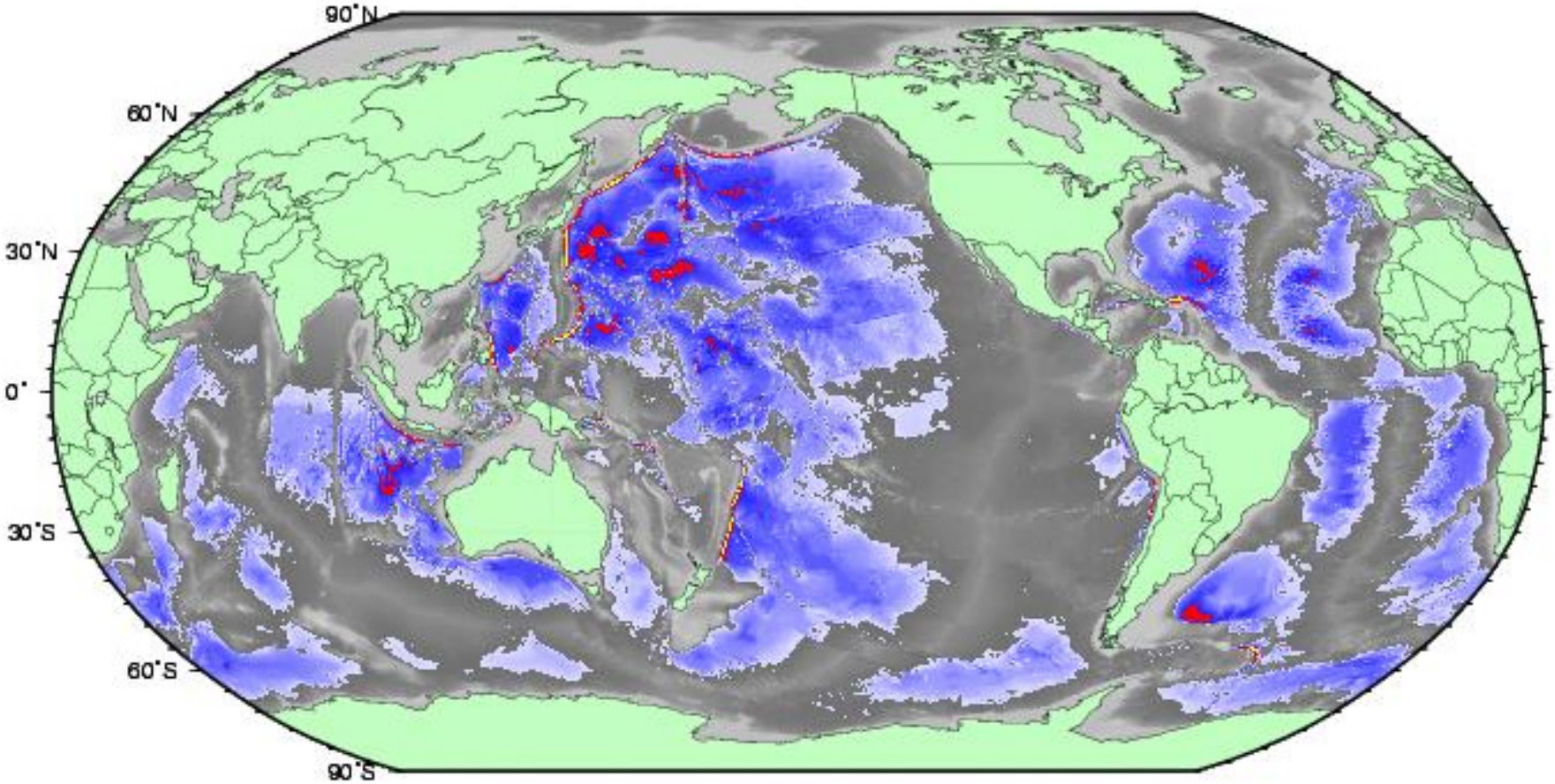
Evolution of a Deep Ocean Exploration Vehicle

ABE:
6,000m AUV

Jason 2:
6,500m ROV



HROV
11,000m

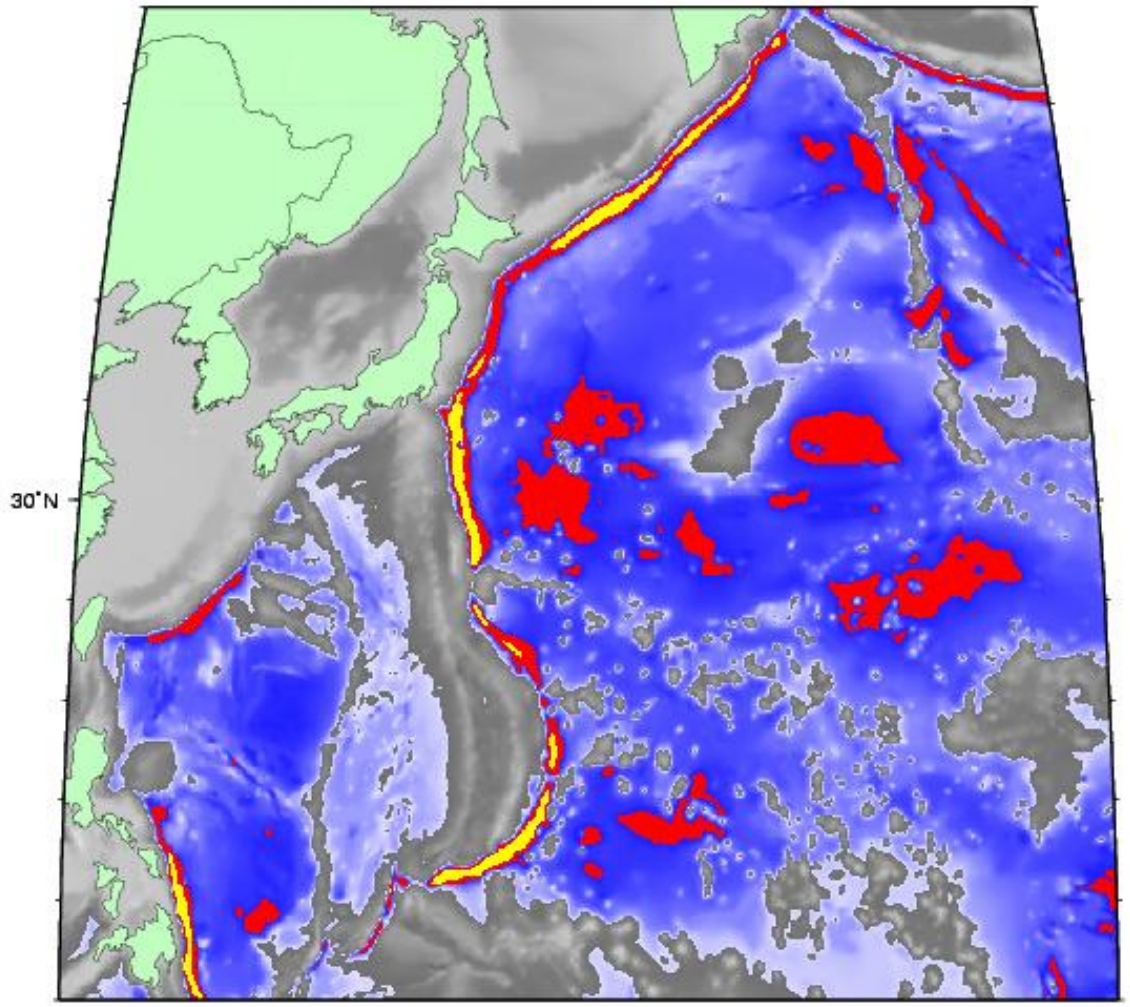


Global Ocean depth chart

Robinson projection

-10000 -7000 -6000 -4500 0

SPAWAR Systems Center San Diego



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SPAWAR
Systems Center
San Diego

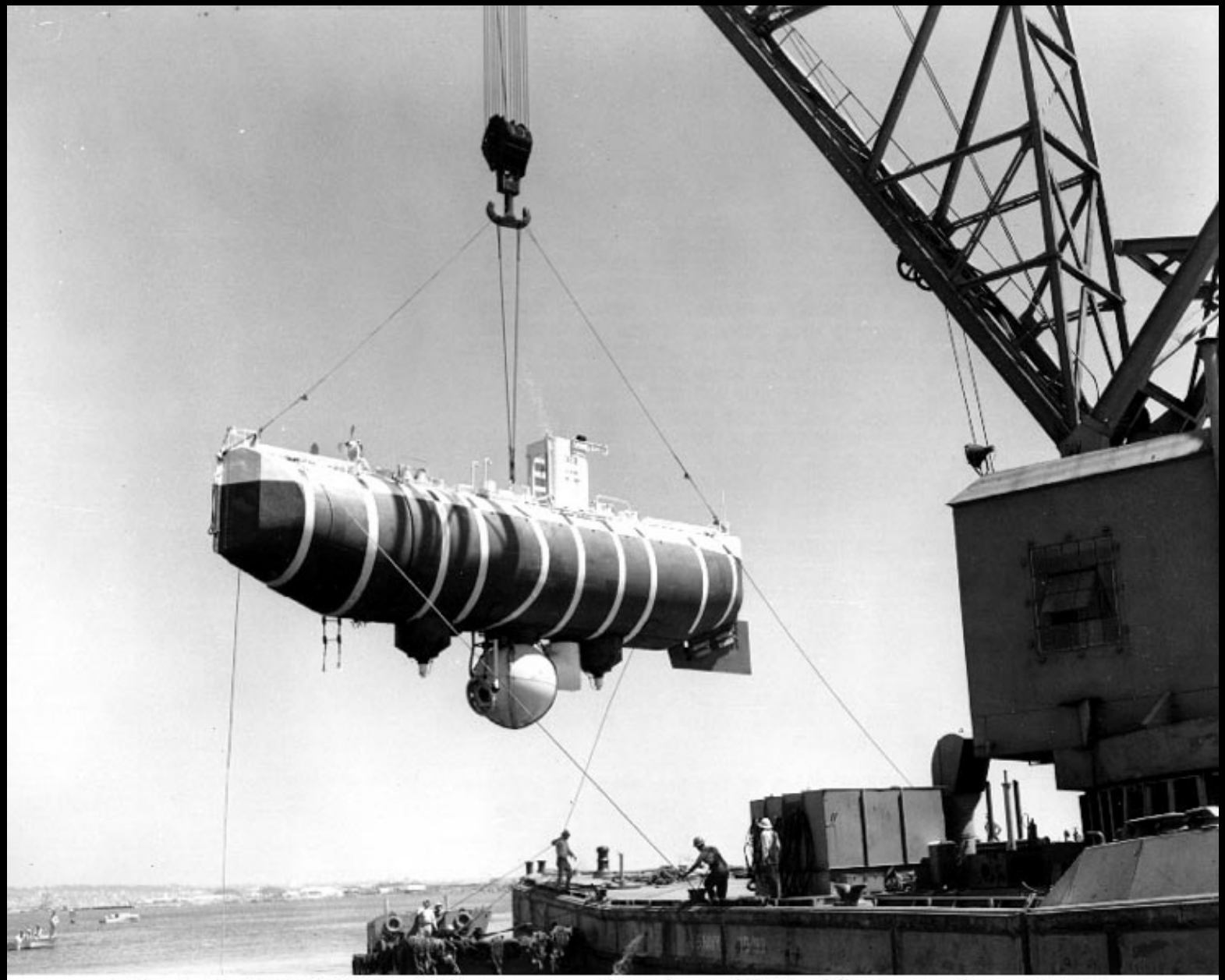


Photo # NH 96799 Trieste preparing for mid-Pacific operations, 1959


JAMSTEC

海洋科学技術センターの船舶等の概要

支援母船「よこすか」

全長　105.2m

幅　16.0m

深さ　7.3m

総トン数　4,439トン

航海速力　約16ノット

航続距離　9500マイル

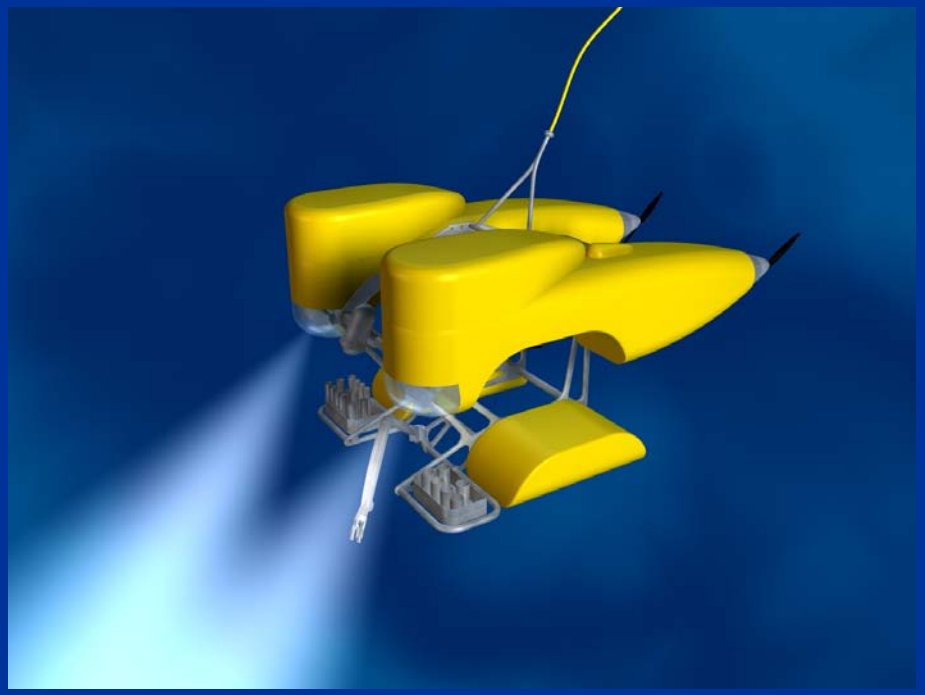
乗船者数　60名

R. V. Yokoska

JAMSTEC
Japan Marine Science & Technology Center

HROV Operations

HROV's Two Configurations



AUV Mode

1120 kg (2460 lb) Air Wt
50 ceramic spheres
2.5 cu ft syntactic foam
50 lb (wet wt) payload

ROV Mode

1510 kg (3320 lb) Air Wt
74 ceramic spheres
5 cu ft syntactic foam
100 lb (wet wt) payload

HROV Operational Goals

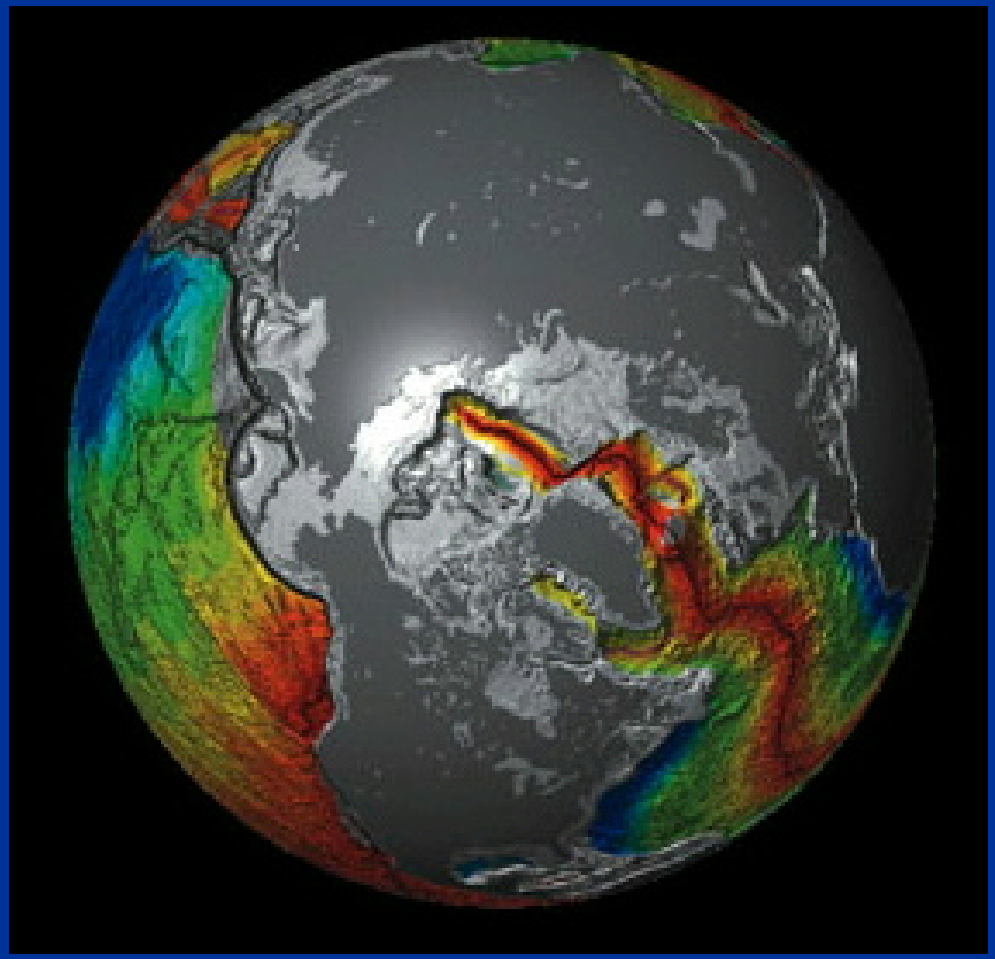
- Benthic Margins below 6,500m
- Under Ice Operations
- Event Response
- Marginal Environments
- Public Outreach

Science Mysteries Under the Polar Ice Caps

- Characteristics of vents hosted in ultra-slow spreading crust
- Serpentinization, cold upper mantle
- Deep axial valley
- Hydrographic isolation
- Vent fauna

The Gakkel Ridge

- The slowest-spreading mid-ocean ridge on Earth (full rate 1.33 cm/year at its western end, near Greenland; 0.6 cm/year at the Laptev Sea shelf)
- Geographically and oceanographically isolated from other mid-ocean ridges



AICC 3/31/2005

HROV Science Mission Requirements

- High resolution bathymetry
- High quality imagery
- Water column sensing (e.g. CTD, OBS, methane)
- Water Sampling (hot/cold)
- Hi/Lo temperature probes
- Push coring
- Heat-flow probe (1 to 1.5 M long)
- Geotechnical/Geochemical
- Rock sampling/drilling
- Biological sampling (grabs/boxes)
- Flexible science sensor payload interface

Scientific Sensors

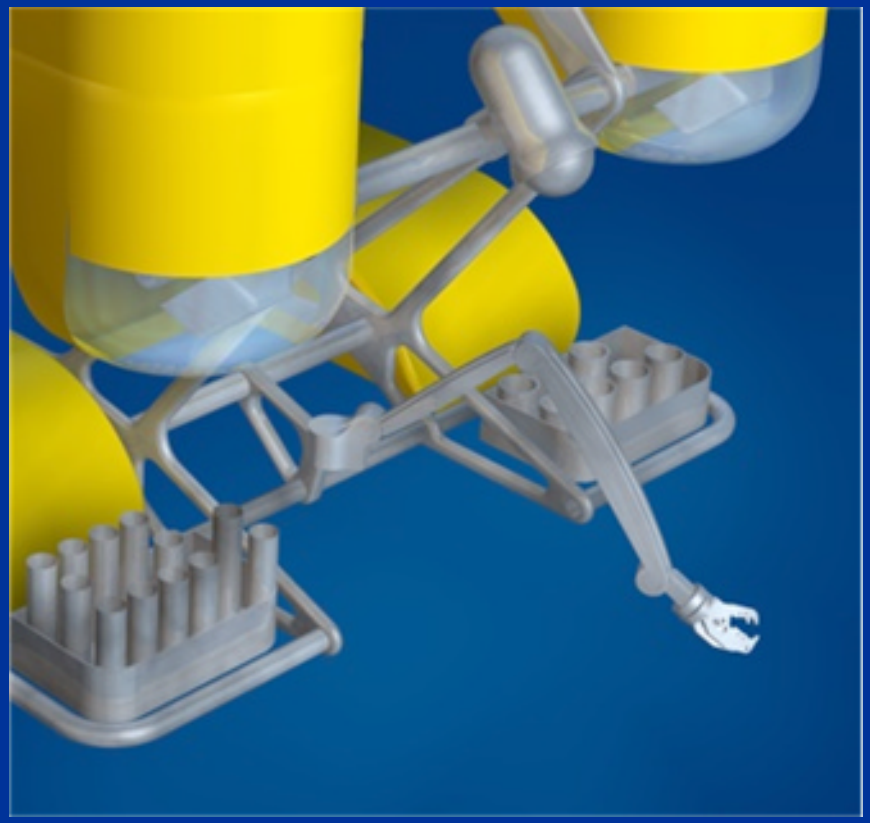
- SeaBird 49 FastCAT CTD
  - 2 CTD's on vehicle
  - Includes integral pump for T/C sensors
  - Pressure: 0 – 11,000 m, accuracy 0.1% full scale range
  - Conductivity: 0 to 9 S/m, accuracy 0.0003 S/m
  - Temperature: -5° to +35° C, accuracy 0.002° C
- Honeywell HMR2300 3-Axis Digital Magnetometer
  - Range ±2 gauss, <70 µgauss resolution
- Optical Backscatter Sensor
  - Manufacturer TBD
- 300 KHz Doppler Sonar – RDI Workhorse ADCP
- 675 kHz Scanning Bathymetric Sonar - Imagenex

Optical Imaging Functional Breakdown

Configuration	Minimal Resolution	Lighting	Storage
Mosaic collection and stills in AUV or HROV mode (dynamic range)	1.4+ megapixels	Survey, strobed, monochrome	Internal hard disk + uplink (thousands of images)
Hi-resolution color stills for AUV and HROV sampling modes	3.3+ megapixels	Strobed Full-spectrum	Internal, uplink +
Quality color video in HROV approach and sampling modes (workspace)	>400 TVL	Video frame rate (fractional)	Uplink
High sensitivity B&W video for HROV approach and sampling modes	>400 TVL	Video frame rate (fractional)	Uplink

Preliminary Manipulator Design Summary

- 6 degree-of-freedom (DOF) serial manipulator
- 11,000m Depth Rated
- 1.3 m (~51 in.) in length
- 45 kg (100 lb) max dry weight / 4.5 kg (10 lbf) max wet weight
- Design tip force of 50 N (11 lb)
- Design tip torque of 54 N-m (40 ft-lbf)
- Specialized end effectors placed on manipulator prior to sampling task (may be same as sampling container)

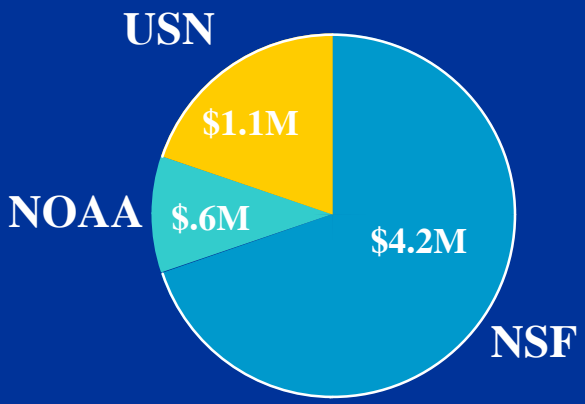


HROV Operations Summary

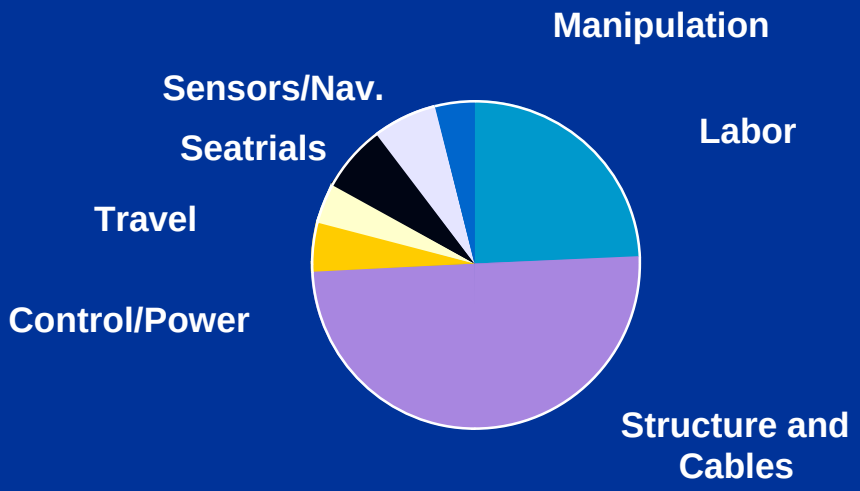
- Two 20 foot shipping containers
- Five person operations team
- 24 hour operations:
  - 48 hour mission
  - 12 hour turn-around
- Day rate ~$10,000/day ($US) for 11,000m operations.
- AUV Mode 2.5 to 3 times ABE coverage
- ROV mode over-the-side operations requirements similar to CTD operations.
- ROV horizontal footprint TBD (~20km).

HROV Project Budget Overview

HROV Funding Sources



Cost Breakdown



Total

NSF/NOAA	$4,776K
USN/SPAWAR	$1,098K

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Main Electronics and Battery Housings

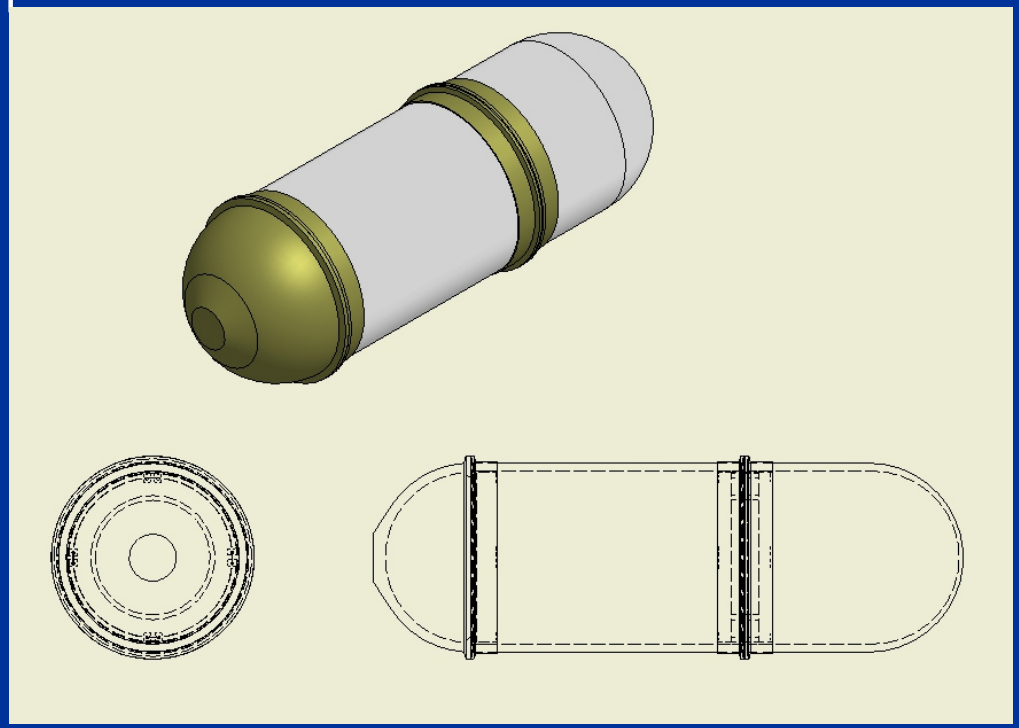
Mechanical Characteristics

Ceramic/Titanium (Grade 5) construction

Titanium hemispherical endcap
(flat for single penetration shown)

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 Ceramic Buoyancy Spheres

Custom Technical Ceramics, Arvada, Colorado

Nominal Dimensions

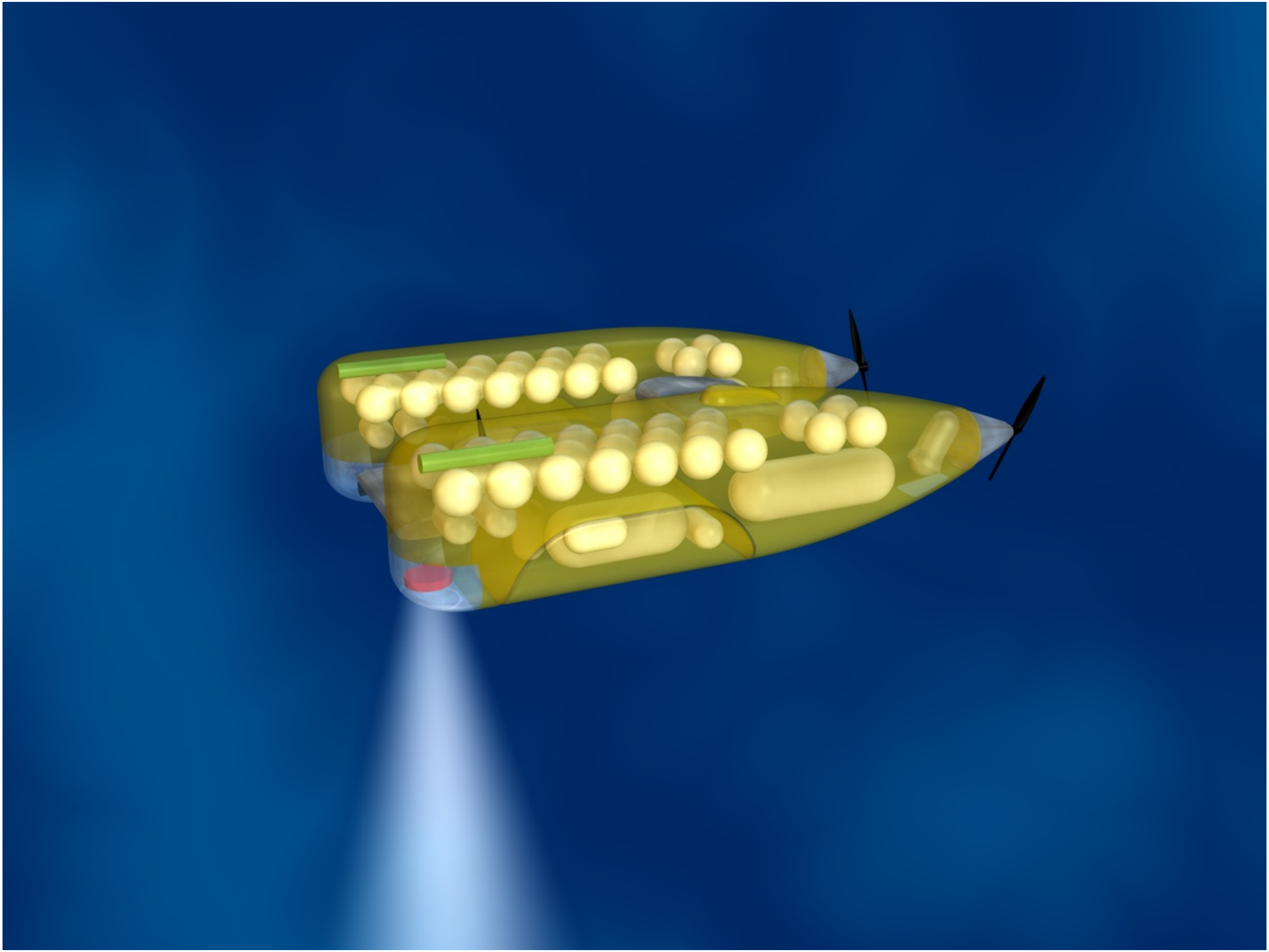
- OD 10.2”
- Wall thickness 0.188” min, +0.04” variation
- Weight 4.1 kg (~9 lb)
- Displacement 20.6 lb
- Buoyancy 11.6 lb
- Wt/Disp Ratio ~0.4

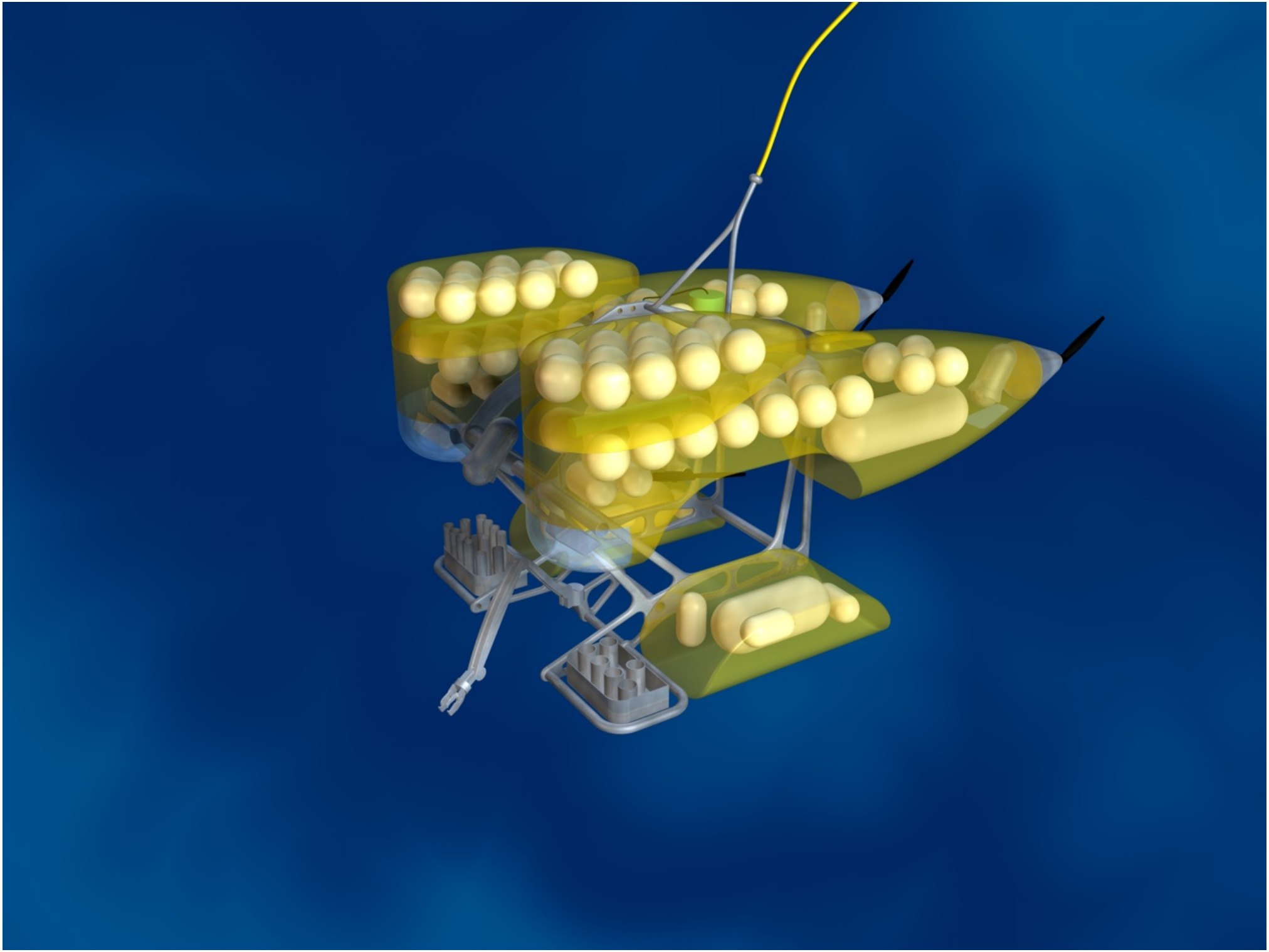
Slip-molded, one-piece, 0.999 Alumina

10 sample spheres procured

Pressure tests conducted at SWRI

- 10 cycles to 18 ksi with acoustic emission monitoring
- Destructive test to 30 ksi (chamber failed at 29,369 psi)





Light Fiber Optic Tethers

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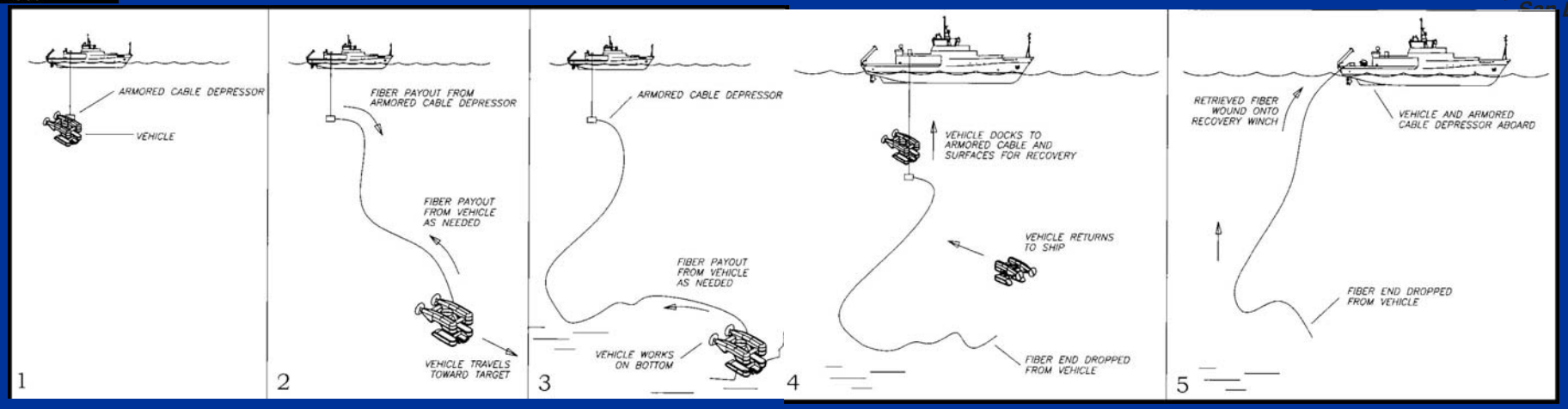
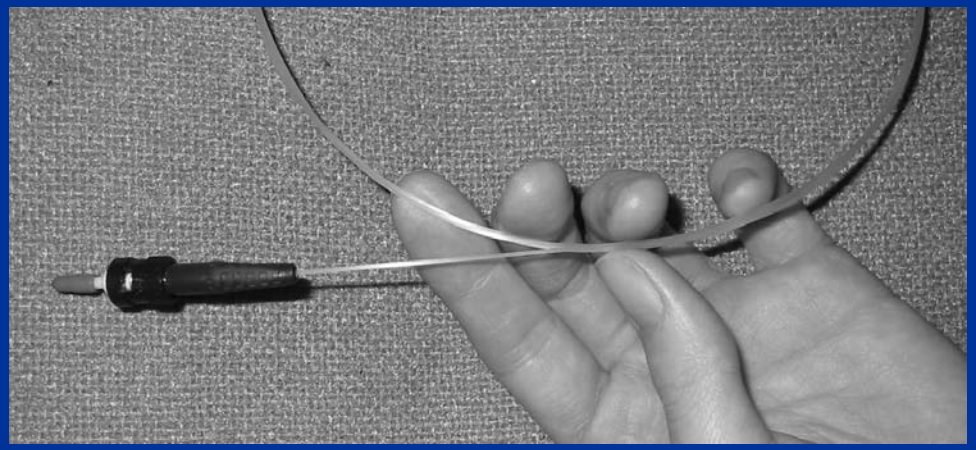


Mission Concept: Self Powered Vehicle with Lightweight Fiber Optic Tether



0.8mm Diameter Fiber Optic Tether

12 Mile Fiber Optic Tether Pack

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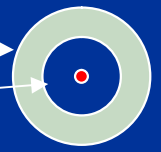
Candidates for HROV Tether

SPAWAR Systems Center San Diego

0.25 mm Polymer Buffer

0.12 mm Optical Fiber



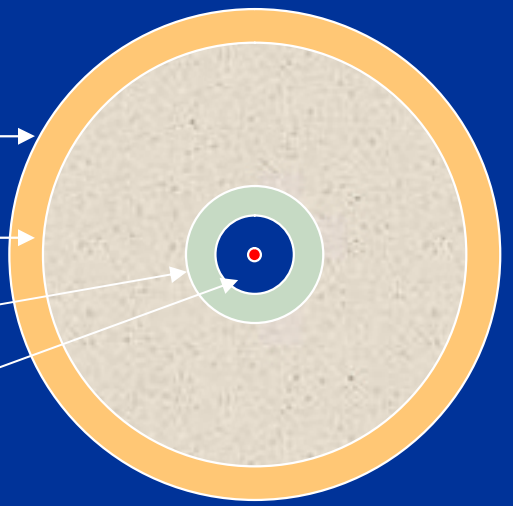
Buffered Optical Fiber

0.78 mm Anti-Abrasion Jacket

0.76 mm FRP Strength Member

0.25 mm Polymer Buffer

0.12 mm Optical Fiber

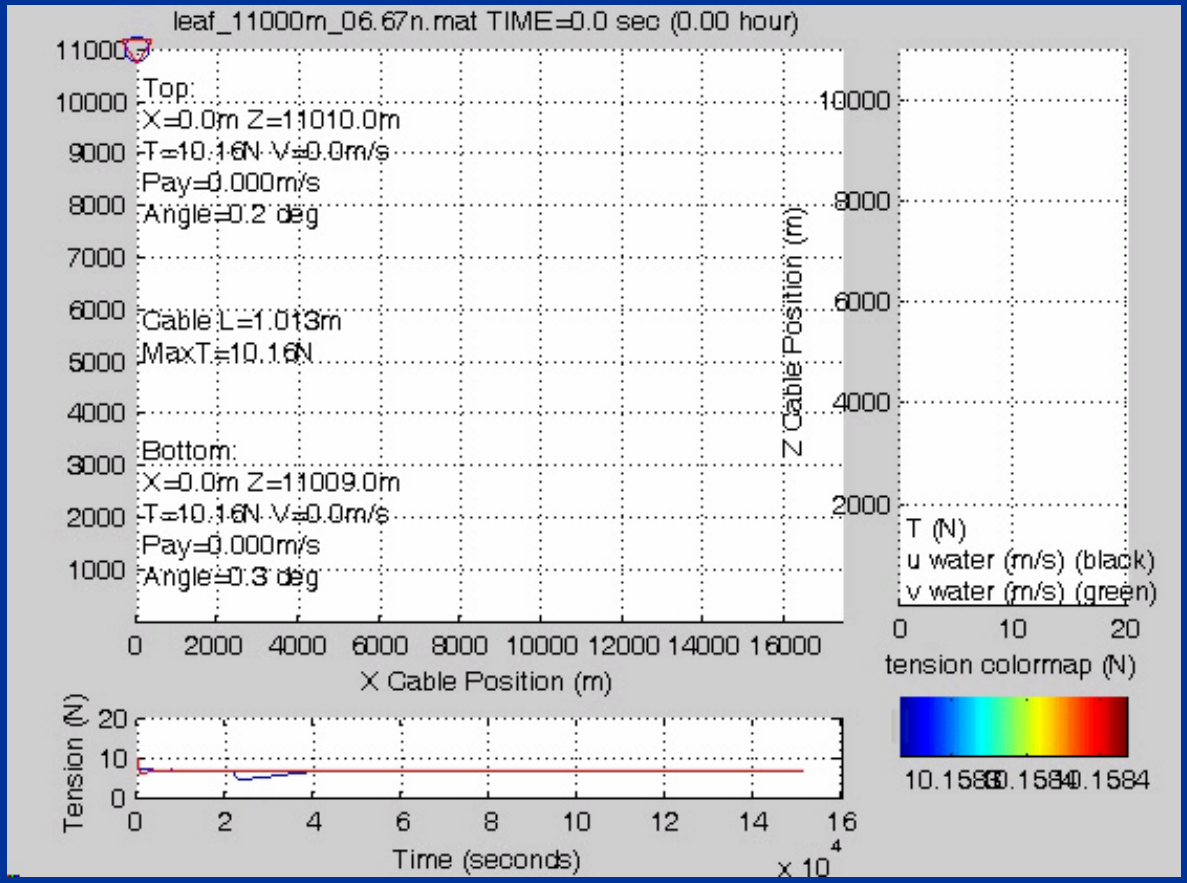


Fiber Optic Micro Cable (FOMC)

Buffered Fiber Validation

Mission Parameters:

- 0.25mm Fiber Tether
- Vehicle descends from surface to 11,000m for 6 hours at 30 m/min (0.5 m/sec or 1 knot) .
- Remain resident 36 hours on sea floor.
- At T=42 hours, vehicle would cut cable and surface autonomously.
- Currents: 0.25 m/s surface current for top 200m, linearly decreasing to 5cm/sec at sea floor.
- Bare fiber tether payout tension = 6.7 N.
- Tether Drag Model:
  - CDn = 1.5
  - CDt = 0.7 / Re



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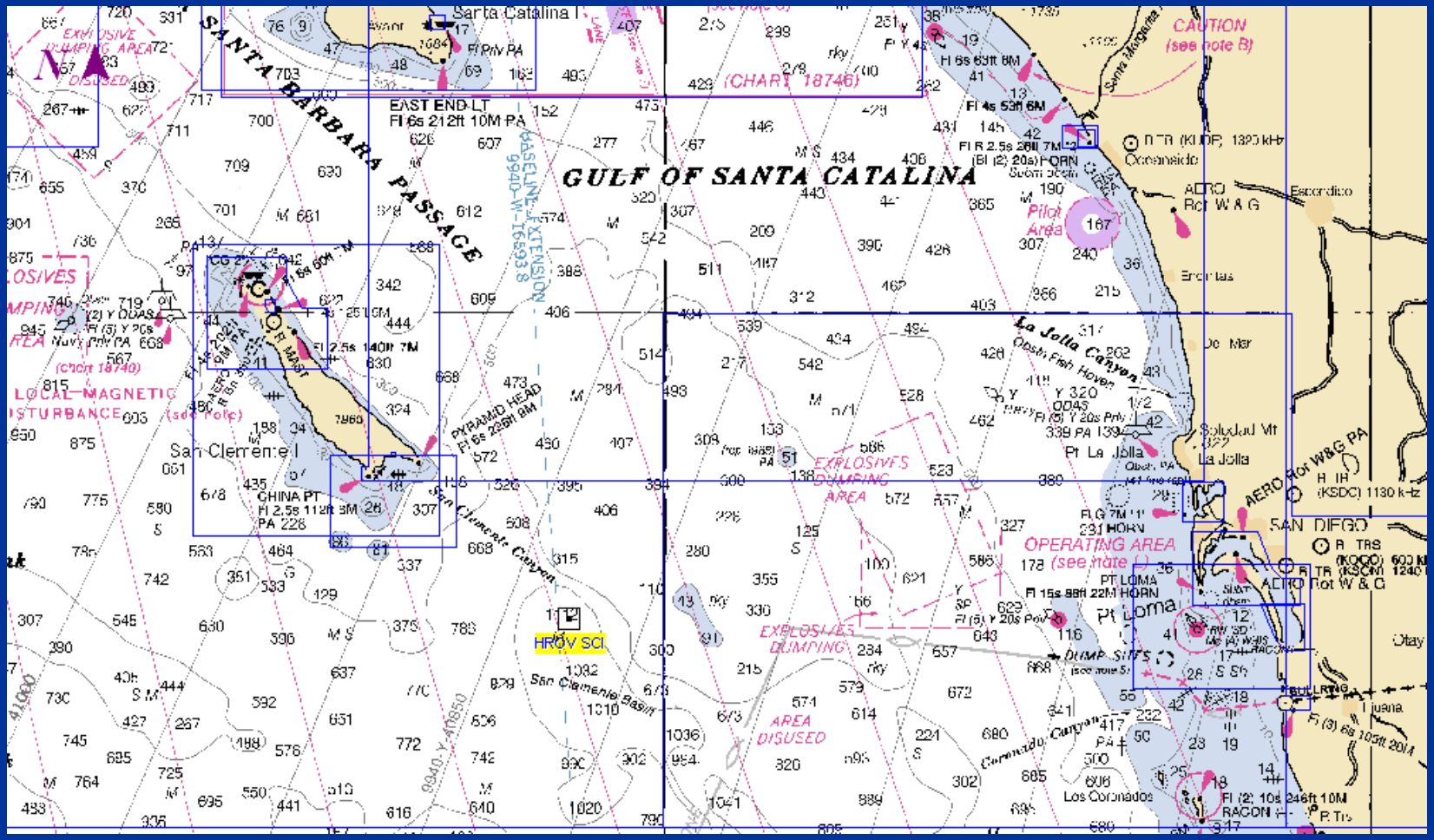
Fiber Tether Deployment Test
November 1-2, 2004



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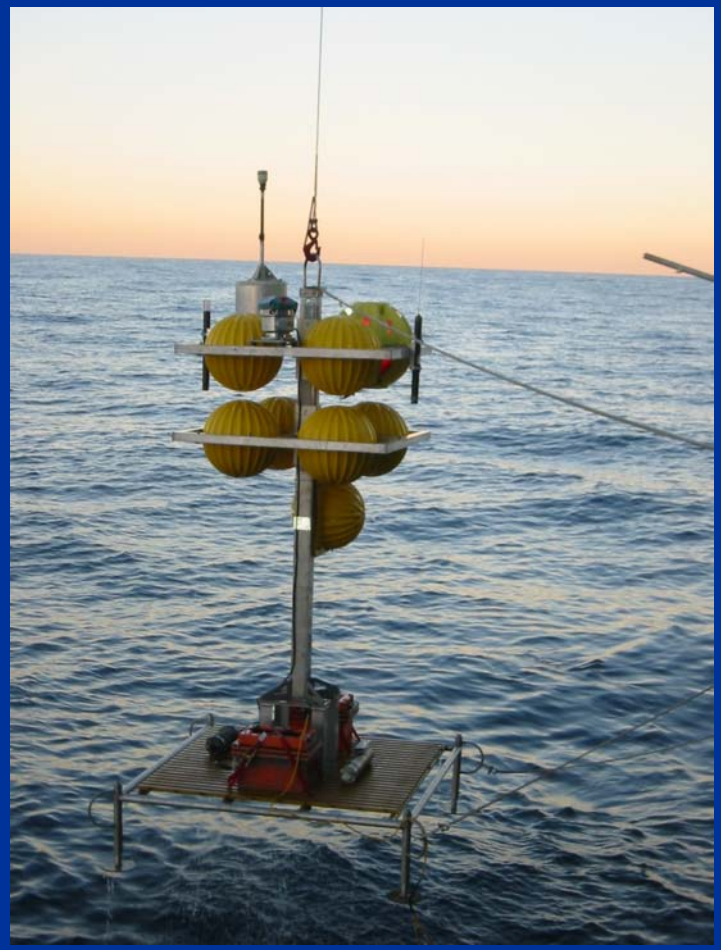
Fiber Tether Deployment Test
Test Conditions: November 1-2, 2004

- Water depth 2000 m, flat sand and mud seafloor
- Cable pack mounted on elevator
  - Free-fall through water column, 30 m/min
- Cable pack mounted on deck of ship
  - Deploy cable through weighted flex-hose
- Instrumentation
  - Optical Time Domain Reflectometer on ship to monitor optical fiber
    - Bending buffered fiber at pack allows measurement of distance paid out
  - ADCP mounted on elevator (upward firing)
  - ADCP on ship
  - Long baseline acoustic navigation
  - CTD, XBT, DGPS

Fiber Tether Deployment Test

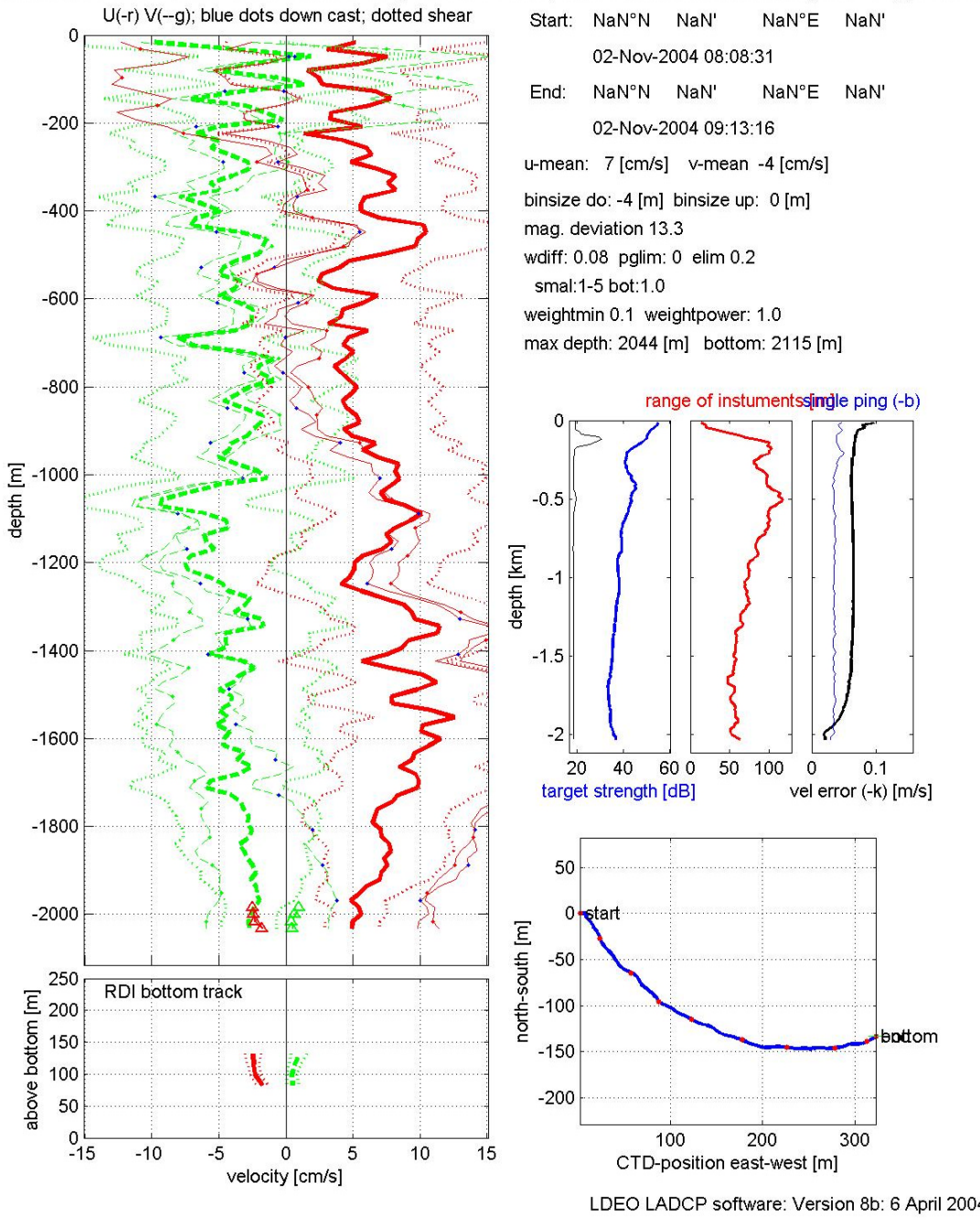
Elevator canister mounted on top of elevator



Break-Away bell mouths

ADCP Current Profile:

Preliminary Current Profile from ADCP data from November 2004 Fiber Tether Trials in San Clemente Canyon



San Clemente Island Test Results

- FOMC survived for 4 hours until test was terminated
- Buffered Optical Fiber survived for 3:45
  - Fiber broke 112m from end of flex hose, close to ship
  - Fracture analysis of broken end
    - Cause: excessive tension caused by build-up of adhesive from FOMC in flex-hose combined with ship motion
    - No evidence of external damage due to marine life

Project Milestones to Date

- 11KM Floatation development complete:
  - Syntactic SG of .58
  - Ceramic sphere SG of .40
- Work Space design tools in place.
- Electric Manipulator development underway
- Prototype LED lighting array built and tested
- Microfiber tether development:
  - Pressure testing of candidates
  - Modeling
  - Initial field tests
- Conceptual vehicle development underway
- Main pressure cases in production

Project Goals for CY 2005

- Complete conceptual development of both vehicle configurations leading to detailed structural design
- Complete manipulator design and have both hardware and software components in test
- Complete fabrication and test of main and auxiliary pressure housings
- Make final choices on propulsion and have fabrication underway
- Jason in water tests of LED lighting
- Purchase of vendor supplied components
- Control system development
- Final electrical complete with fabrication underway
- Attend AICC meeting in March -- develop ice operations
- Second elevator test (deep) with addition of shallow AUV tests

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Mr. Don Peters	Overall Mechanical System Design
Dr. Al Bradley	Propusion and Energy Storage
Mr. Bob McCabe	Fabrication, Operations, Design.

- AOPE/DSL Design Staff as required (approx. 15 eng & tech staff)

The End