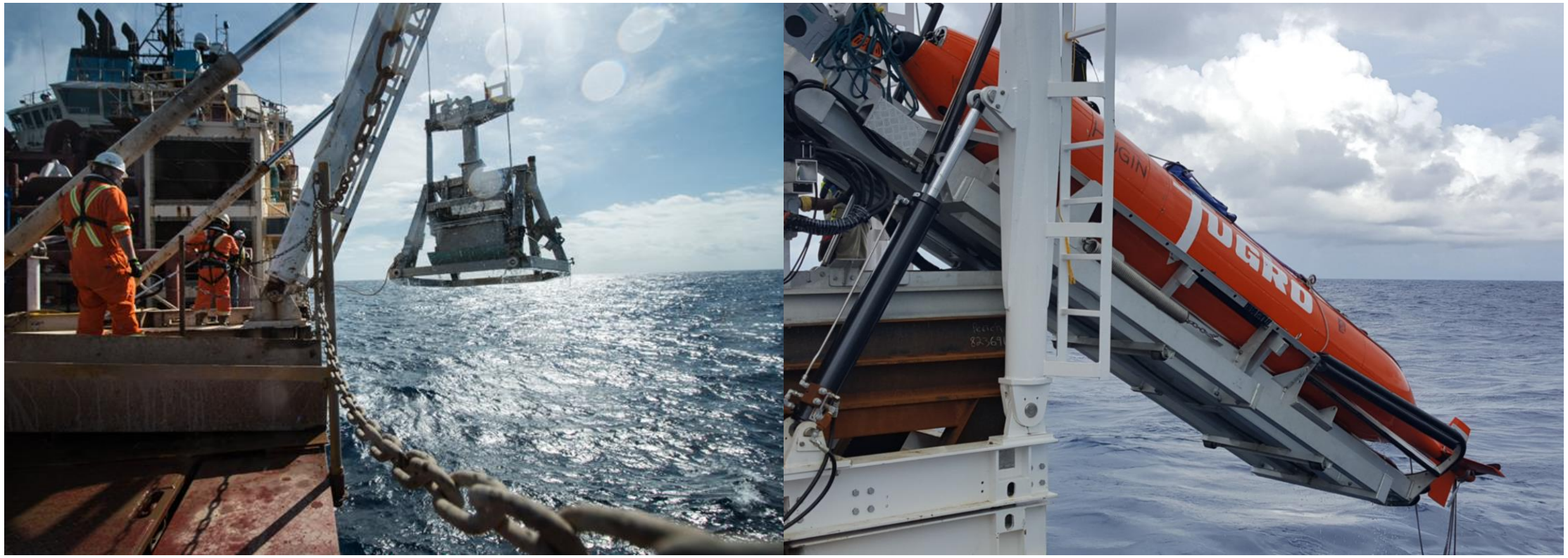

Using Simultaneous Operations of AUV and Seabed Sampling to Optimize Marine Mineral Exploration Programs

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Overview

- Background on Seabed Mineral Resources
- Objectives of the DeepGreen Metals Survey
- Simultaneous Operations (AUV and Seabed Sampling)
- AUV Data Processing and Interpretation
- Summary

Seabed Mineral Resources

Three important classes of marine mineral deposits:

Seafloor Massive Sulphides

- Copper, Zinc, Gold, Silver with Indium, Gallium, Germanium, Tellurium, Titanium

Manganese Nodules

- Copper, Nickel, Cobalt with Manganese, Titanium, Molybdenum, Rare Earth Elements, Lithium

Cobalt Rich Crusts

- Cobalt, Nickel, Platinum, with Rare Earth Elements, Tellurium, Molybdenum

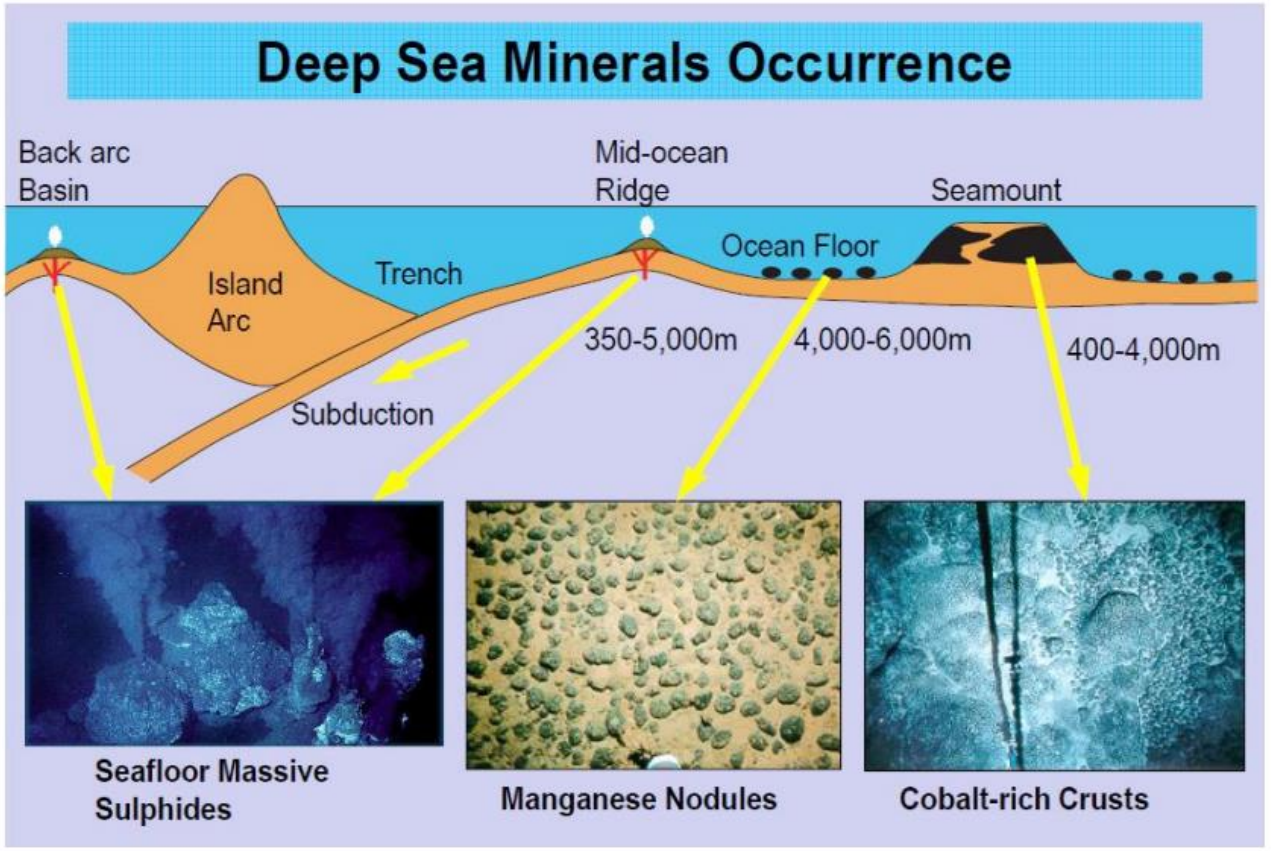
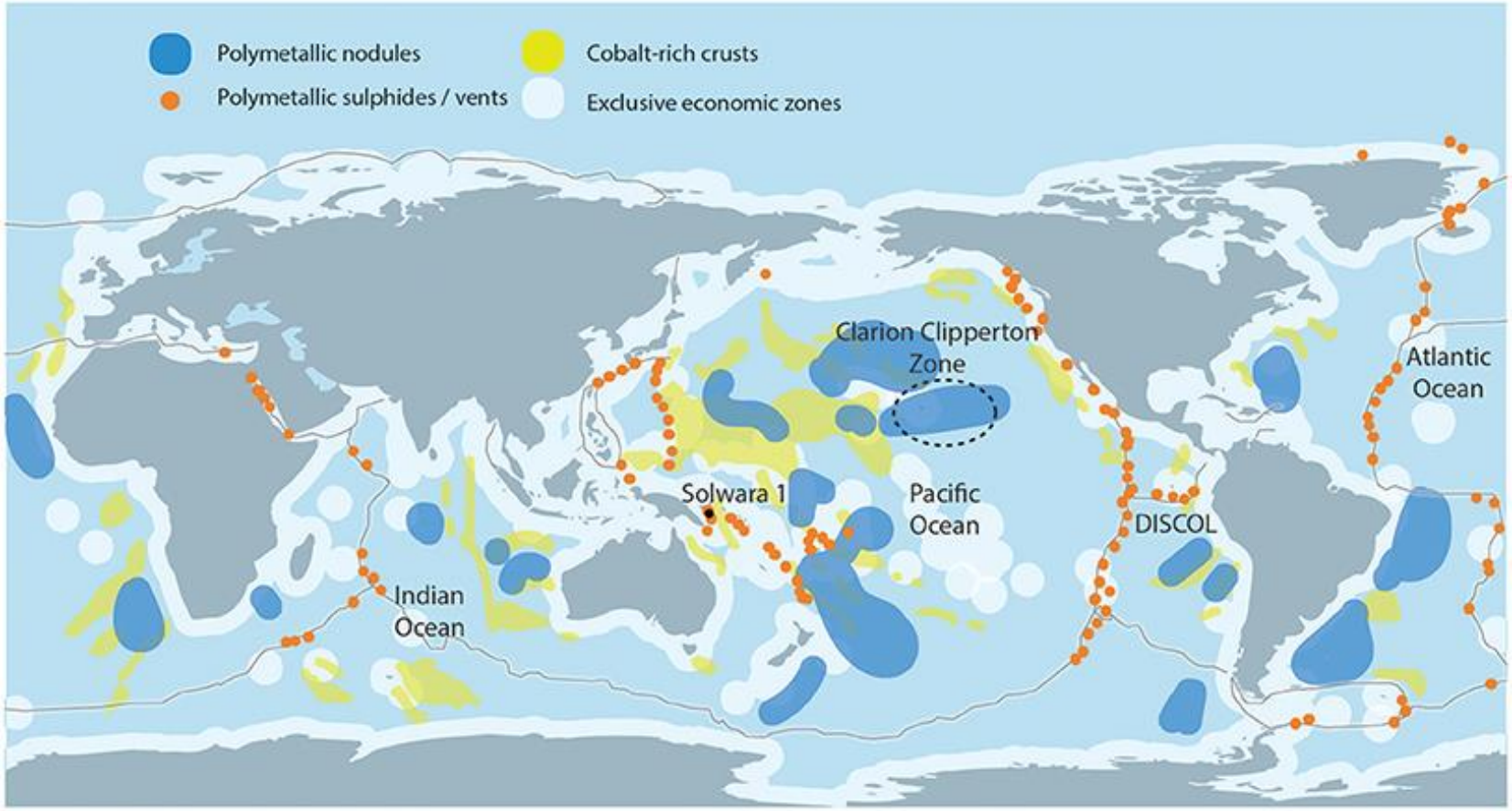


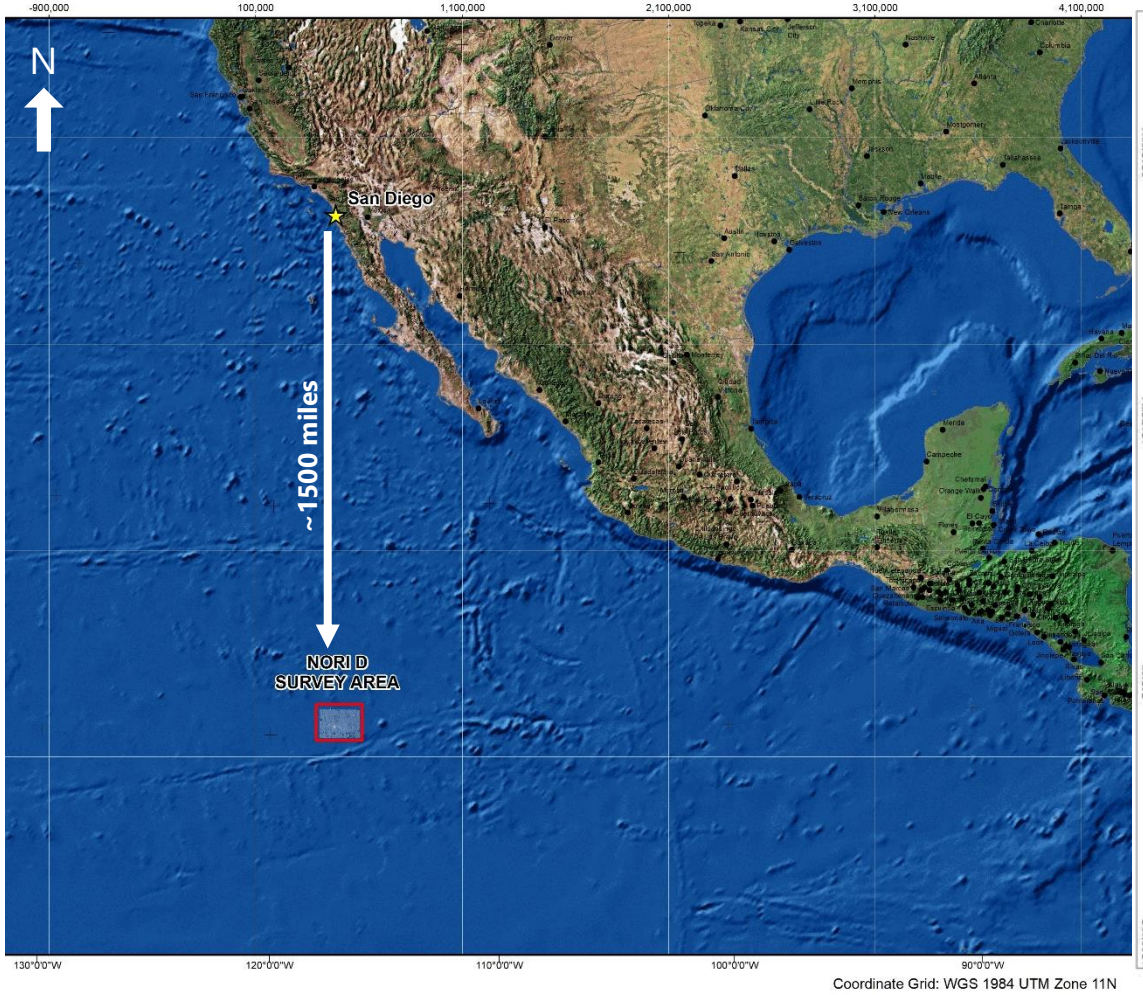
Image from: https://www.sprep.org/attachments/VirLib/Regional/pacific-possible-deep-sea-mining.pdf

Seabed Mineral Resources

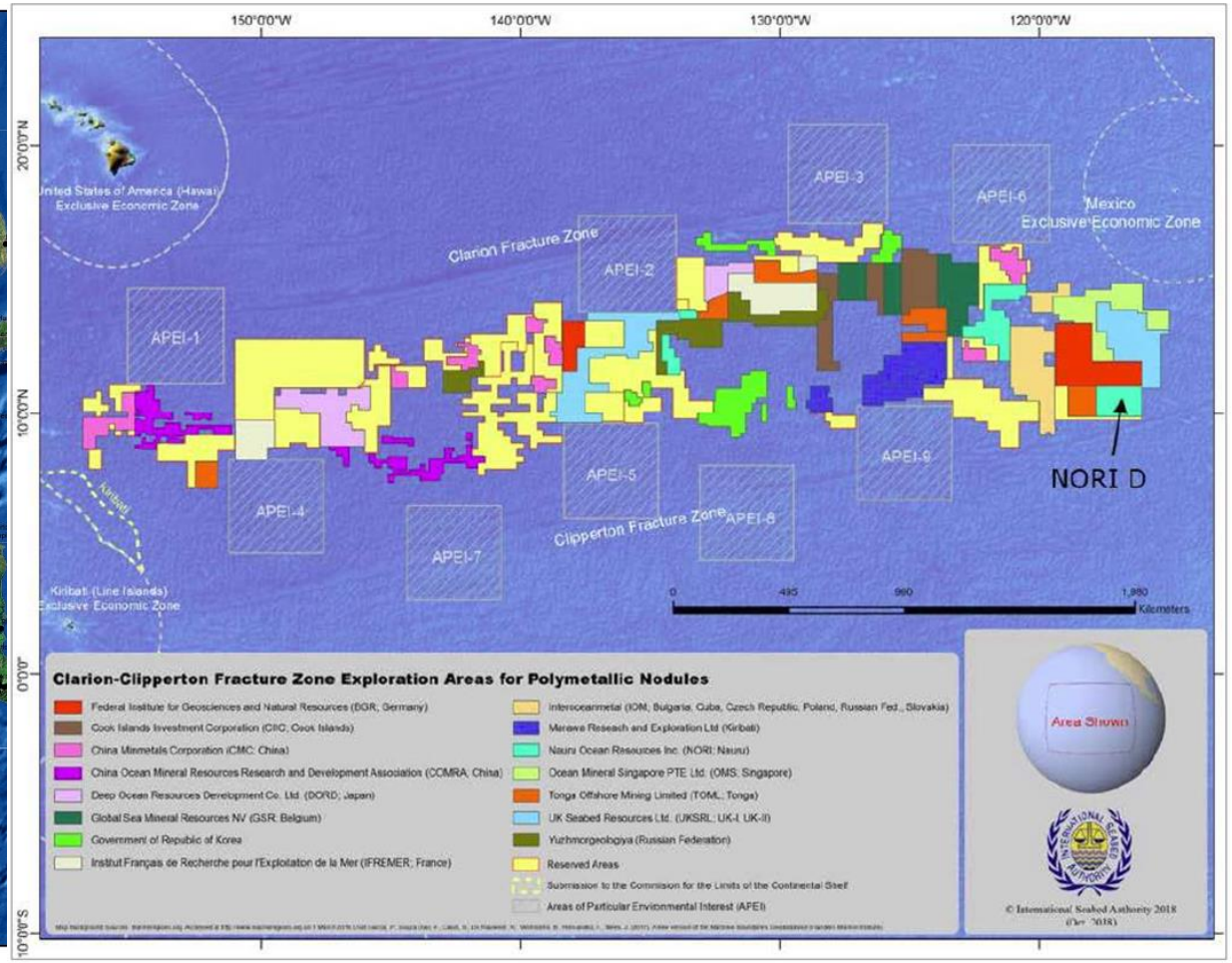


- Since 1982, 27 seabed mineral exploration contracts have been granted globally by the International Seabed Authority (ISA).
- 15 of these projects to are within the Clarion Clipperton Zone (CCZ).

Survey Area Location Map



Coordinate Grid: WGS 1984 UTM Zone 11N



Objectives of 2018 DeepGreen Survey

- Collect high-resolution autonomous underwater vehicle (AUV) geophysical data including: multibeam echosounder bathymetry and backscatter, camera imagery, side scan sonar, and subbottom profiler.
- Collect seabed samples by a box corer.
- Select a collector test area for additional detailed geophysical surveying and to acquire mineral samples and geotechnical samples for laboratory analysis.
- All the information and data collected during the survey would be utilized to support an updated mineral resource estimation.

Maersk Launcher

AUV - HUGIN Echo Surveyor VII (ESVII)

Rated for 4,500 m water depth

Payload Sensors:

Bathymetry and Backscatter:

- Simrad EM2040-7 Multibeam Echosounder

Side Scan Sonar:

- Edgetech 2205 Triple frequency Side Scan Sonar

Subbottom Profiler:

- Edgetech DW106 and 424 Sub-bottom Profilers

Camera Imagery:

- Digital still high resolution camera (Canon EF Lens 24mm/77mm)

Photo Courtesy Lane Wootan


Photo Courtesy Lane Wootan

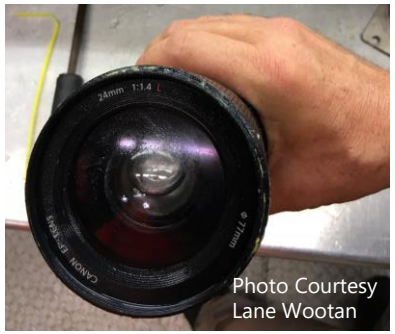


Photo Courtesy Lane Wootan


Photo Courtesy Lane Wootan

Box Corer – Large-form 0.75 m^2 area


Photo Courtesy Jeff Croucher

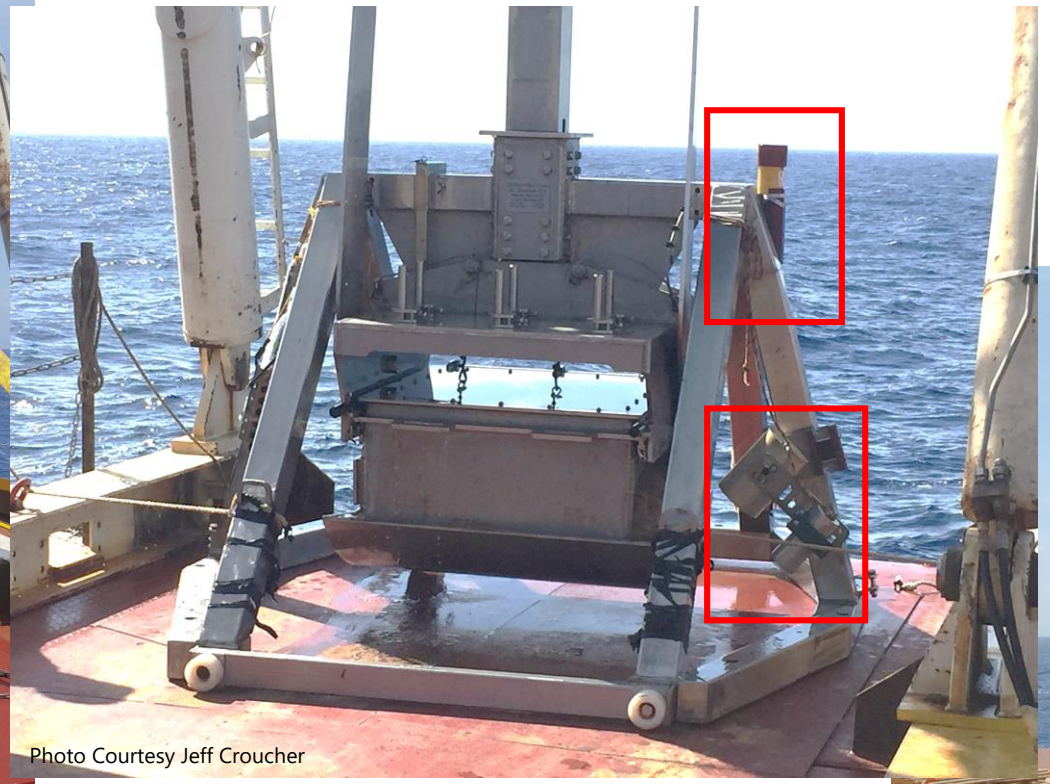
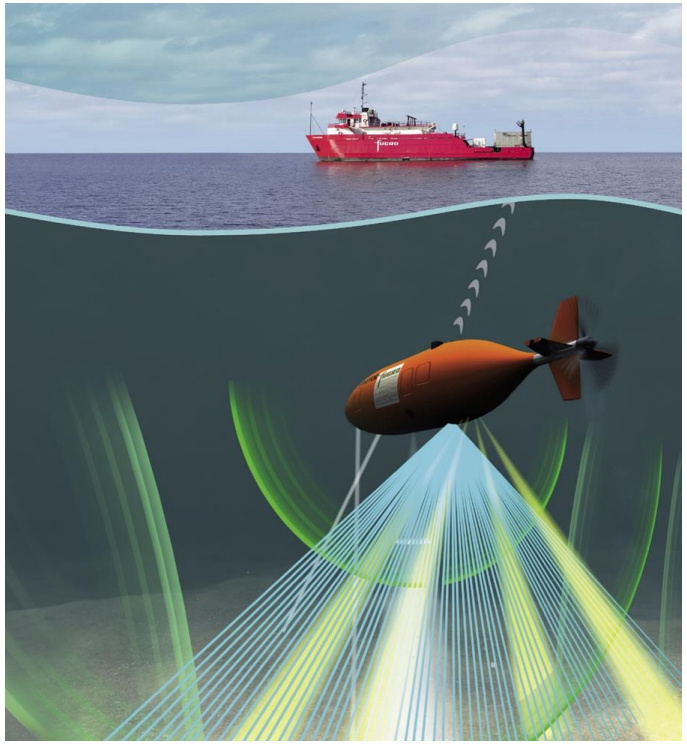


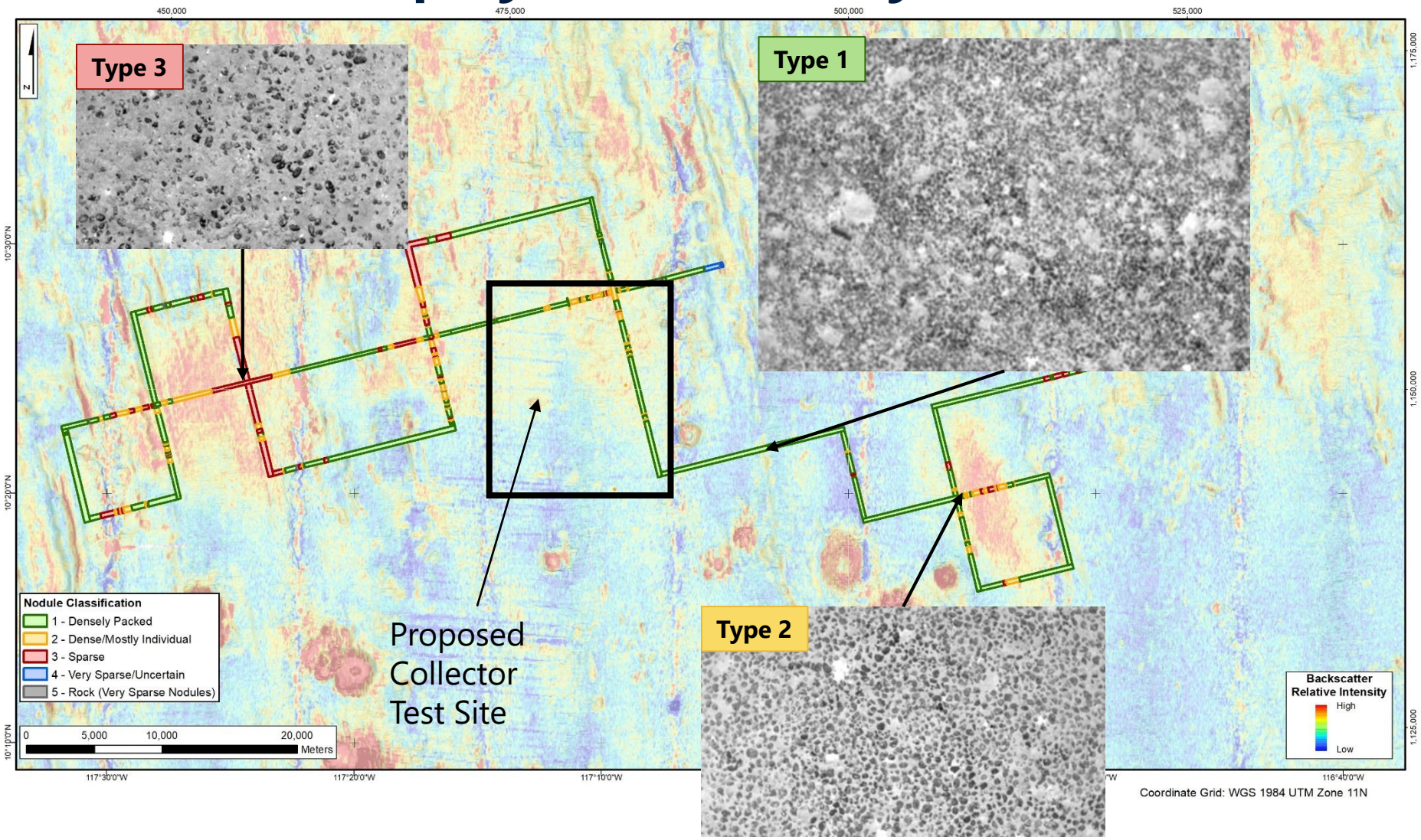
Photo Courtesy Jeff Croucher

Fugro deployed one of the few large-form box corers in existence - much larger than the standard 0.25 m^2 box core normally used.
This corer obtained a sample with a square area of 0.75 m^2 and average recovery around 40 cm.


Photo Courtesy Jeff Croucher

Reconnaisance AUV Geophysical Survey





Simultaneous Operations – AUV and Box Coring

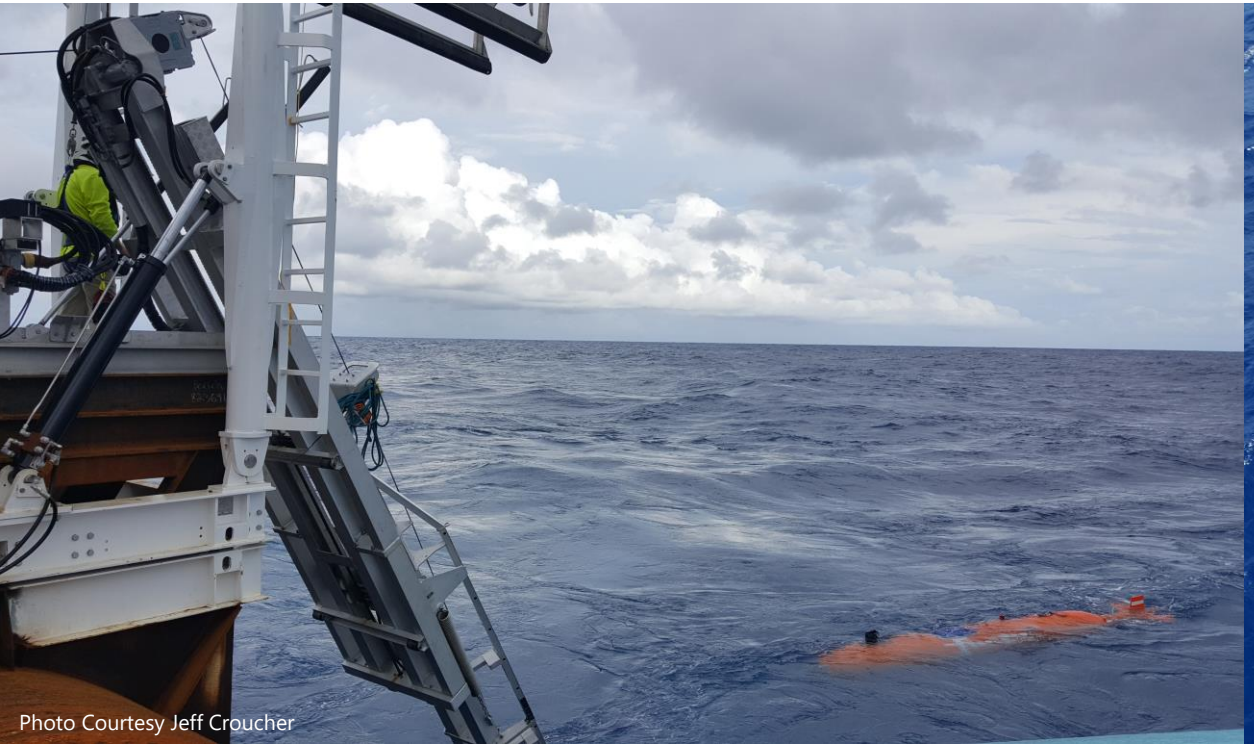


Photo Courtesy Jeff Croucher

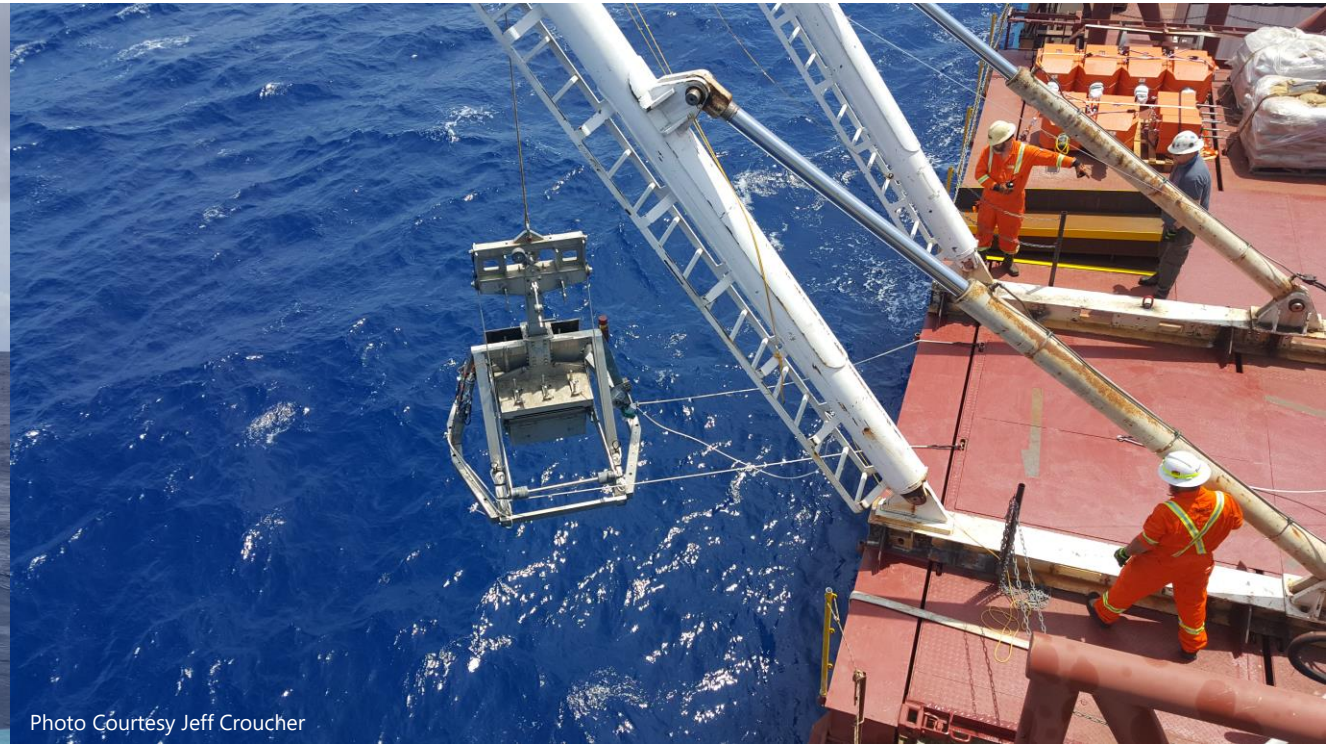
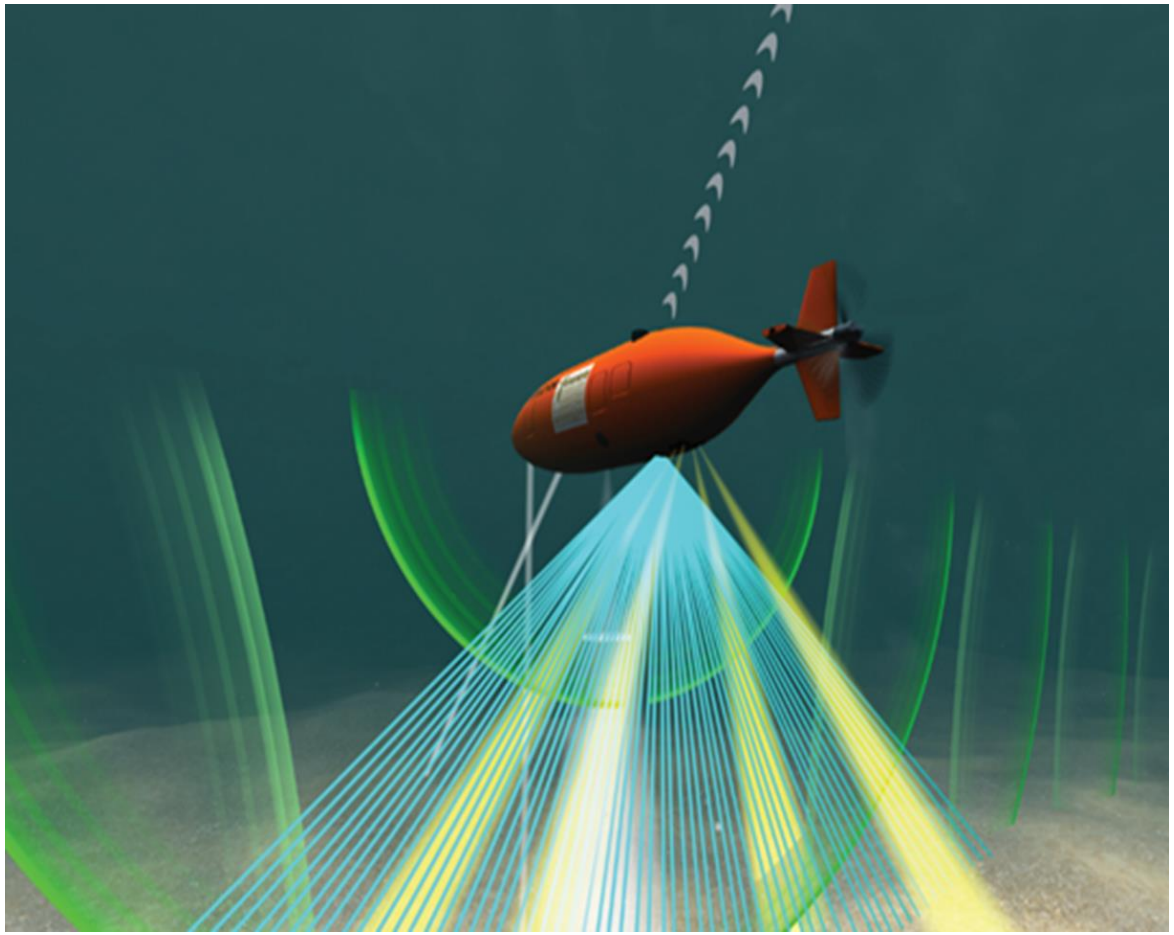
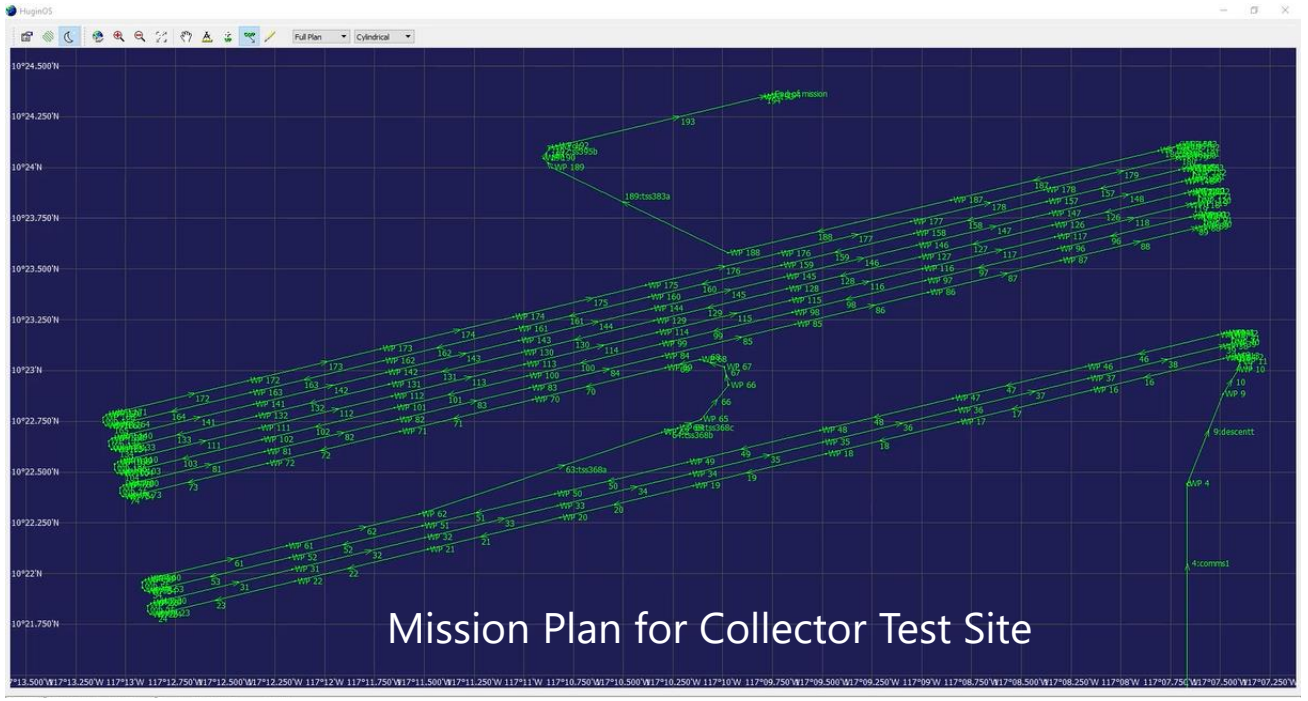


Photo Courtesy Jeff Croucher

Simultaneous Operations - AUV

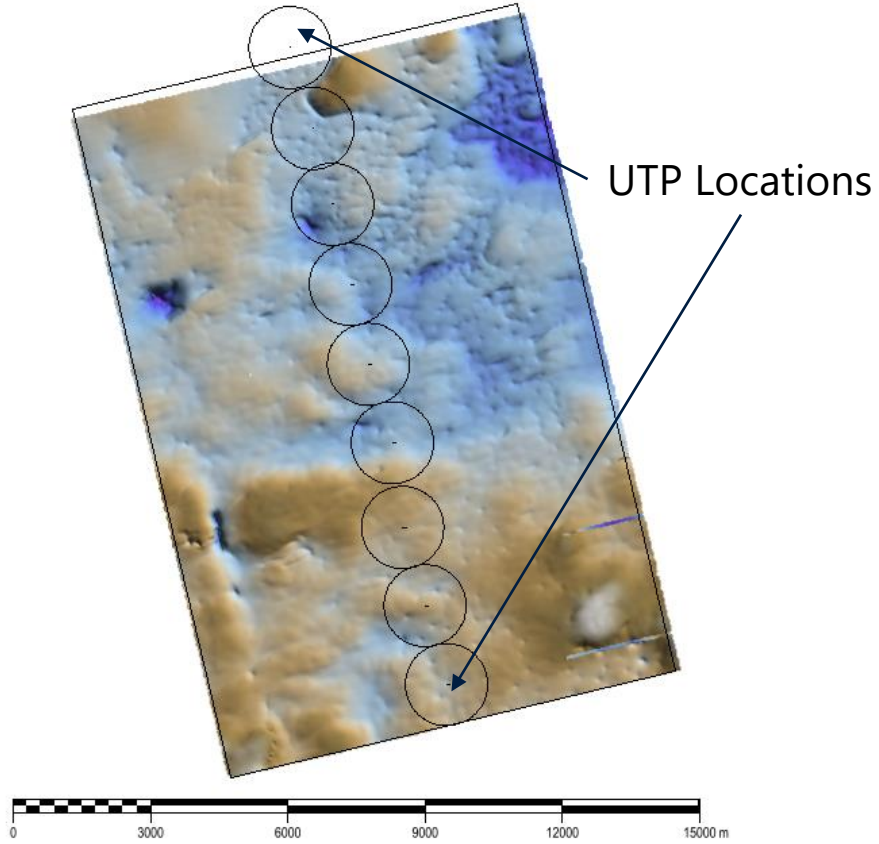




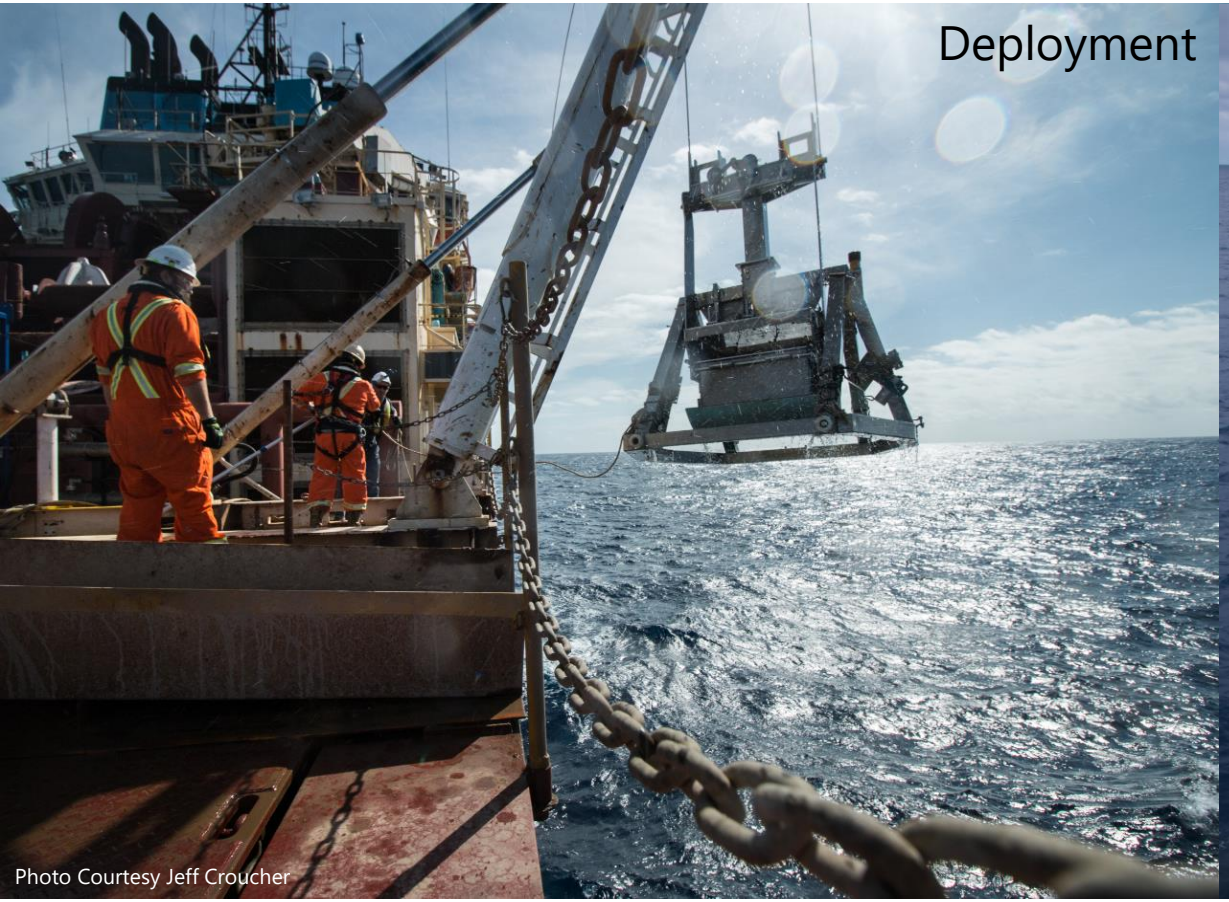
Mission Plan for Collector Test Site

Underwater Transponder Positioning (UTP)

- To optimize offshore time, data acquisition of the Collector Test Site was completed by the AUV in UTP mode.
- Transponders were set on the seafloor at 1,800 m intervals.
- While the AUV was autonomously surveying, the vessel left the AUV to perform box coring operations.



Simultaneous Operations - Box Coring Operations



AUV Data Acquisition and Processing

14 TB of data!

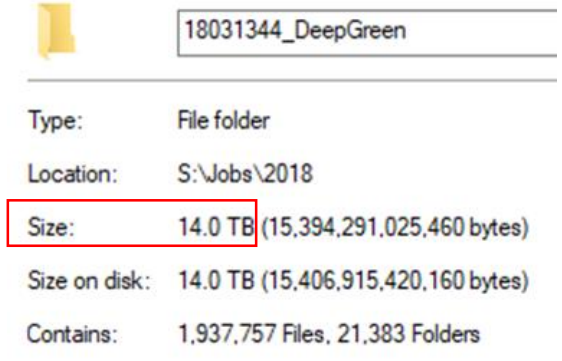
Lines: 2286 km

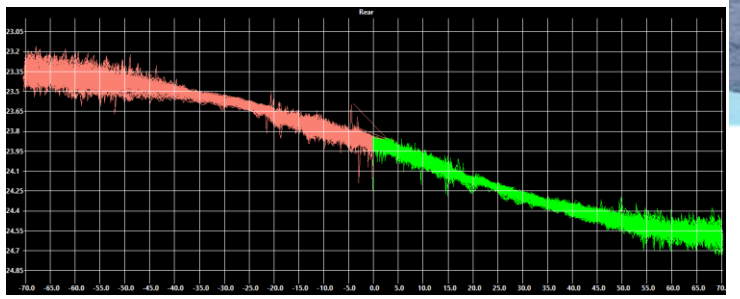
Total Area: 375 km^2

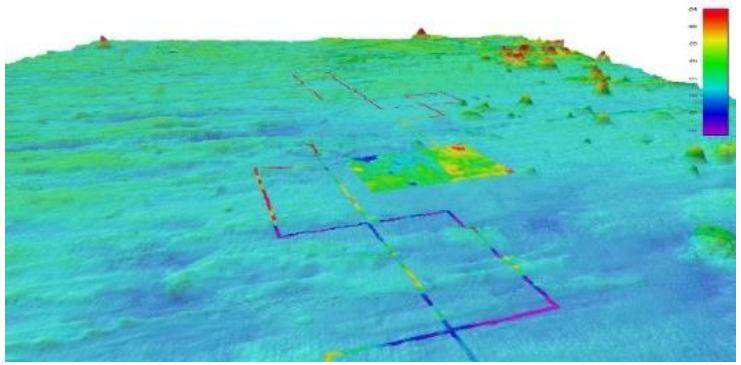
4 AUV altitudes: 90 m, 35 m, 22 m, 6 m

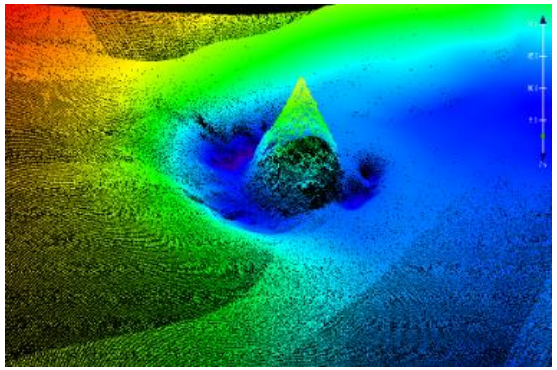
Payload Sensors:
MBES Bathy & Backscatter (200 kHz, 400 kHz)
Side Scan Sonar (240, 540, 1600 kHz)
Subbottom Profiler (1-10 kHz, 4-24 kHz)
Camera Imagery (2x2 bin)

Over 15 different software applications







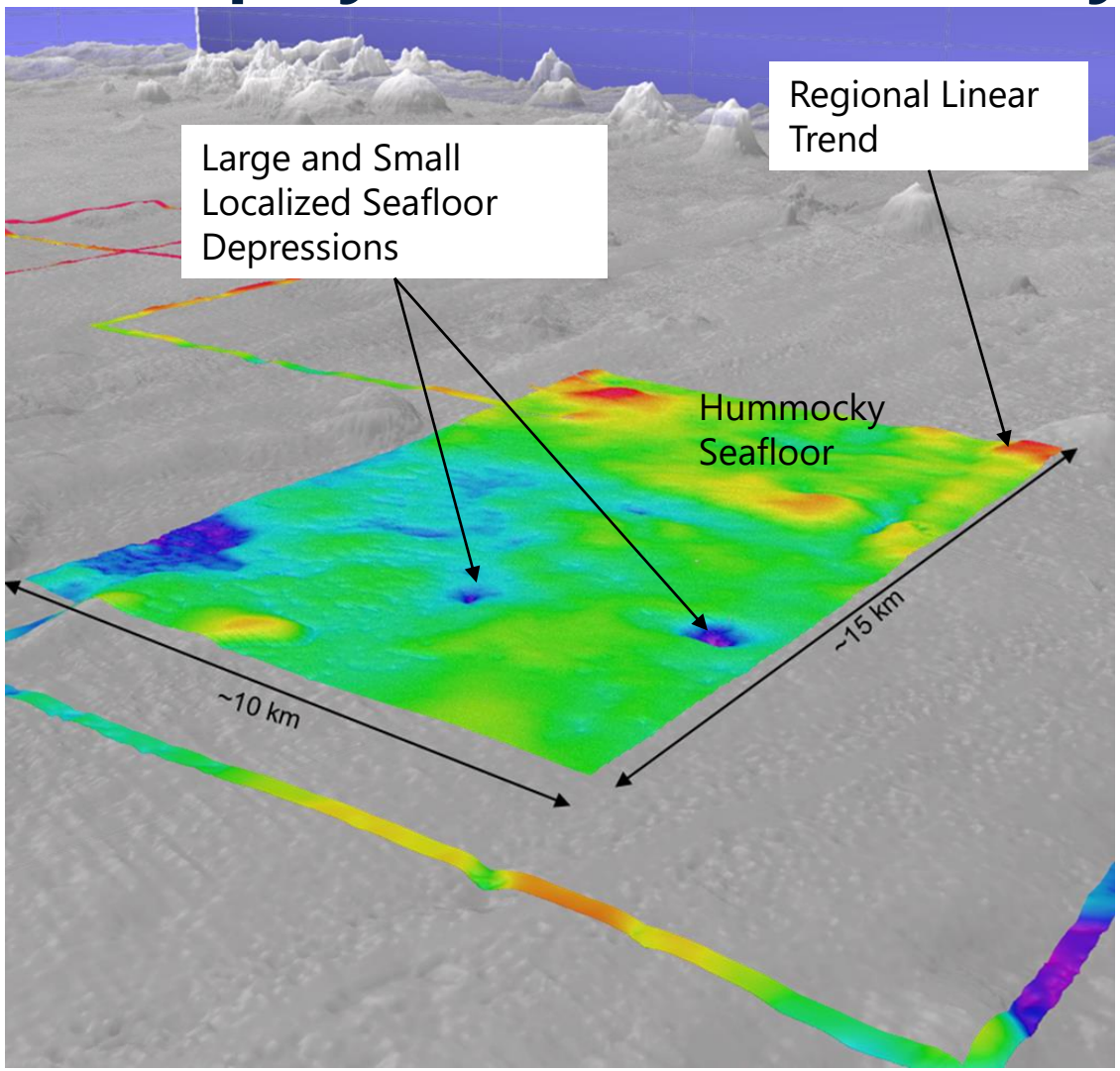


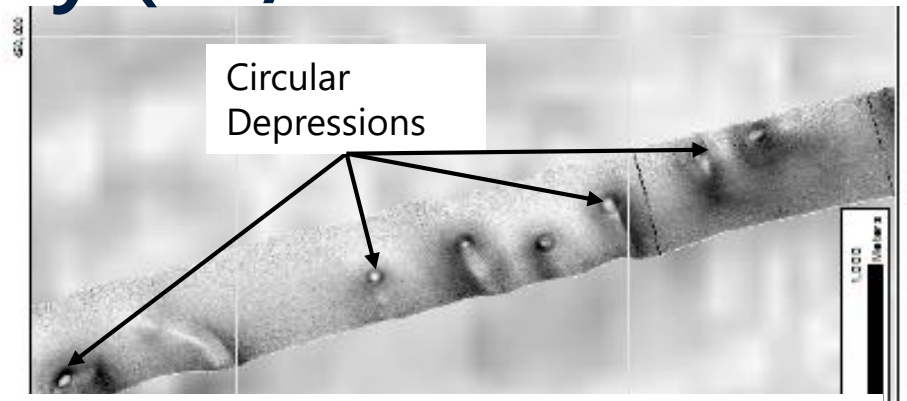
MSS – Mooring Sites
DSAO – Detailed Survey Area
PRZ – Preserve Reference Zones
CHP – High Priority Camera

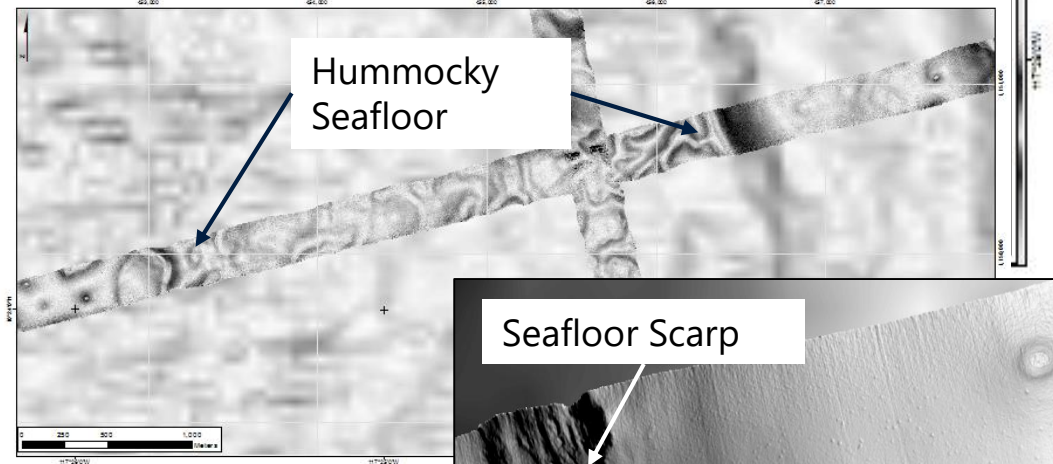
High-Resolution AUV Geophysical Data

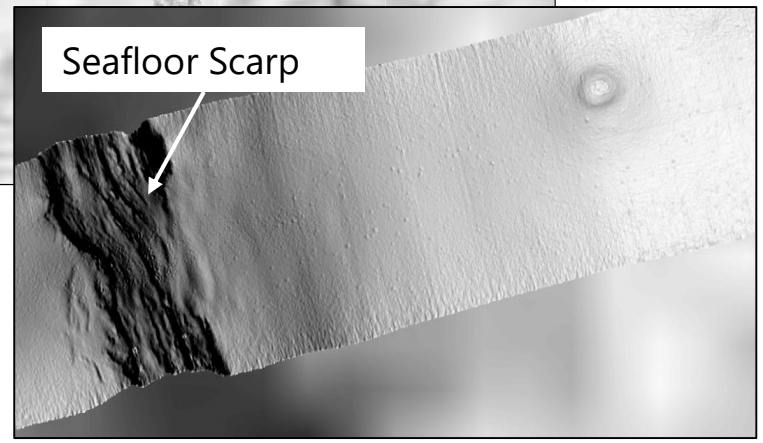
AUV Altitude:			35 m	6 m	22 m
Sensor	**Data Item**	**Details**	**DSAO**	**CHP**	**Collector Test Site**
MBES	**Bathy**	Bin Size	1 m	15 cm	27 cm
	Backscatter	Bin Size	1 m	15 cm	15 cm
Side Scan Sonar	**SSL**	Bin Size	50 cm	N/A	27 cm
	SSH	Bin Size	50 cm	N/A	15 cm
	SSX	Bin Size	N/A	7 cm	N/A
Camera	**Orthos**	Bin Size	N/A	3 mm	N/A
Subbottom Profiler	**Subbottom**	Frequency	1 - 10 khz	3.5 - 20.5 khz	1 - 10 khz

Geophysical Data - Bathymetry (22/35 m Altitudes)



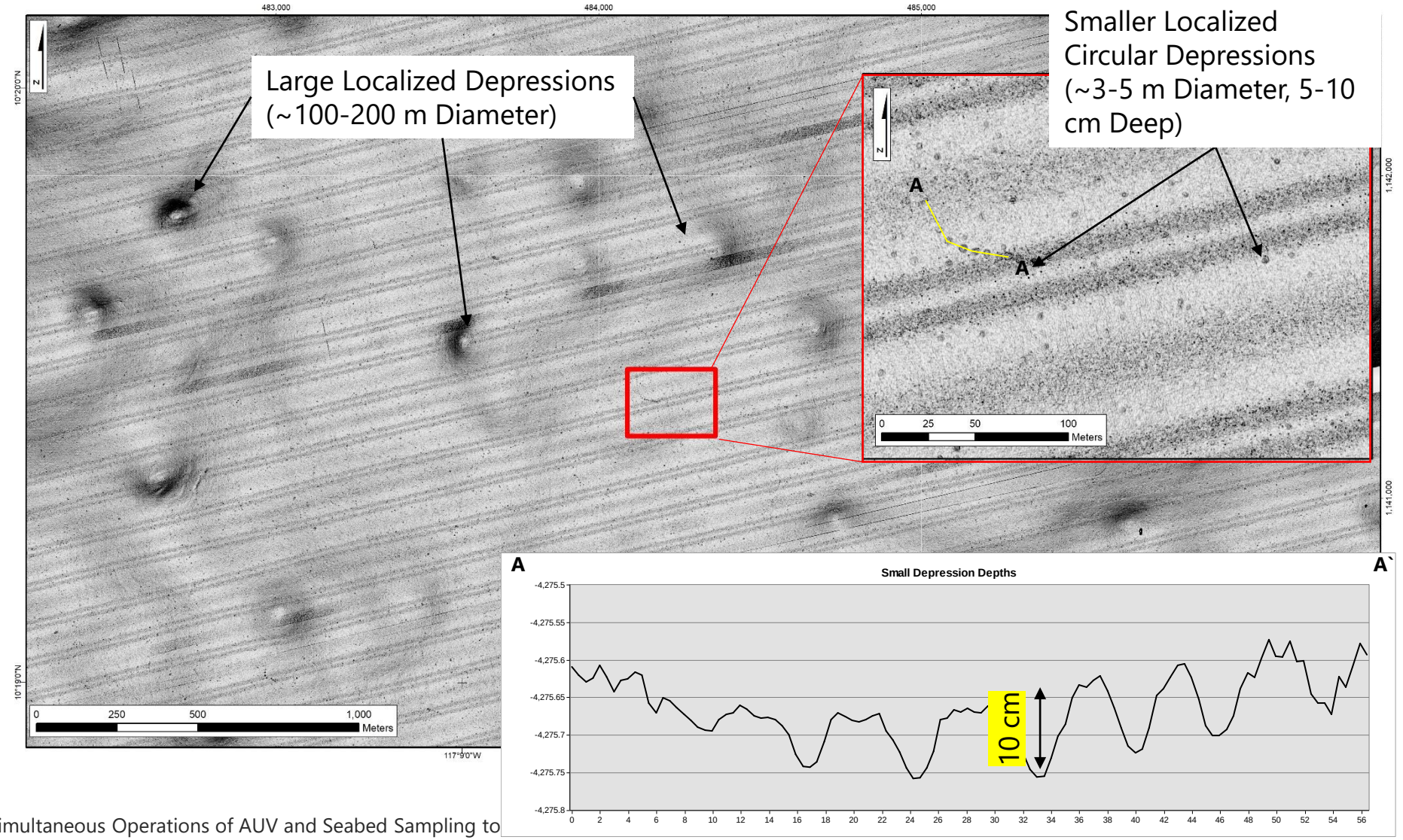




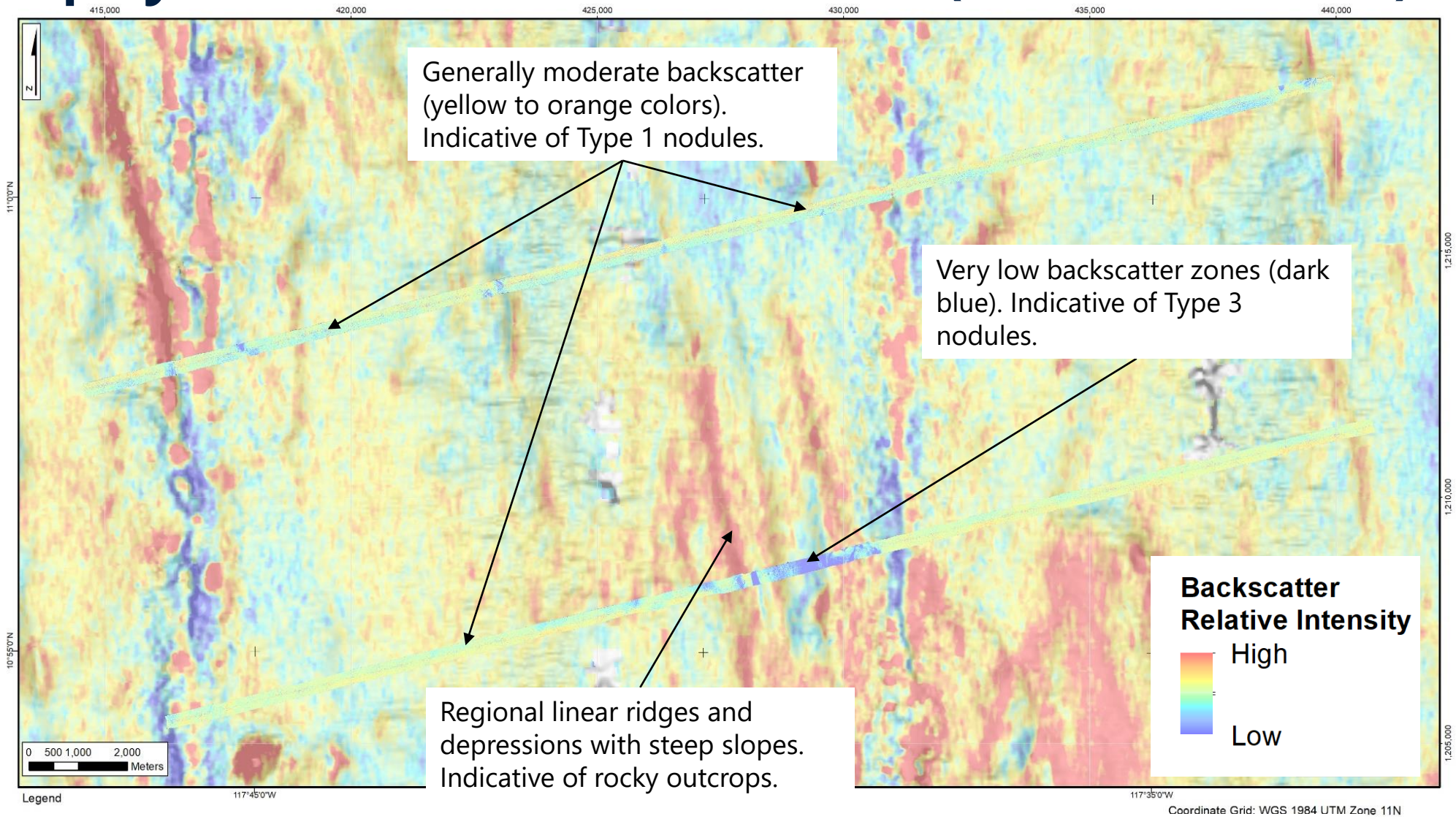


Images are greyscale slope renderings of AUV MBES bathymetry.

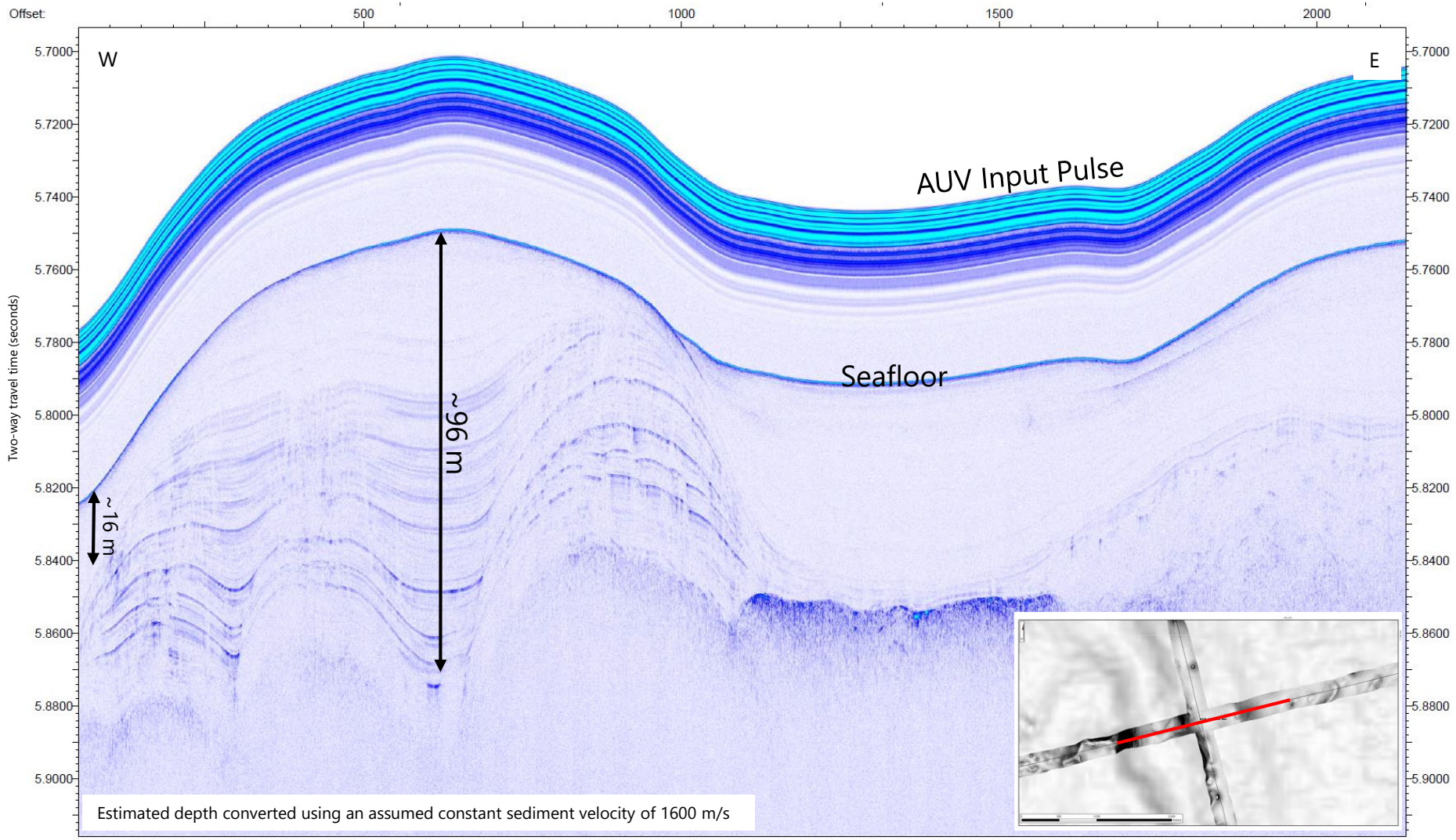
Geophysical Data - Bathymetry (22 m Altitude)



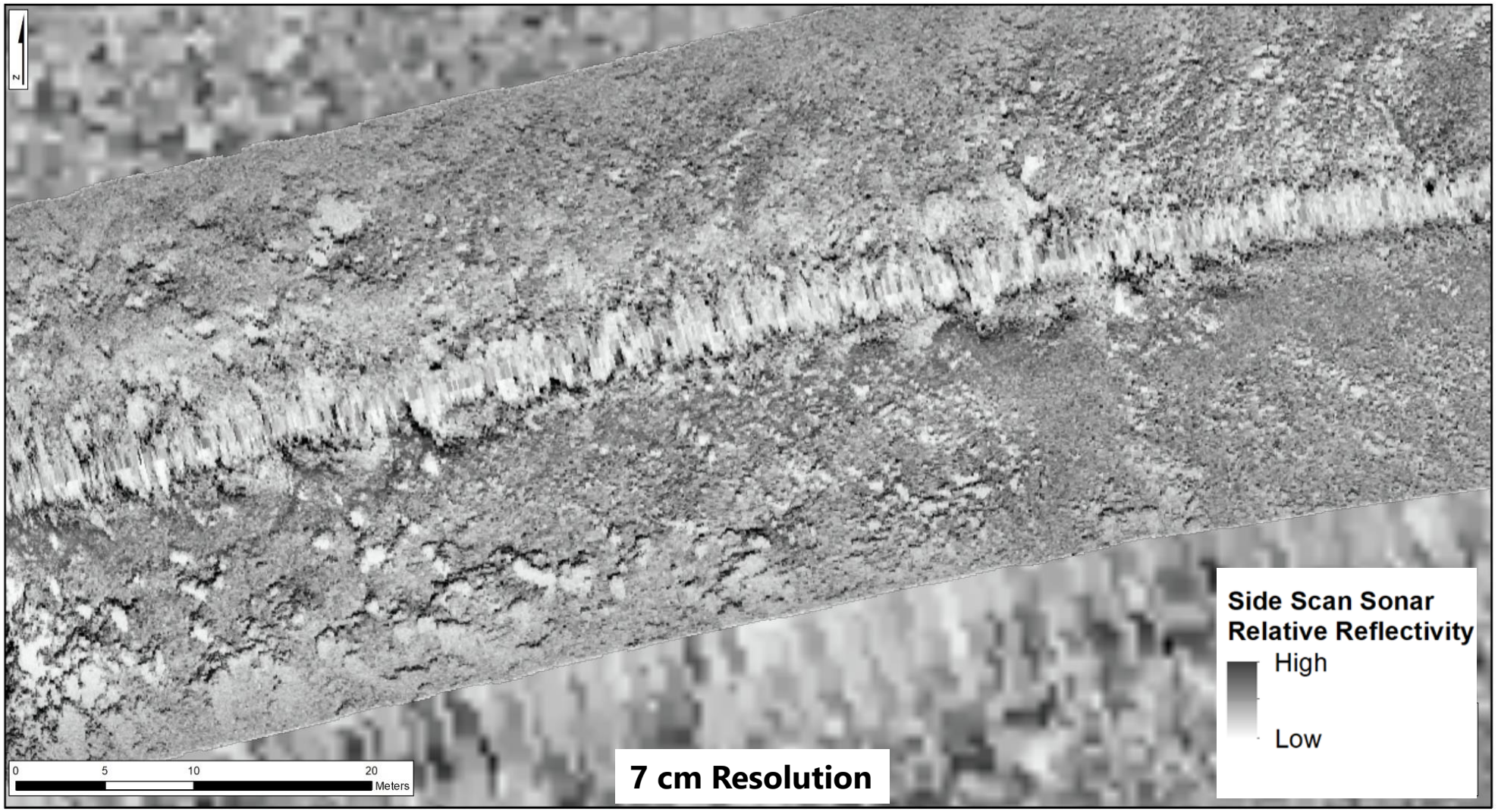
Geophysical Data – Backscatter (35 m Altitude)



Geophysical Data – SBP (1-10 kHz, 35 m Altitude)

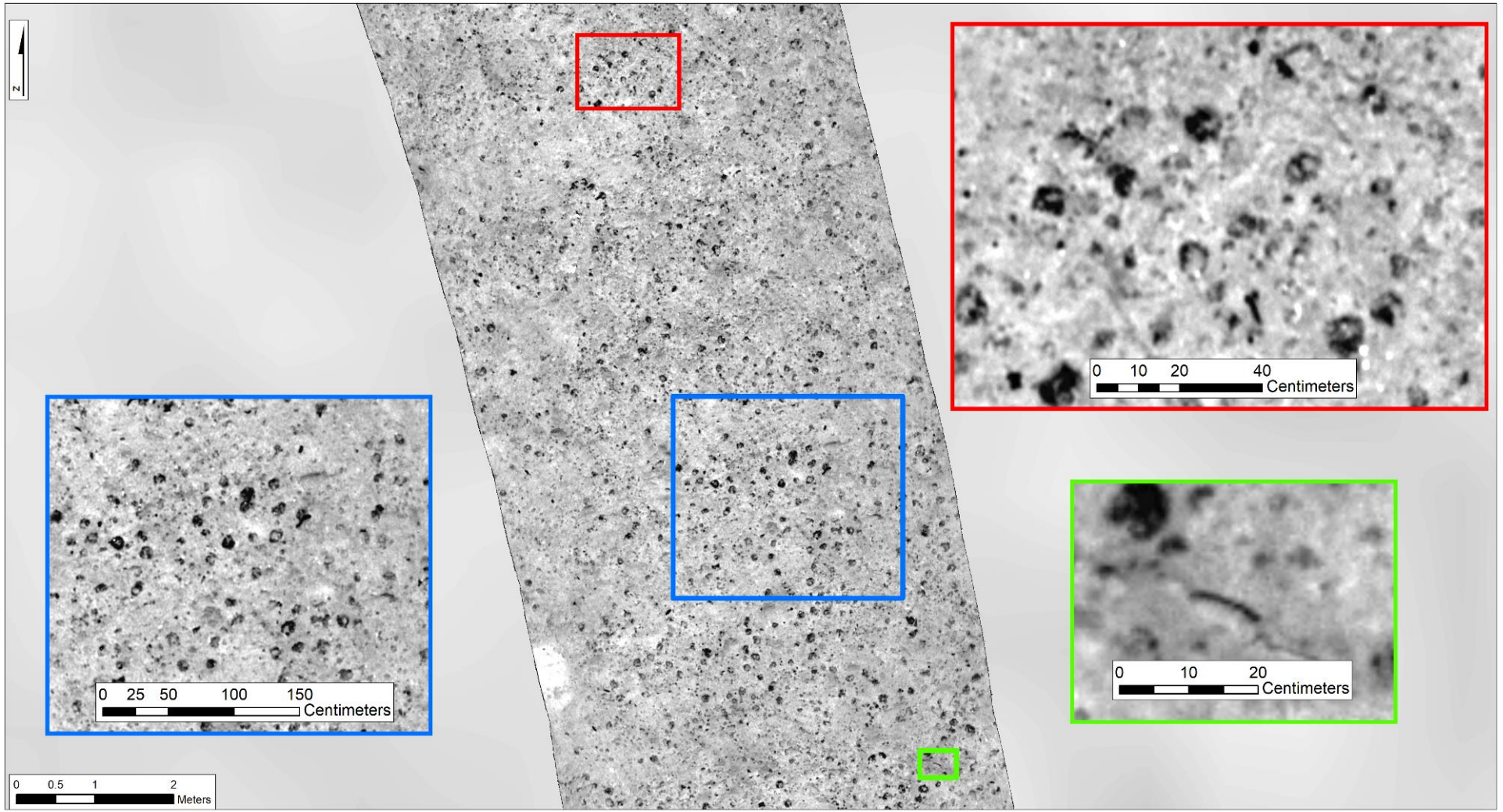


Geophysical Data – Side Scan Sonar (6 m Altitude)



Coordinate Grid: WGS 1984 UTM Zone 11N

Geophysical Data - Camera Imagery (6 m Altitude)



Note: Camera Imagery is preliminary.

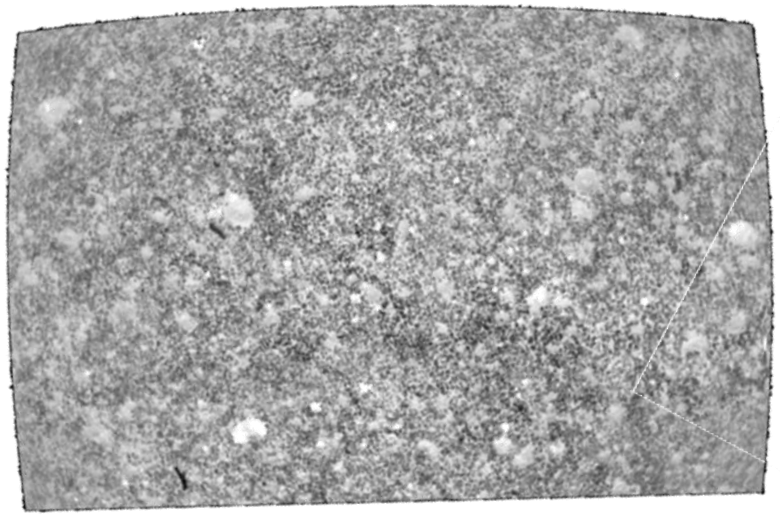
Coordinate Grid: WGS 1984 UTM Zone 11N

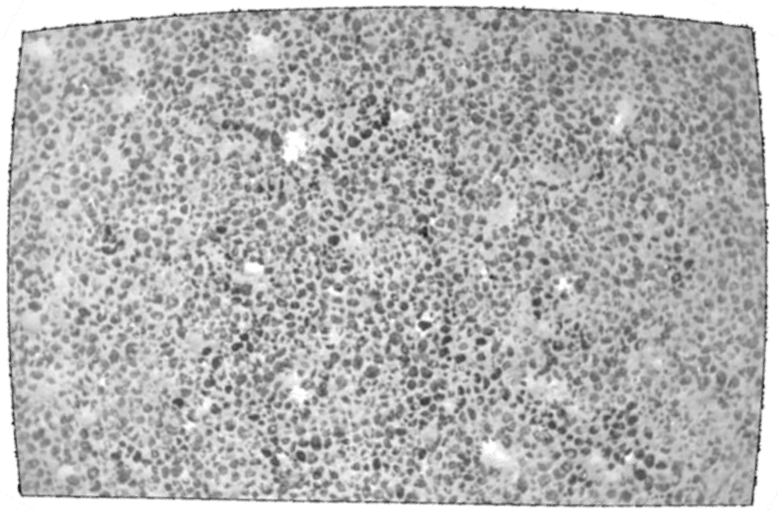
Nodule Classification based on Photogrammetry Data

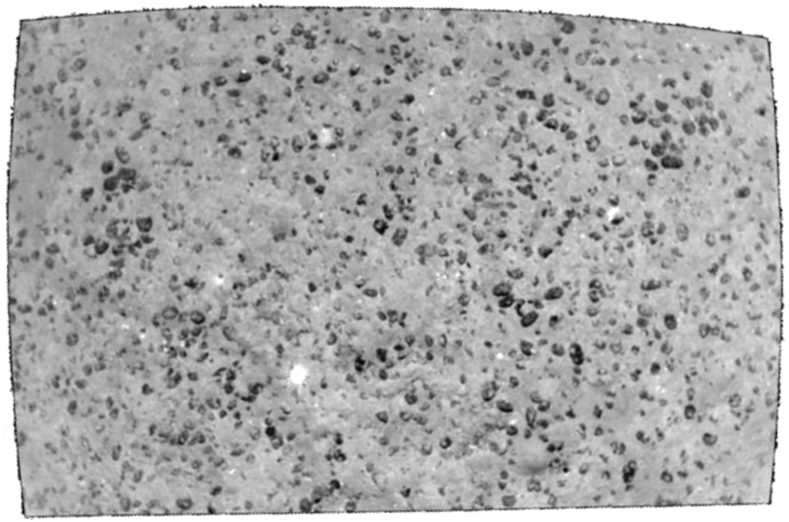
Type 1
- Densely Packed/Interconnected
- >50% Nodules
- ~1-10 cm, uncertain
- Low Confidence in Camera Imagery to Resolve Individual Nodules

Type 2
- Mostly Individual/Locally Interconnected
- ~20-40% Nodules
- ~5-20 cm
- Moderate Confidence in Camera Imagery to Resolve Individual Nodules

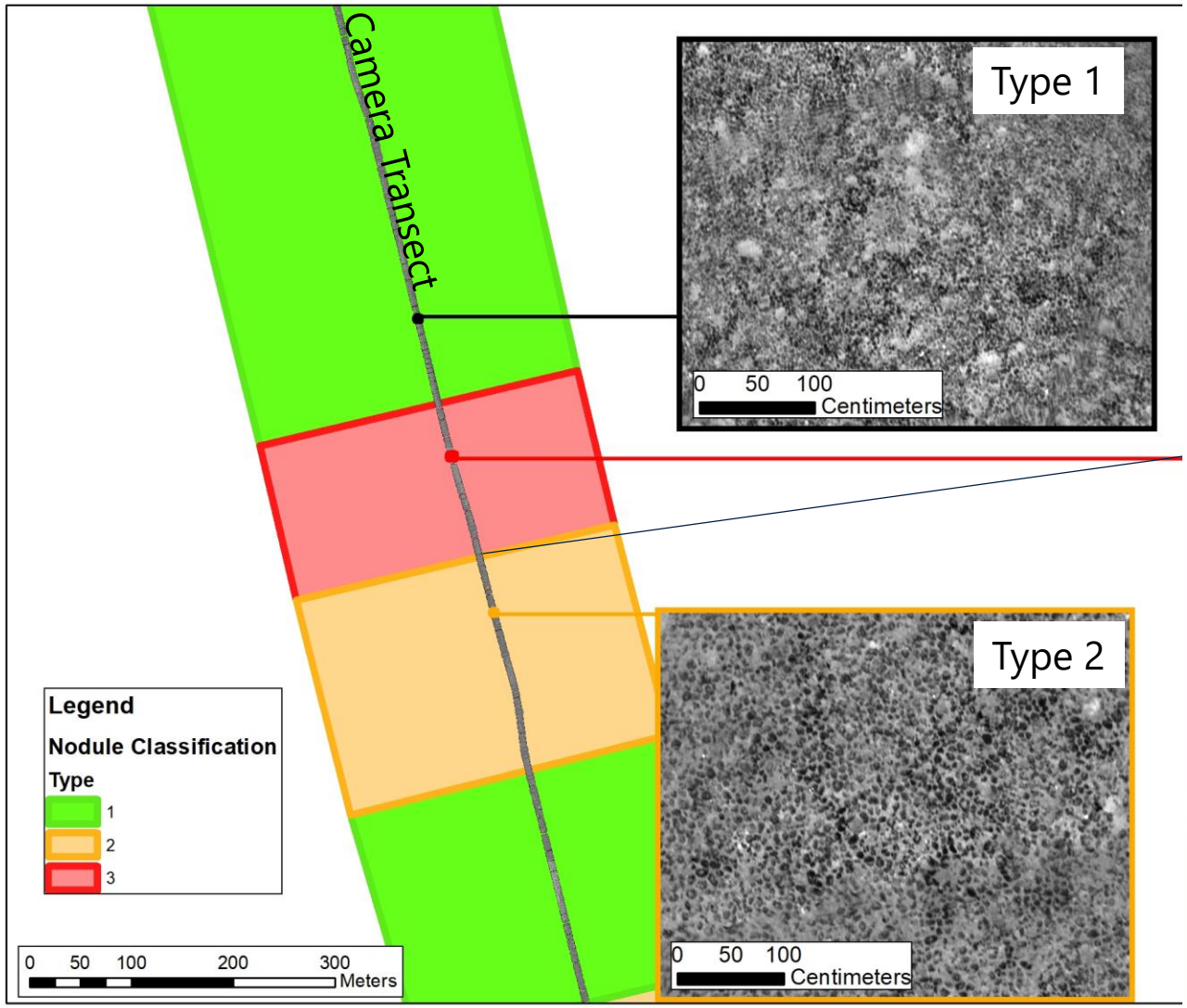
Type 3
- Mostly Individual/Sparse
- 10-20% Nodules
- ~5-20 cm
- High Confidence in Camera Imagery to Resolve Individual Nodules

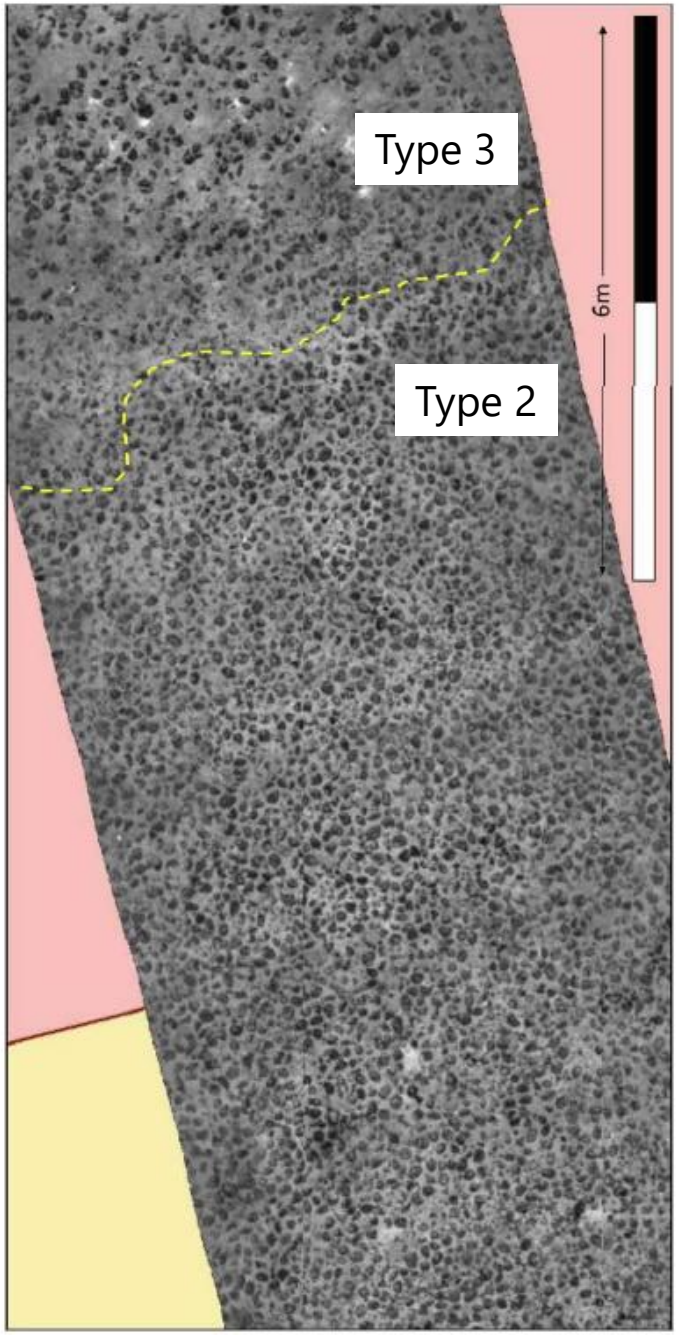




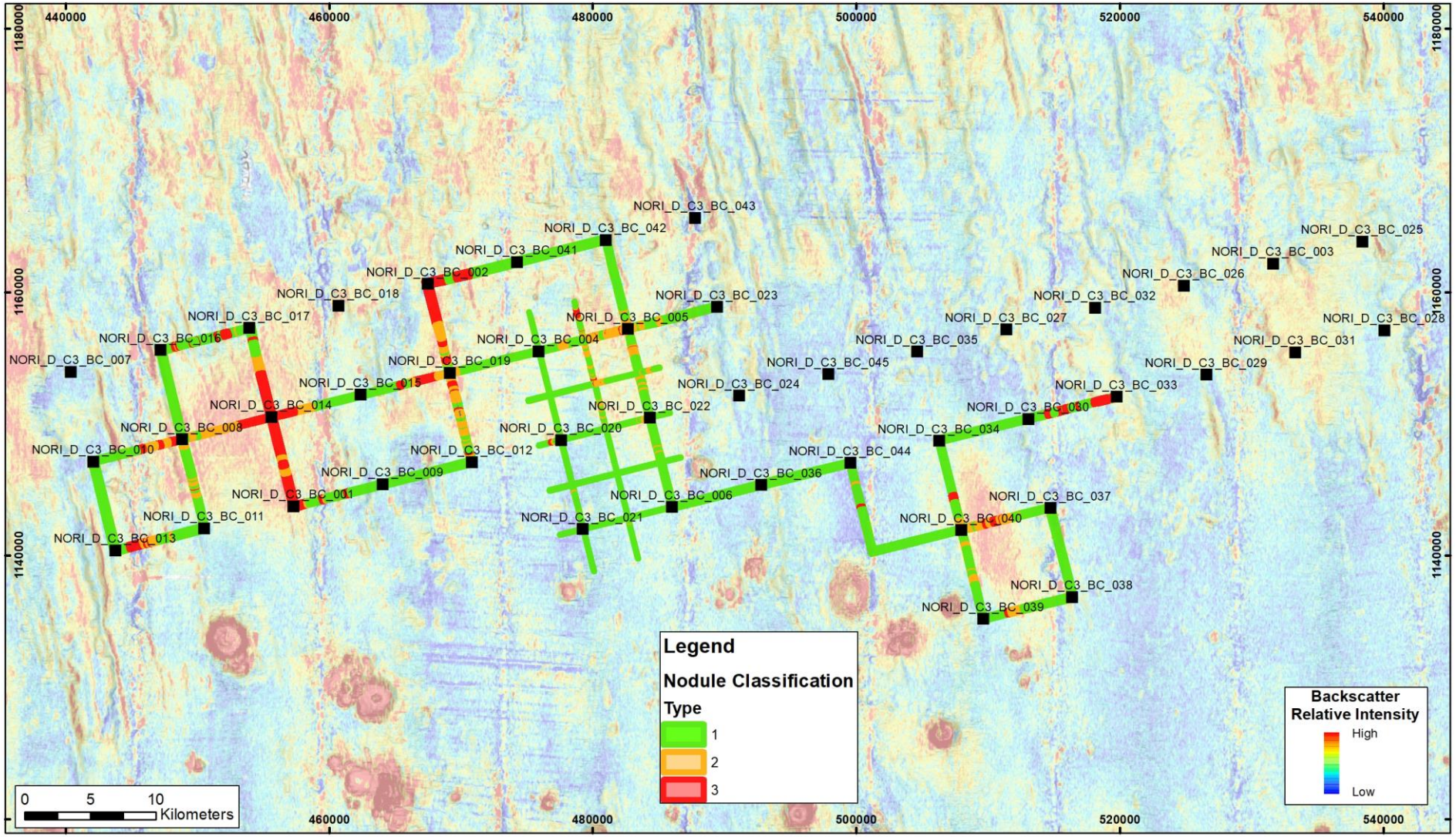


Nodule Classification based on Photo

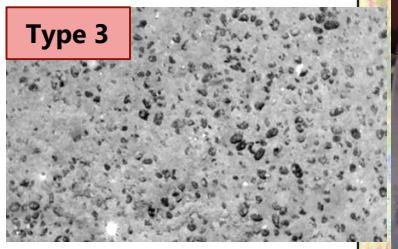


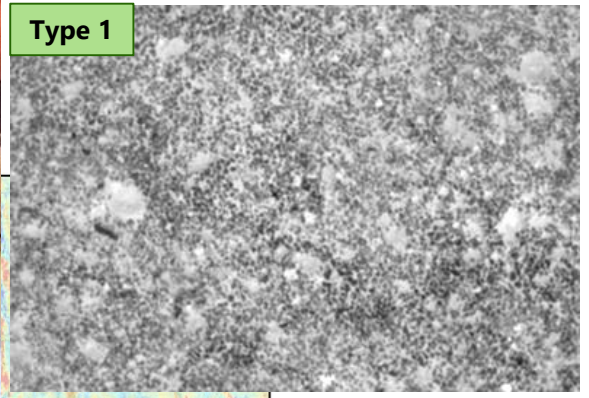


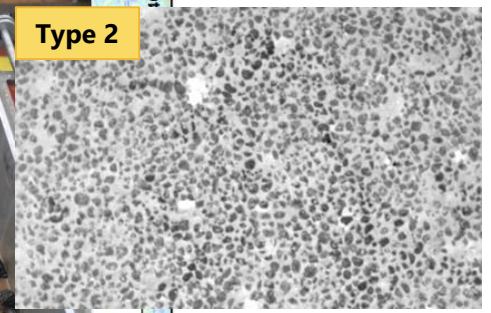
Integration of Seabed Samples and Geophysical Data



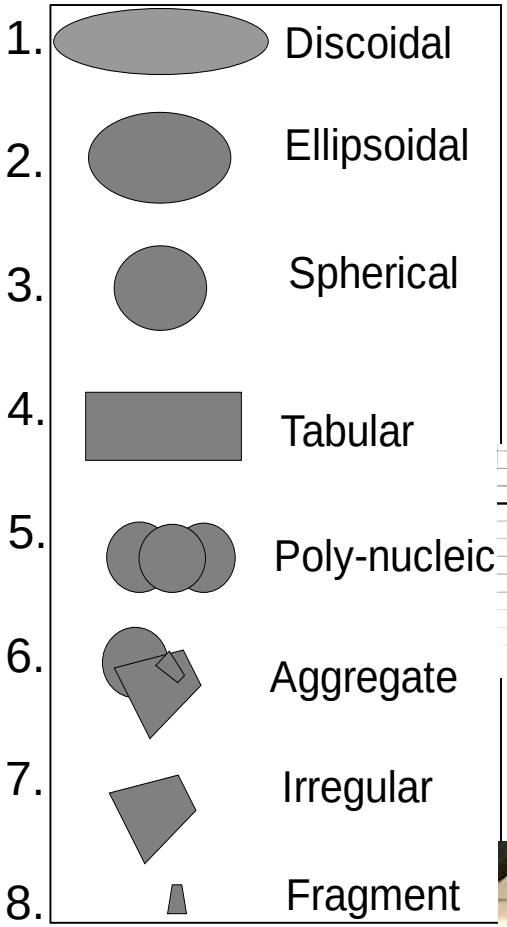
Box Coring Res

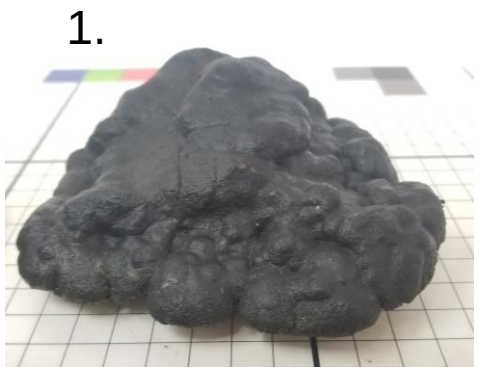


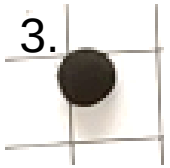


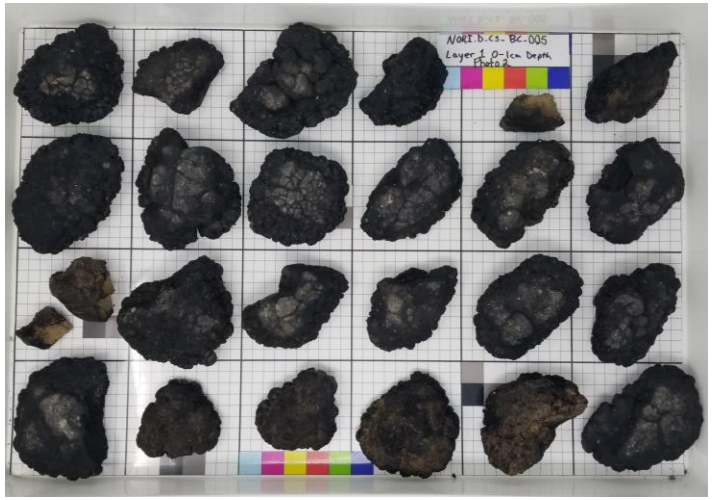


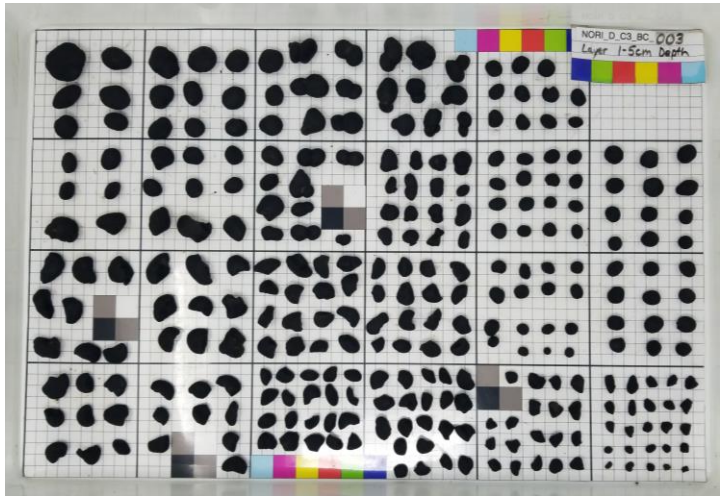
Box Coring Results - Various Nodule Shapes



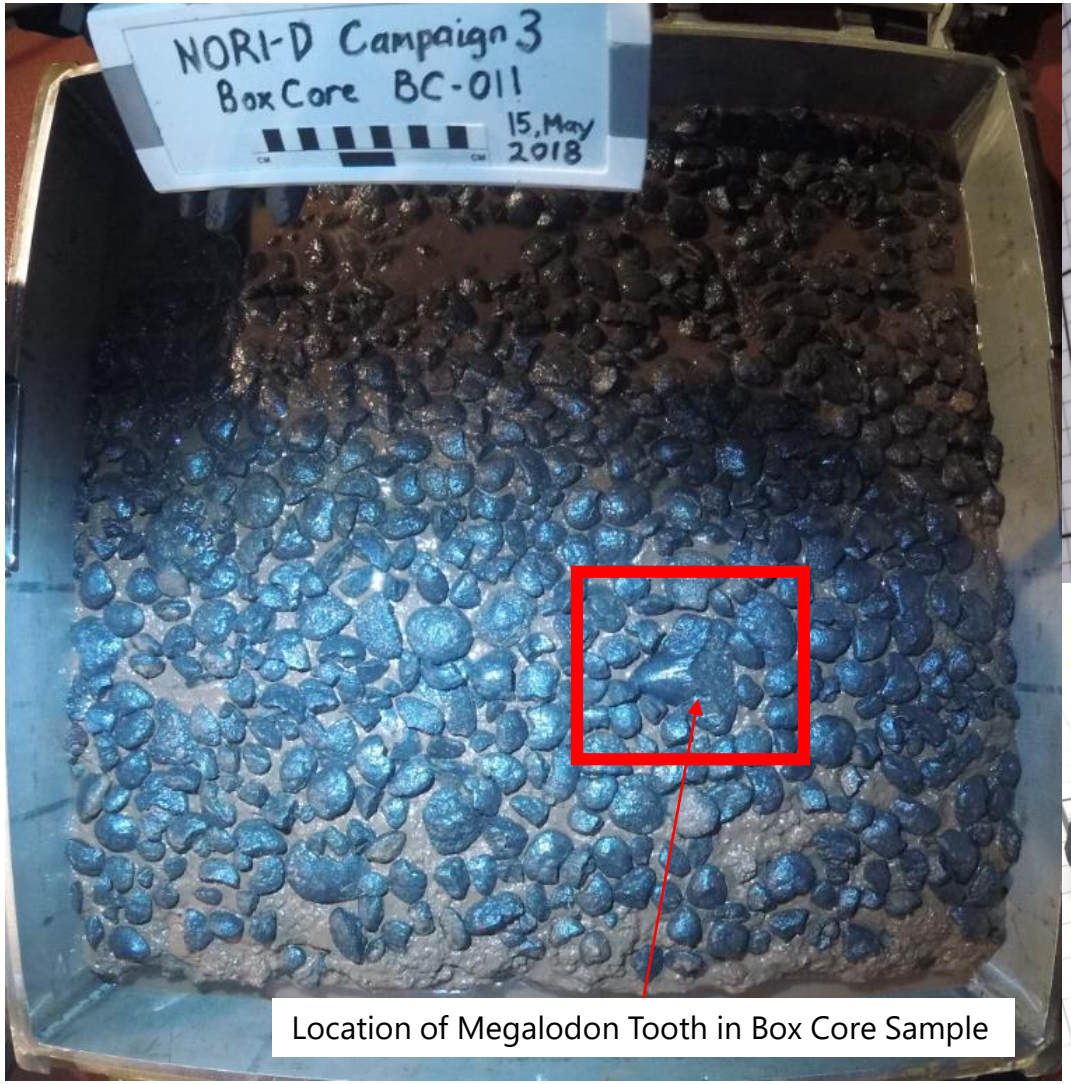








Box Coring Results - Interesting Samples



Potentially mineralized bone? Weighing about 2.83 kg

Summary

- The DeepGreen 2018 campaign was Fugro's first commercial simultaneous operations survey consisting of AUV and seabed sampling.
- The successful collection of data and interpretations provided the client with sufficient information to decide the location of the optimal collector test site during the survey.
- Successful SIMOPs allowed for collection of 45 box cores and ~150 km^2 of geophysical data acquisition.
- Services that added value to the survey were the ability to process and interpret over 14 terabytes of camera imagery and geophysical data and to build a high-quality interpretational GIS database as well as systematically processing box core samples while offshore.
- In turn, the data collected during this successful campaign and subsequent onshore work and interpretations were included in the recently released NI 43-101 Technical Report for "NORI Area D Clarion Clipperton Zone Mineral Resource Estimate"

Thank you!

Christine Devine[1], Daniel McConnell[2], Ian Stevenson[3], Jeff Croucher[2], Kathryn Rovang[2], and Ben Mizell[2]

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