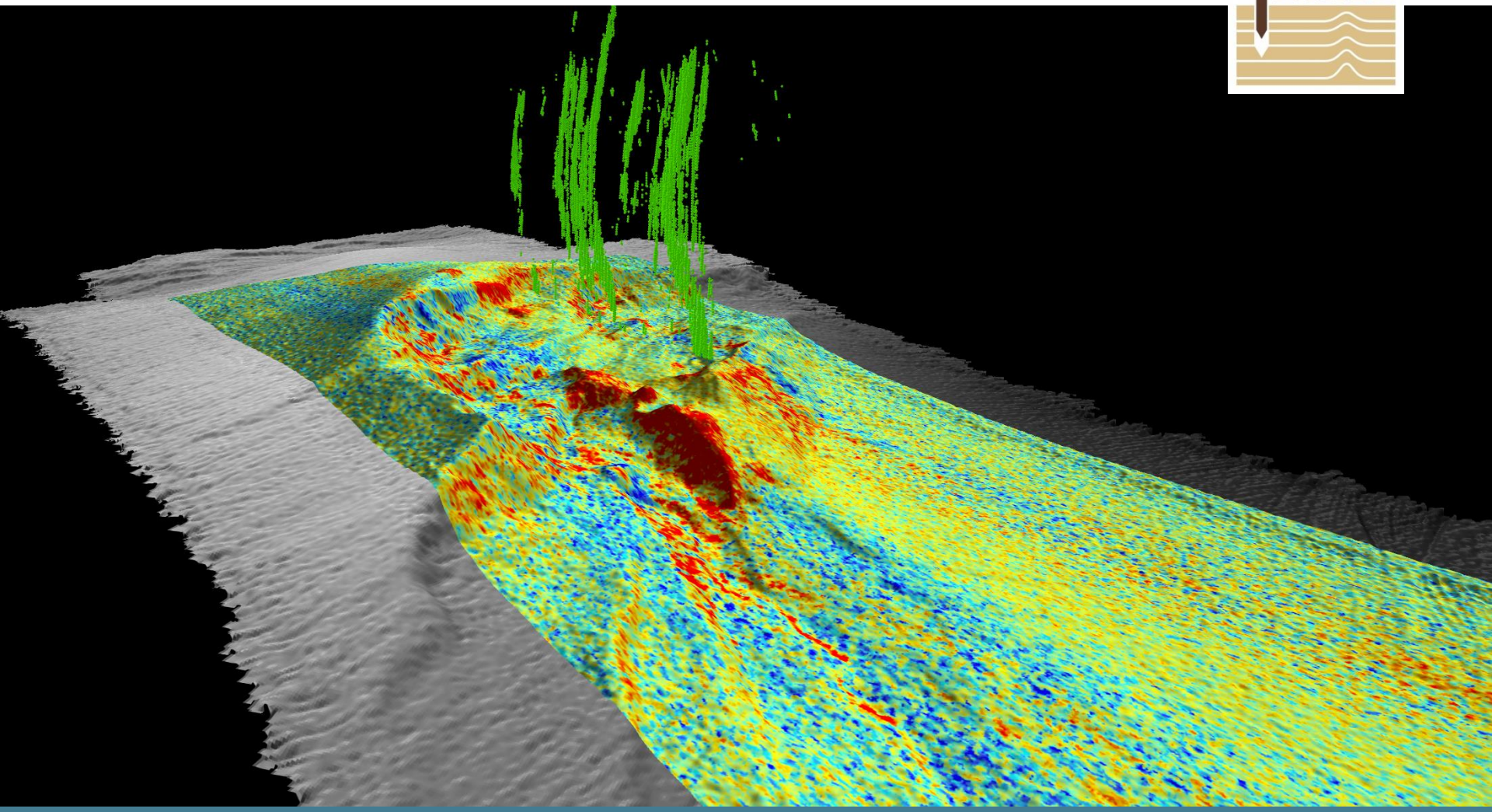


Deepwater Hydrocarbon Seep Detection: Tools and Techniques using Multibeam Echosounders

D. Millar, G.A. Mitchell, J.J. Gharib – Fugro USA

GEBCO Bathymetric Science Day - October 12, 2016

What Are Seeps: How and Why do we Hunt for Them??

Naturally occurring “leaks” from the subsurface

If we can find and sample them, we can tell

If there is the “right” geochemical signature

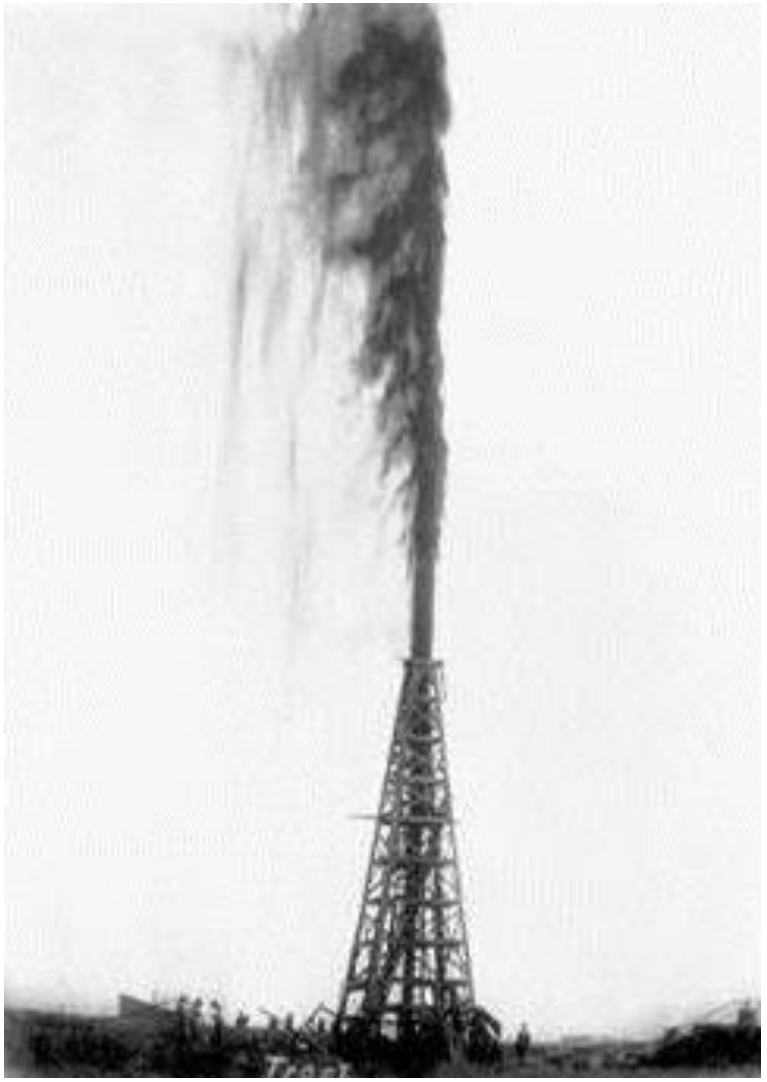
Find the “right” areas to acquire more expensive data

Seeps are difficult to find on the seafloor – so we must hunt for them!

Fugro actions

- Map with the right tool
- Skilled geologists interpret
- Sample accurately – experience counts
- Analyze the results

Clients are always kept in the loop and welcomed to contribute to all stages of the process



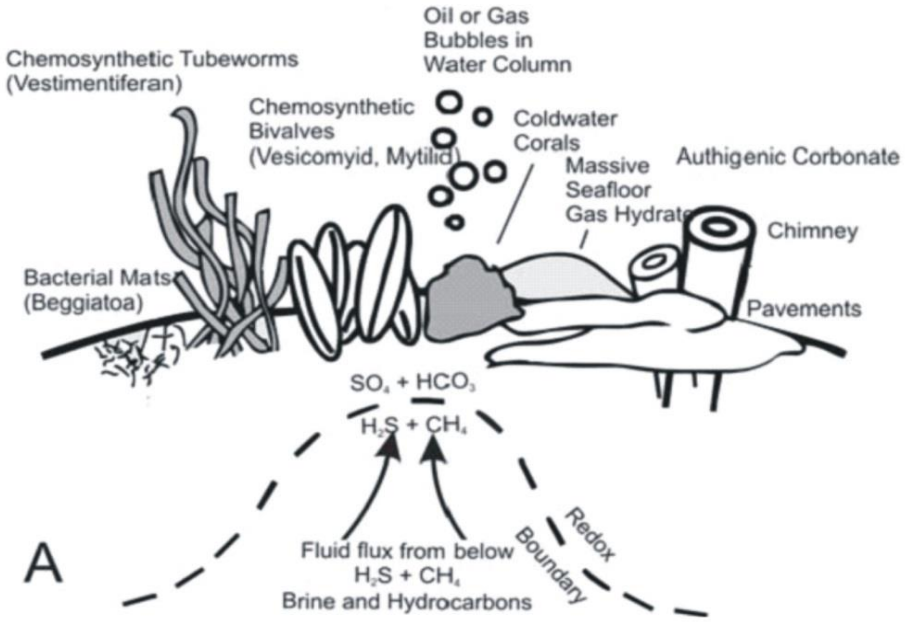
Lucas Gusher on Spindletop Hill

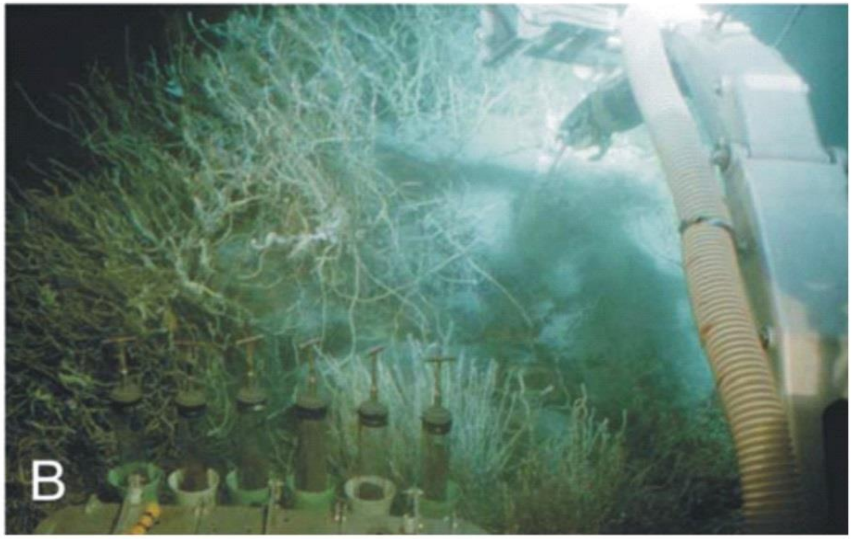
Seep Communities Make Great Acoustic Echoes!

Hydrocarbon seeps occur anywhere oil or gas reach the seafloor. Seeps feed chemosynthetic communities with hard shells, they form minerals, and create gas hydrate deposits.

This leads to hard – and acoustically reflective seafloor – on an otherwise soft seabed

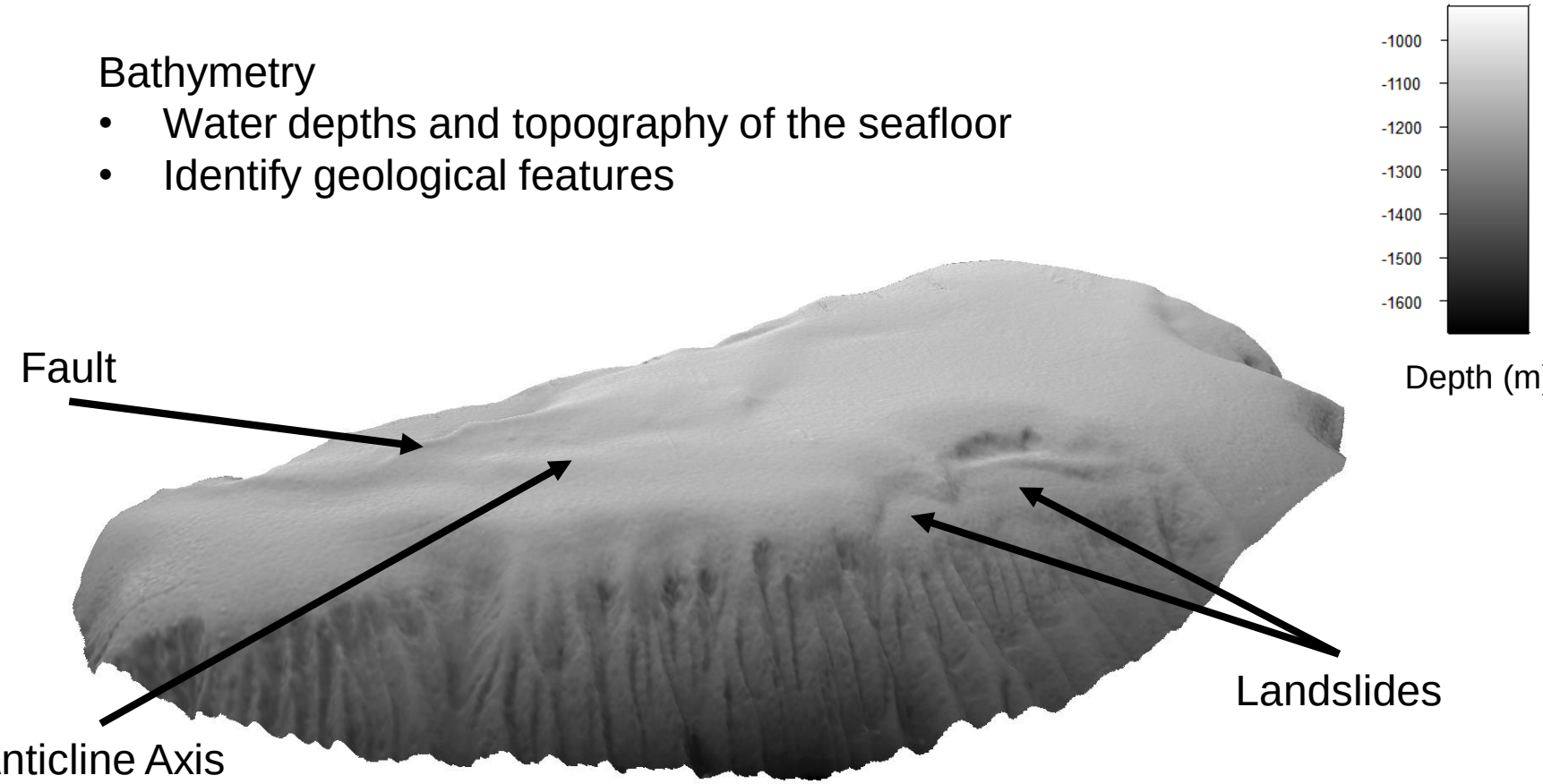
Fugro uses this to find seep locations!

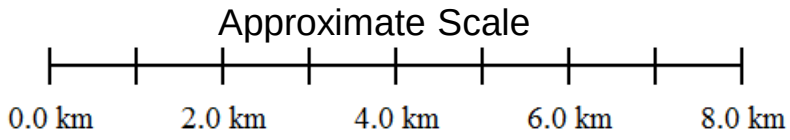




What Information is Obtained from Multibeam Data?

Bathymetry
- Water depths and topography of the seafloor
- Identify geological features





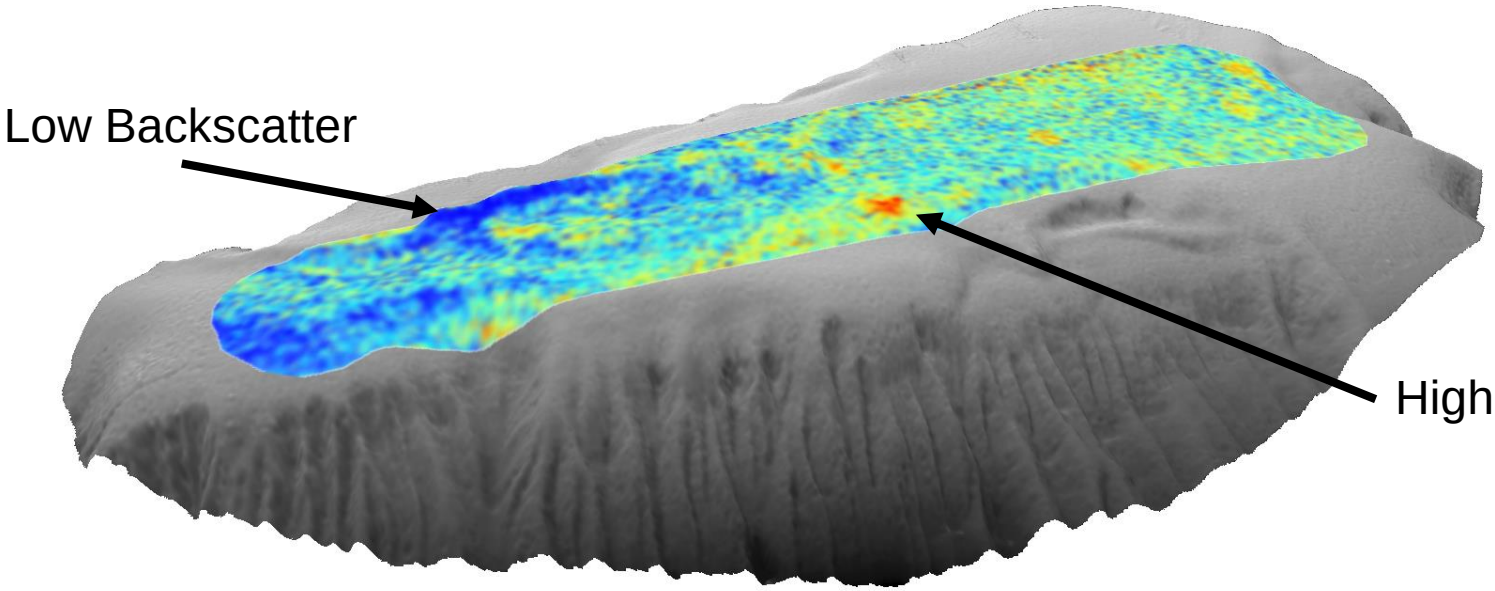
Data courtesy of Anadarko New Zealand Company
Collected by Fugro GeoConsulting, Inc. and NIWA

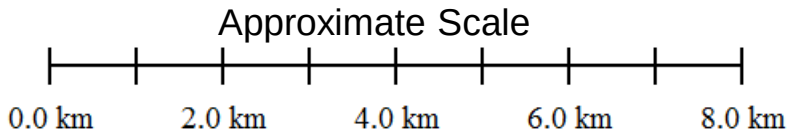
Bathymetry Vertical Exaggeration = 3x

What Information is Obtained from Multibeam Data?

Backscatter Intensity

- Amount of acoustic energy of the seafloor
- Higher backscatter = harder substrate
- Lower backscatter = softer substrate





Data courtesy of Anadarko New Zealand Company
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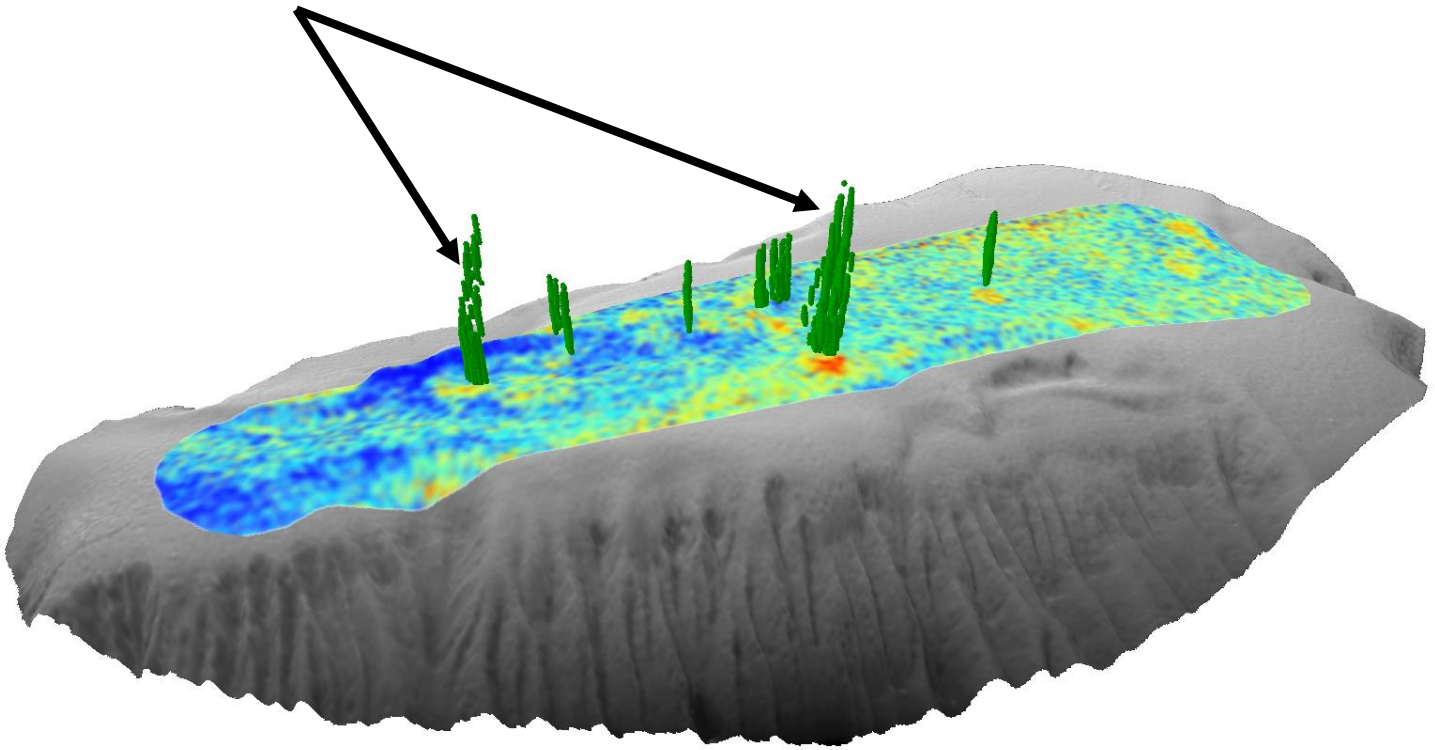
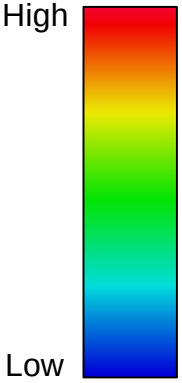
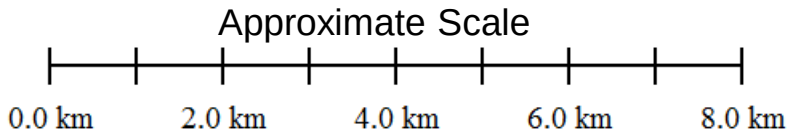
Bathymetry Vertical Exaggeration = 3x

What Information is Obtained from Multibeam Data?







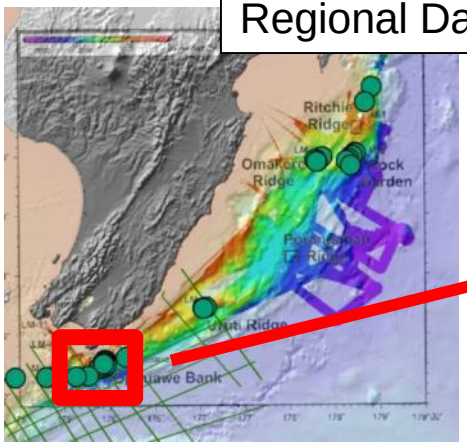
Data courtesy of Anadarko New Zealand Company
Collected by Fugro GeoConsulting, Inc. and NIWA

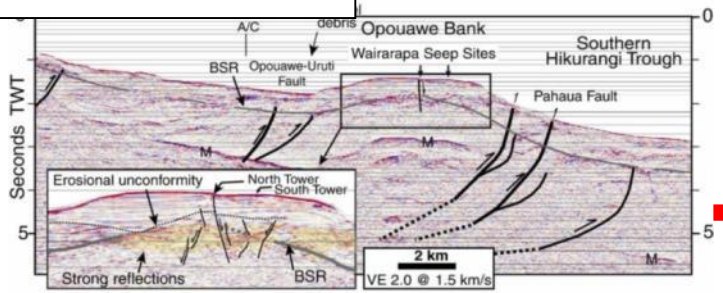
Bathymetry Vertical Exaggeration = 3x

An Integrated Exploration Process

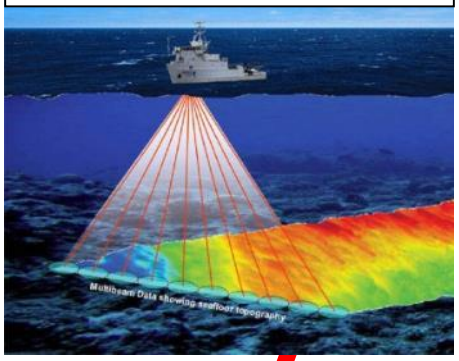
Target Identification

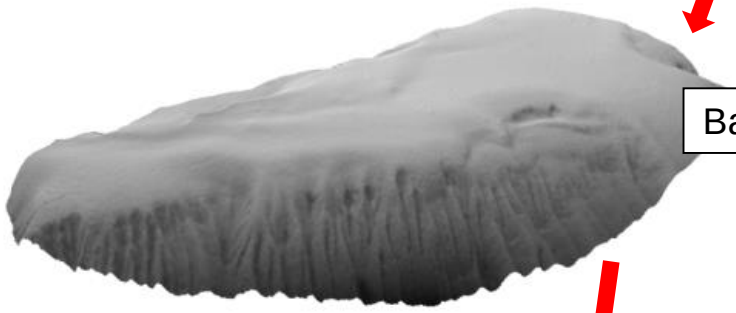
Regional Data and Assessment



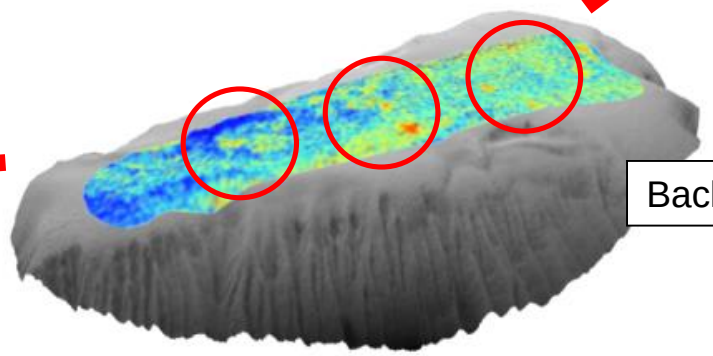


New Multibeam Data

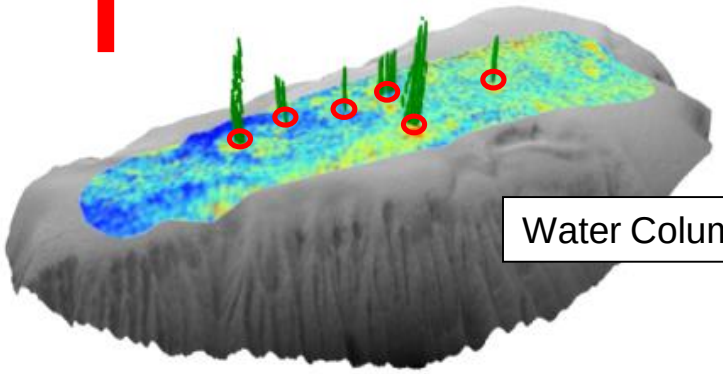




Bathymetry



Backscatter

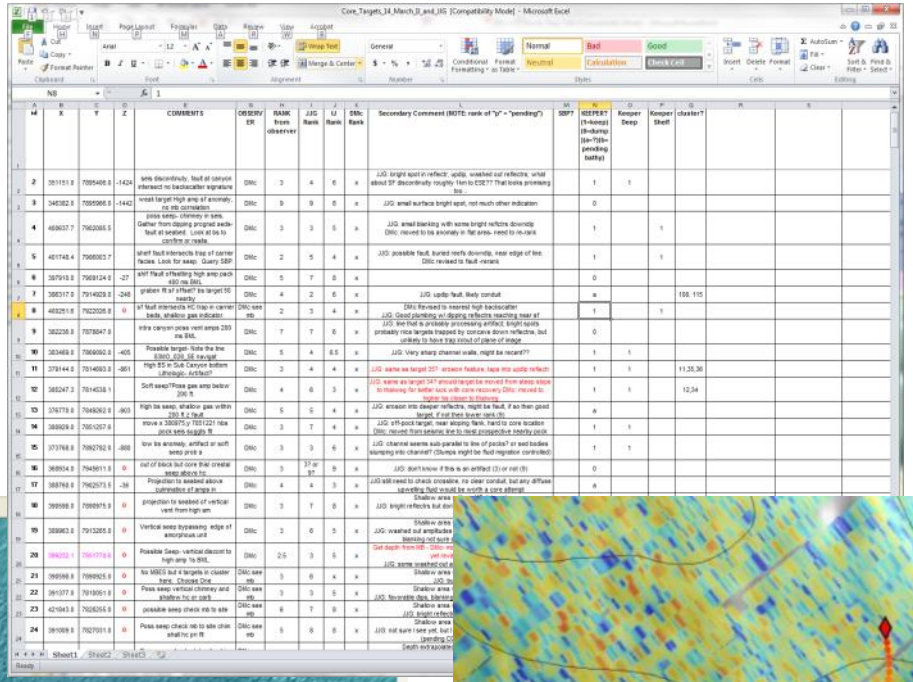


Water Column

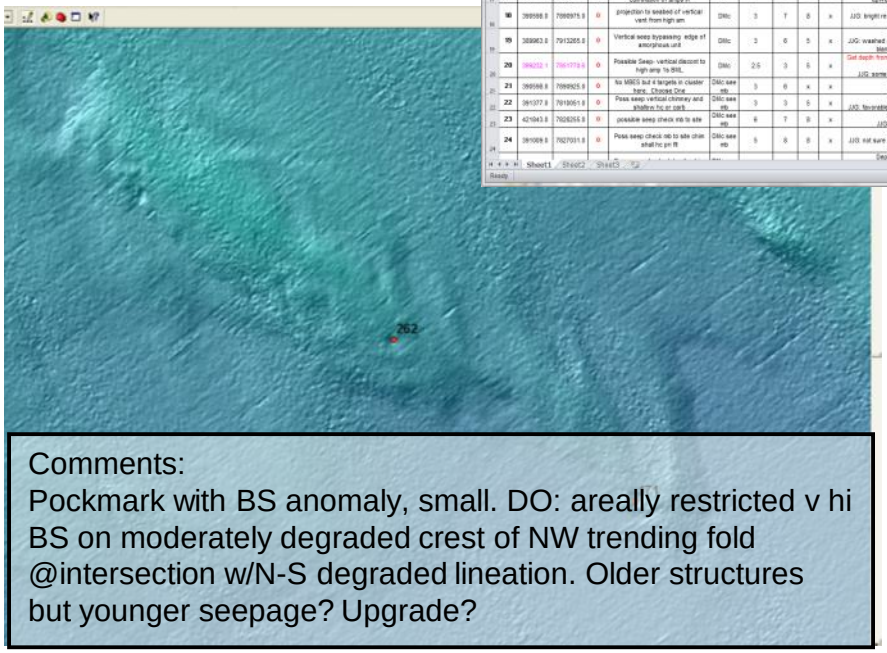
All interpretative stages need geologic expertise and experience to optimize the geochemical sampling location.

The Approach - Target Ranking and Optimization

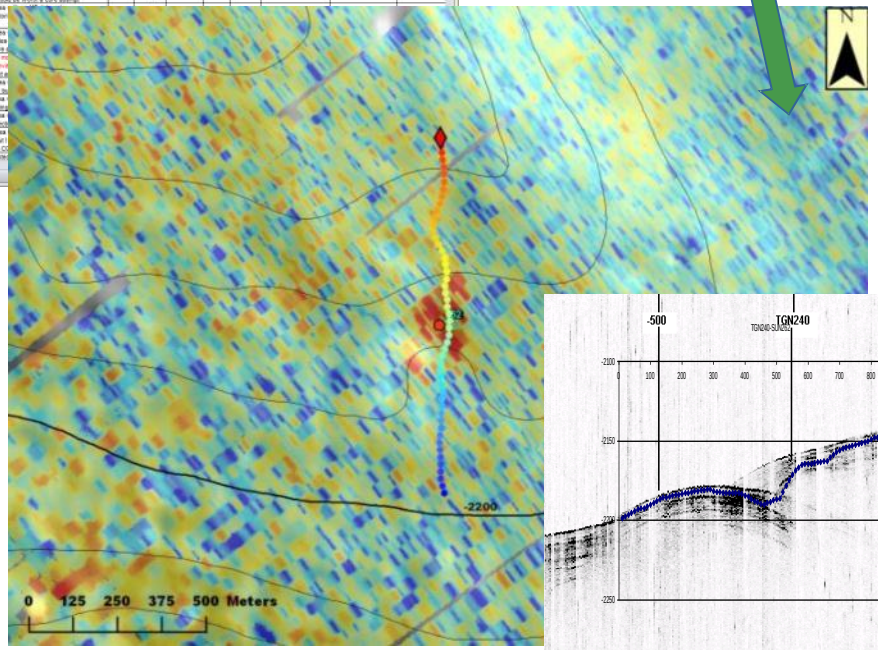
Targets are Identified and Graded/Ranked



Optimizing still continues throughout the coring operation (including reshooting targets)



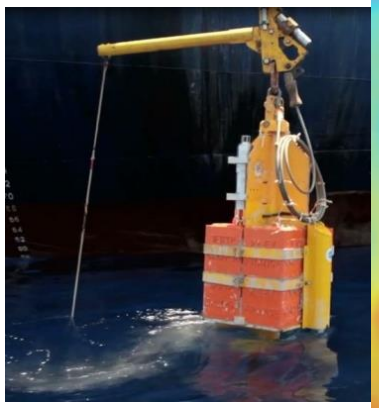
Comments:
Pockmark with BS anomaly, small. DO: areally restricted v hi BS on moderately degraded crest of NW trending fold @intersection w/N-S degraded lineation. Older structures but younger seepage? Upgrade?

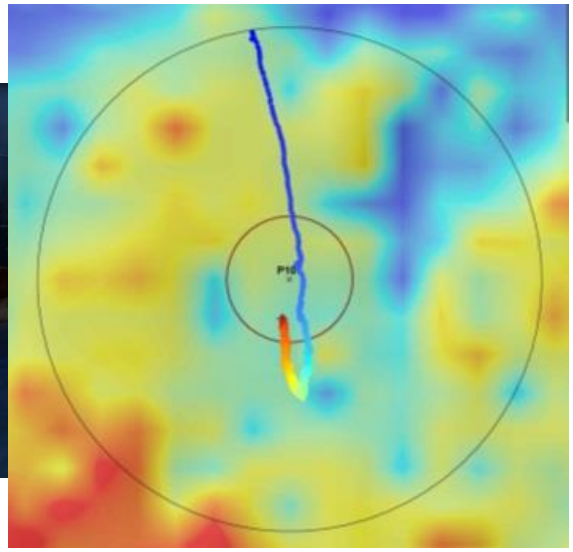


Precision Seep Sampling

Understanding the Target

Making sure the core hits the target



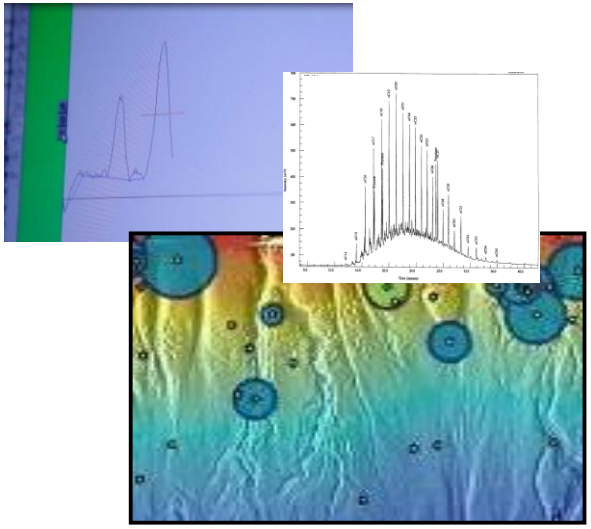


All interpretative stages need geologic expertise and experience to optimize the geochemical sampling location.

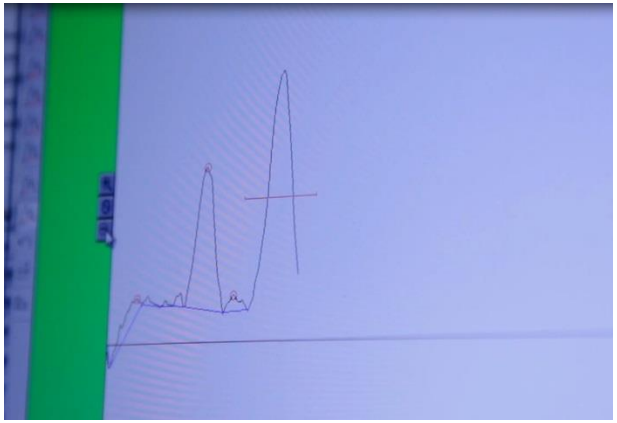
Core recovery with seep-related hardgrounds at the base

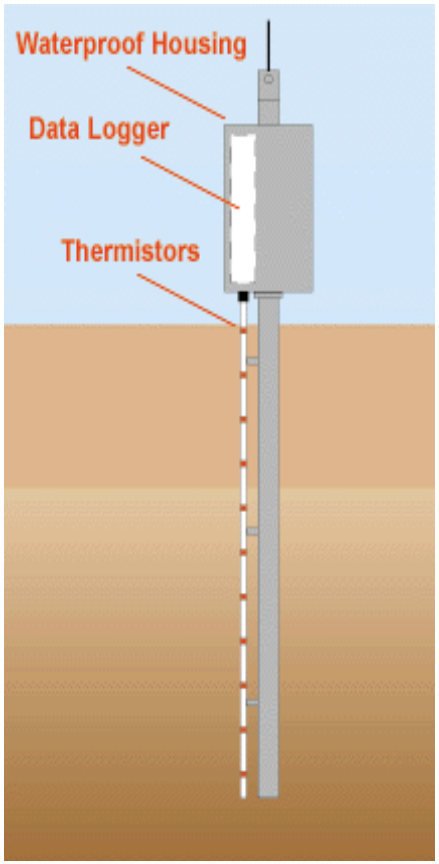
Gas-parting and fine-grained gas hydrates in the sediment

Headspace gases C1-C5 can be analyzed on the vessel to confirm targets, while sediment extracts can be sent to shore-based laboratory more comprehensive analysis



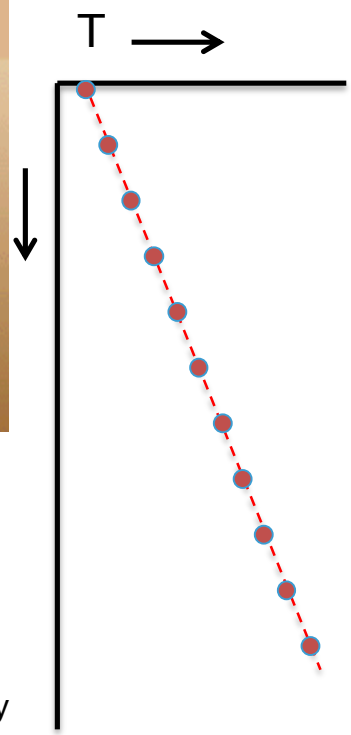
Optional Onboard Analysis – Geochemistry and Heatflow





$Q = -K \, dT/dZ$

dT/dZ & K measured *in situ*



Head space gases C1-C5 can be analyzed on the vessel to confirm targets while sediment extracts can be sent to shore-based laboratory for gasoline range and heavy hydrocarbon (C15+)analysis

Exclusive partnership with US National Academic Heat Flow Facility at Oregon State University

Seep-Hunting & Geochemical Campaigns Benefits

Frontier Region Exploration is Risky & Costly

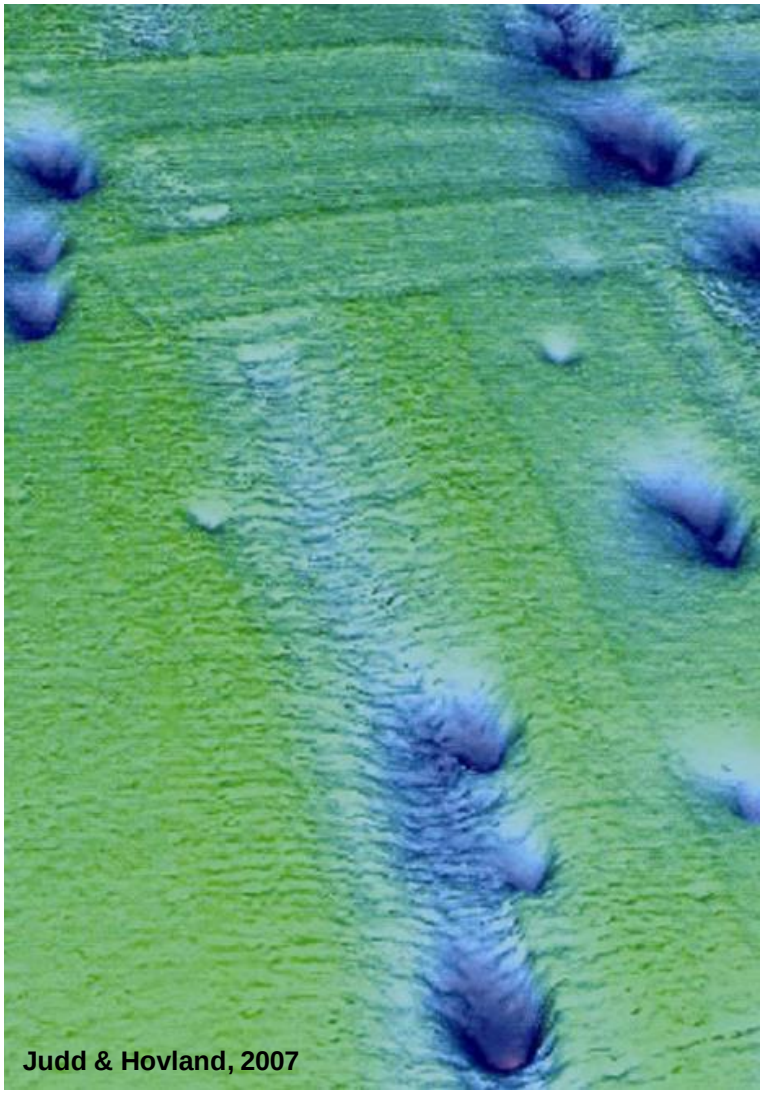
Seep Campaigns Can Reduce Risk & Cost

Yield insights to the system

- Seafloor and shallow subseafloor geologic features
- Geochemical composition of the reservoir
- Maturity of hydrocarbon system
- Basin evolution

Maximize return on investment & aid decision making

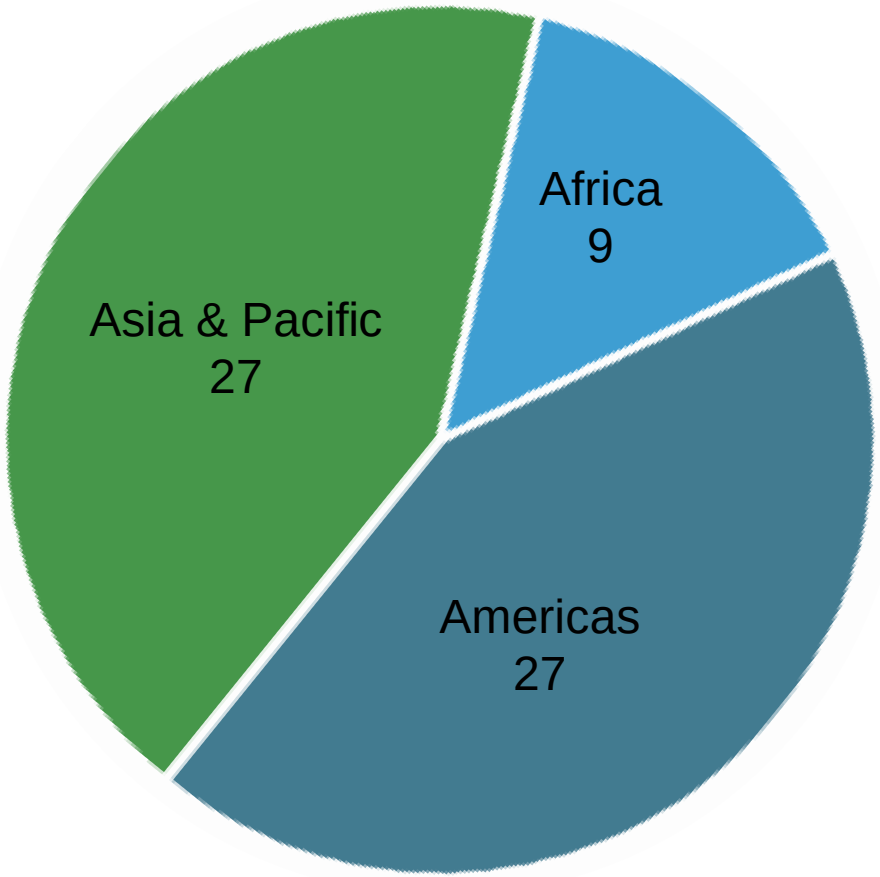
- Onboard experts can optimize ship time by making decisions based on the acquired data
- Provide guidance for prioritizing future exploration work
- Quickly map most or all of a lease block
- Seep campaign results will show you where to carry out more expensive exploration work
- Convincing evidence can be used to attract a farm-in partner
- Lack of convincing evidence for a viable hydrocarbon source means resources can be spent elsewhere



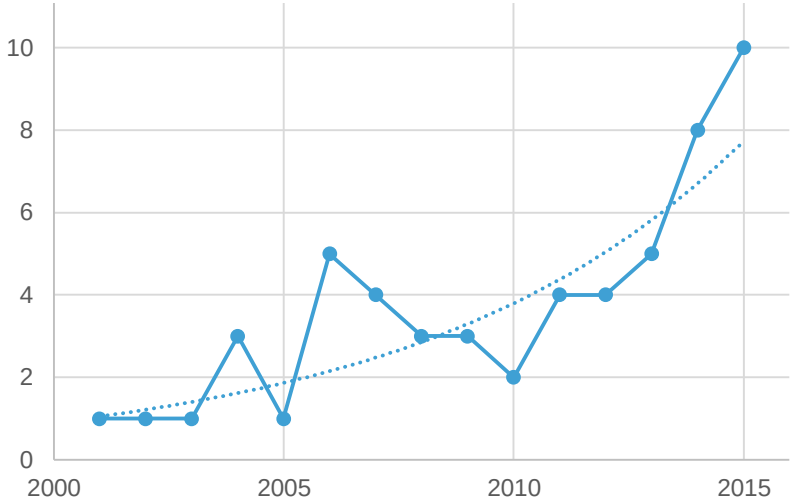
Judd & Hovland, 2007

Modern Seep-Hunting Campaigns – Gaining Industry Acceptance

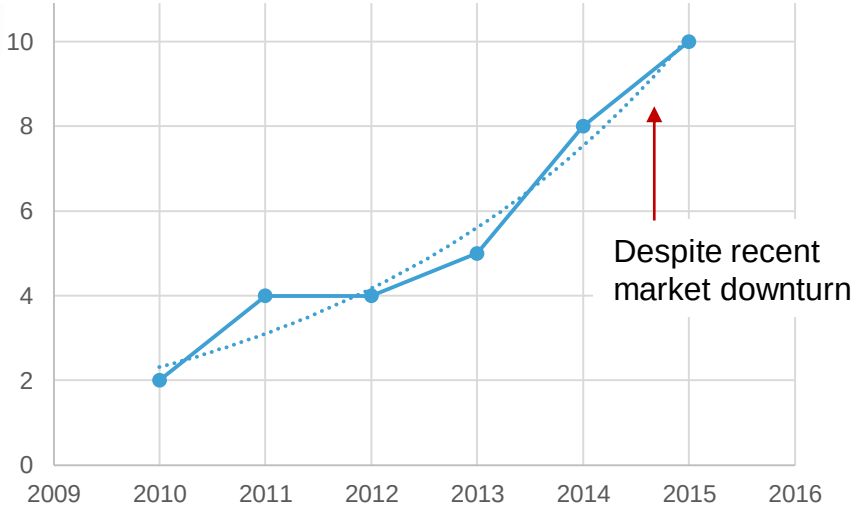
Seep Projects by Region



Projects grew annually by 14% from 2000-2015



Projects grew annually by 30% from 2010-2015



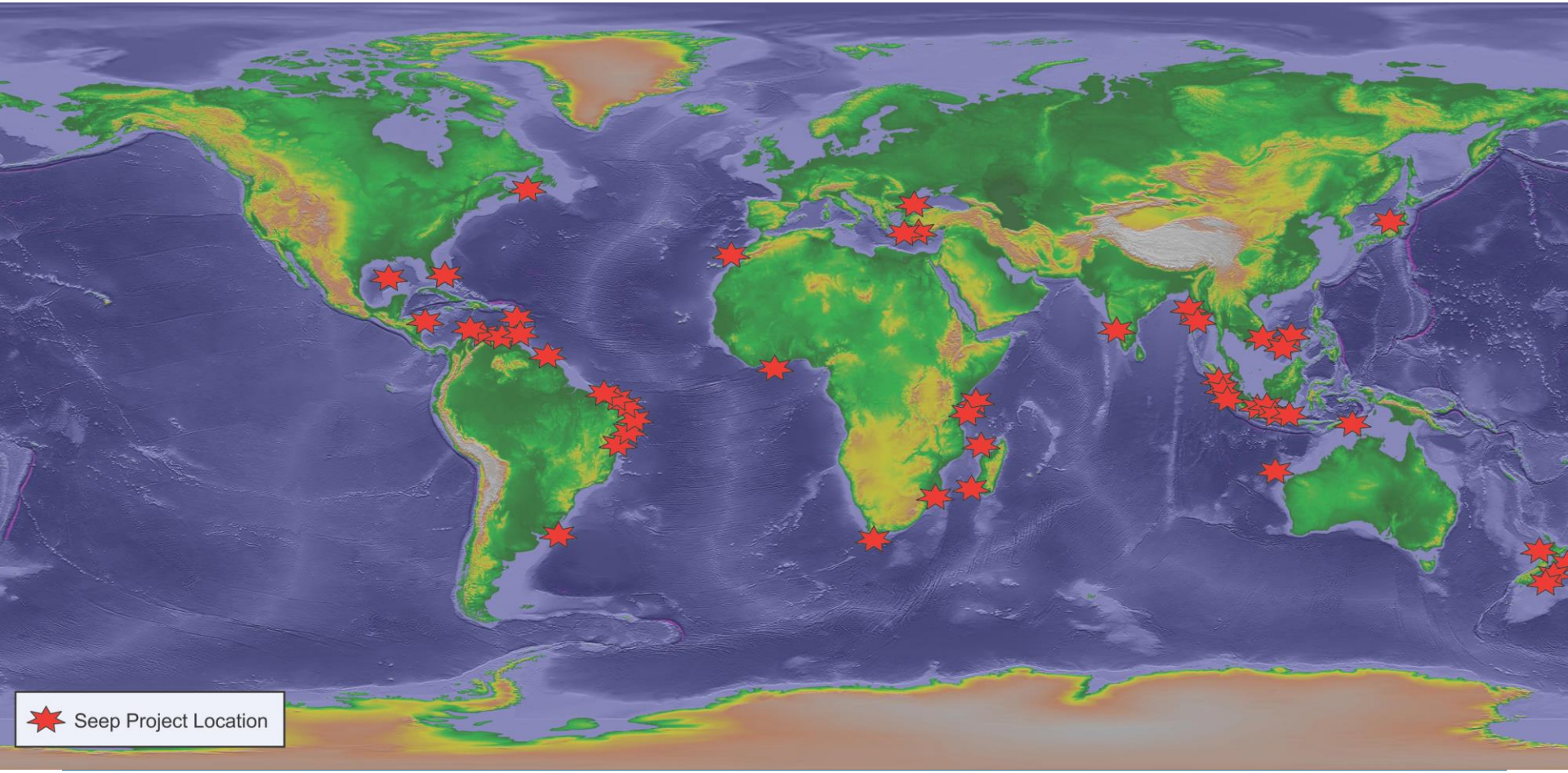
Seep-Hunting & Geochemical Campaign Experience List

Fugro Seep Consultancy - Project Experience		
Region	Client	Year
Myanmar	Woodside*	2016
Myanmar	BG Group	2016
Gigante Mexico Mega Survey 1	TGS/Oro Negro Exploration*	2015-2016
New Zealand	OMV	2015
New Zealand	Chevron	2015
Vietnam	PetroVietnam	2015
Vietnam	Murphy	2015
Colombia	Shell	2015
Honduras	BG Group	2015
Australia	Statoil	2015
Aruba	Repsol	2015
Colombia	Anadarko	2014-2015
Trinidad and Tobago	BHB Billiton	2014
Kenya	Total	2014
Canada - Nova Scotia	Shell	2014
New Zealand	Statoil	2014
New Zealand	Shell	2014
Uruguay	Total	2014
Kenya	Anadarko	2014
Guyana	Anadarko	2013
New Zealand	Anadarko	2013
Mozambique	Petronas	2013
Madagascar	SA Petro	2013
Bulgaria (Black Sea)	OMV	2013
South Africa	Anadarko	2012
Brasil A-F (6 Surveys)	Niko Resources	2011-2012
Indonesia Mega Survey 2	Niko Resources	2011
Madagascar	Niko Resources	2010
Colombia	Reliance	2010
Timor	ENI	2009
South China Sea	Devon	2009
Yellow Sea	Devon	2009
Brasil	Devon	2008
Indonesia Mega Survey 1A - 1H (8 surveys)	TGS/Black Gold Exploration	2007-2008
India	Reliance	2006-2007
Brasil	Devon	2005
Turkey	BP	2004
Turkey	El Paso	2004
Northwest Africa	Kerr-McGee	2004
Indonesia	Unocal	2003
Ghana	Devon	2002
Barbados	Conoco	2001

* current project

Fugro Seep Hunting Project Locations

- Over 50 seep hunting campaigns since 2001
- Mega-surveys in Mexico, Brazil and Indonesia
- Over 2,000,000 km2 has been mapped with modern multibeam surveys
- Most data are proprietary and owned by Fugro customers … not Fugro



Fugro Fleet for Modern Seep Hunting

- Fugro is in the midst of a strong vessel building and technology investment program
- Fugro now have 19 vessels with advanced MBES technology around the globe

Case Study : Gigante Mega Survey

World's Largest Offshore Seep-Hunting Survey

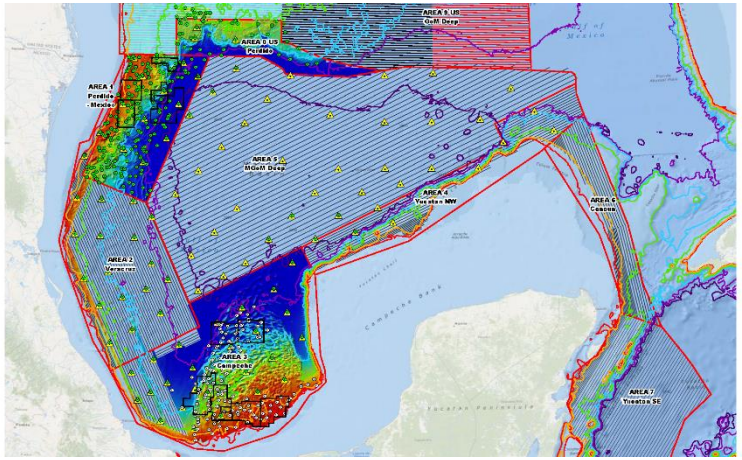
What: TGS-led, industry funded, multi-client seismic, multibeam, and coring program

When: Timed to coincide with denationalization of Mexico's O&G market

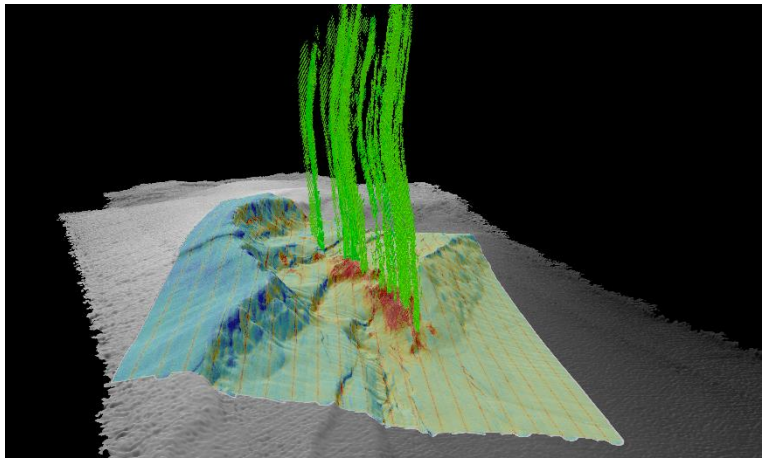
Purpose: to assist O&G clients in making investment decisions in a frontier offshore region (reduce risk)

Fugro's Scope of Work:

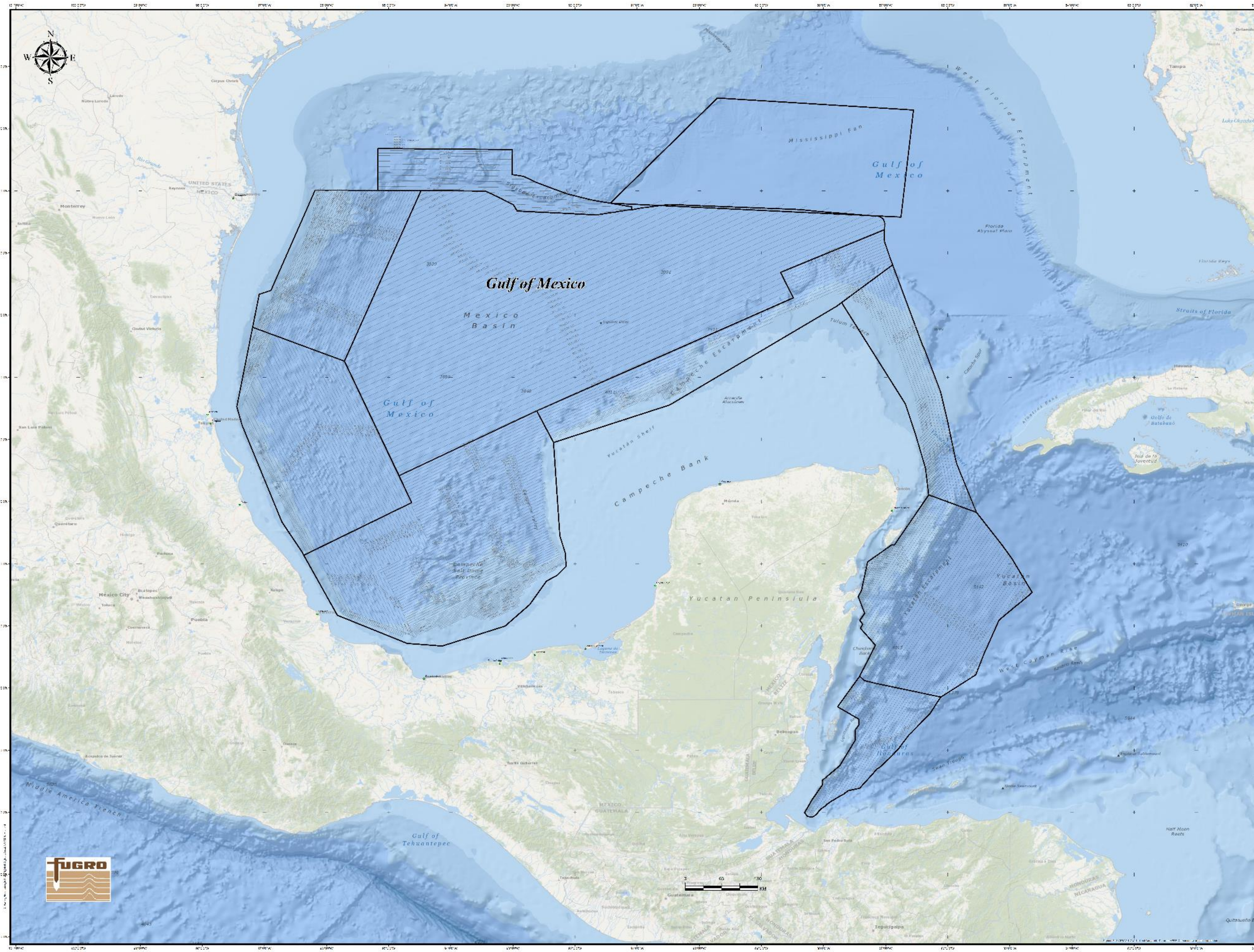
- Fugro to acquire 625,000 km^2 of multibeam echo sounder data and subbottom profiler data
- Fugro uses the data to identify prime locations to sample for geochemistry



Regions of Fugro-acquired multibeam survey as of 10 Apr 16



3D view of data from near the survey region



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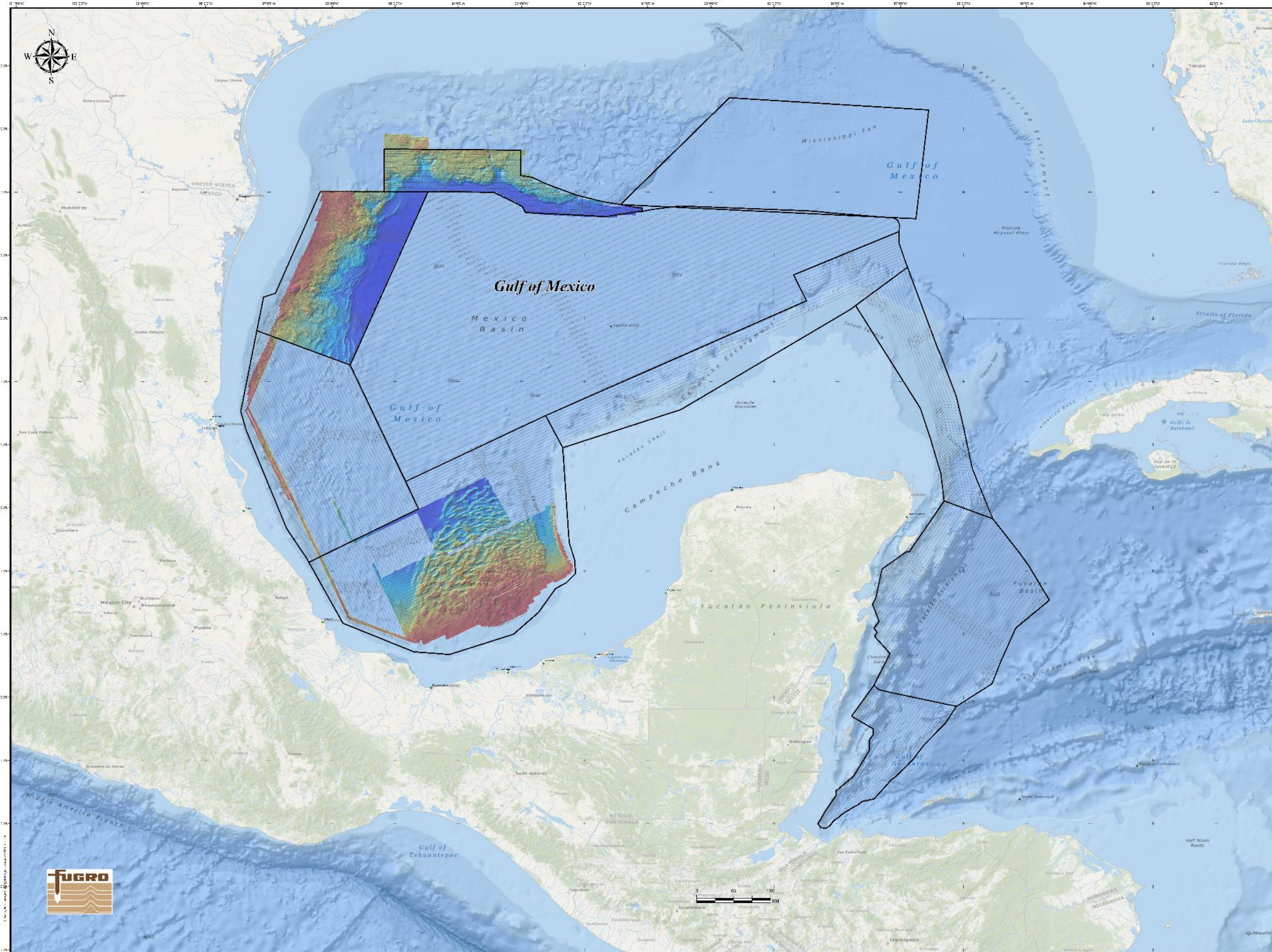
Gulf of Mexico
Mexico Basin
Gulf of Mexico
Gulf of Mexico
Mississippi Fan
West Florida Escarpment
Florida Abyssal Plain
Straits of Florida
Campeche Escarpment
Yucatan Shelf
Campeche Bank
Campeche Salt Dome Province
Yucatan Peninsula
Yucatan Escarpment
Yucatan Basin
West Cayman Rise
Gulf of Honduras
Gulf of Tehuantepec
Middle America Trench
Half Moon Reefs
Monterrey
Mexico City
Puebla
Tampa
Orlando
Mérida
Belmopan
Tegucigalpa
FUGRO
0 65 130 KM



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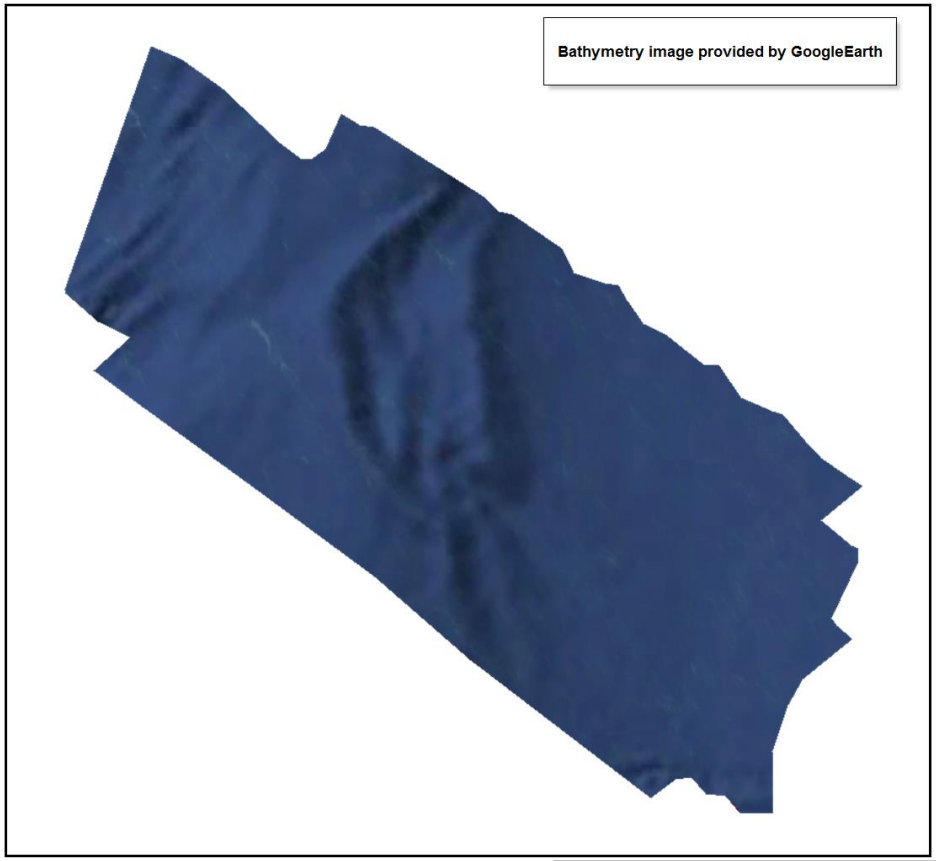
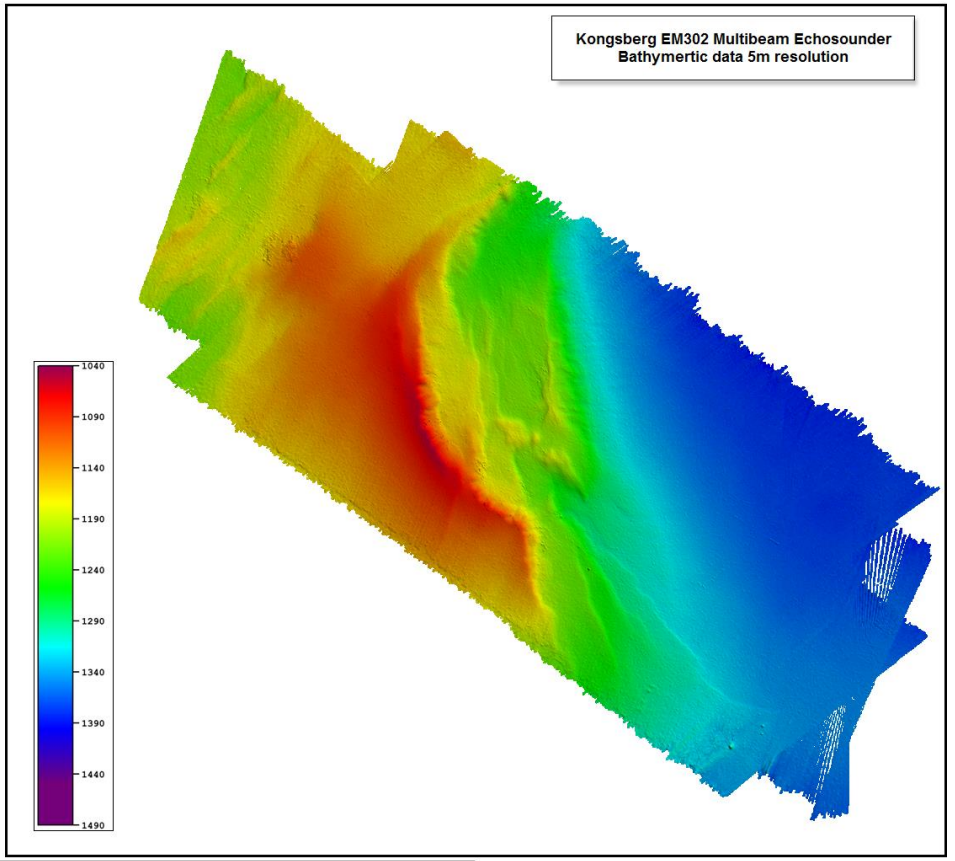
Yucatan Peninsula
Yucatan Escarpment
Yucatan Basin
West Cayman Rise
Gulf of Honduras
Gulf of Tehuantepec
Middle America Trench
Monterrey
Mexico City
Puebla
Tampa
UNITED STATES
MEXICO
Isla de la Juventud
Half Moon Reefs
0 65 130 KM

Seabed 2030 – Can Decimated Data be Made Available?

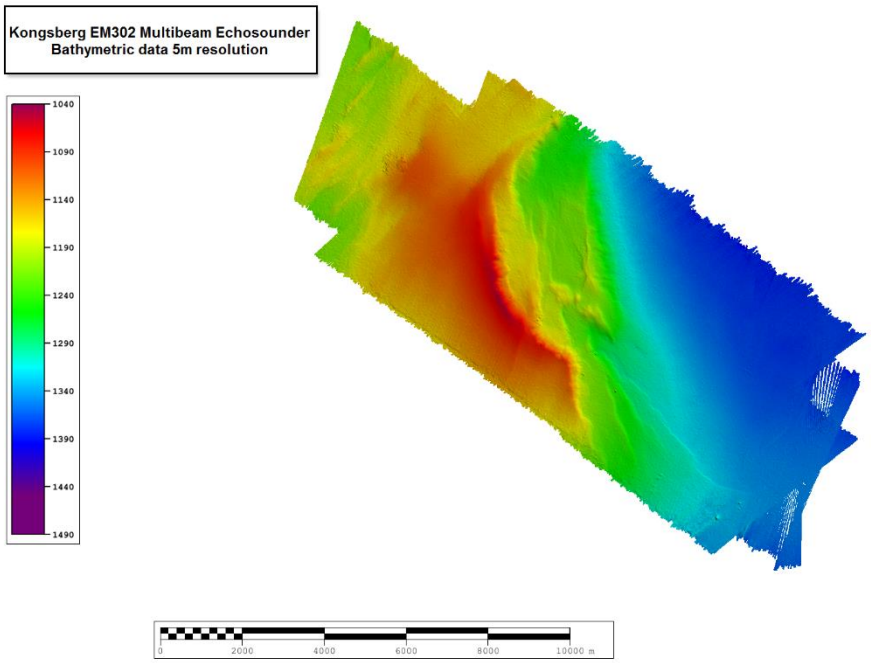




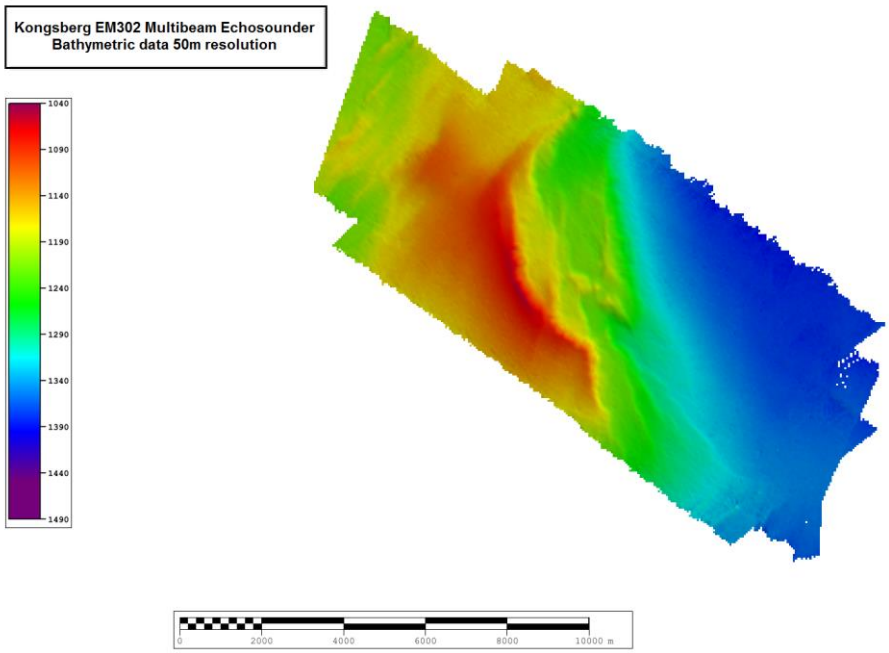
Google Earth

MBES - 5m Grid

Seabed 2030 – Can Decimated Data be Made Available?

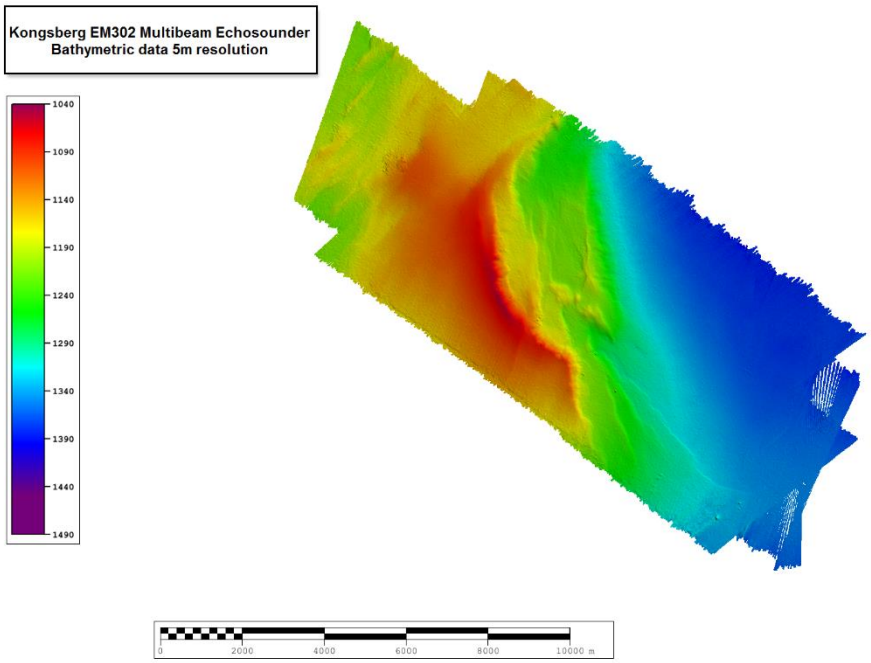


MBES – 5m Grid

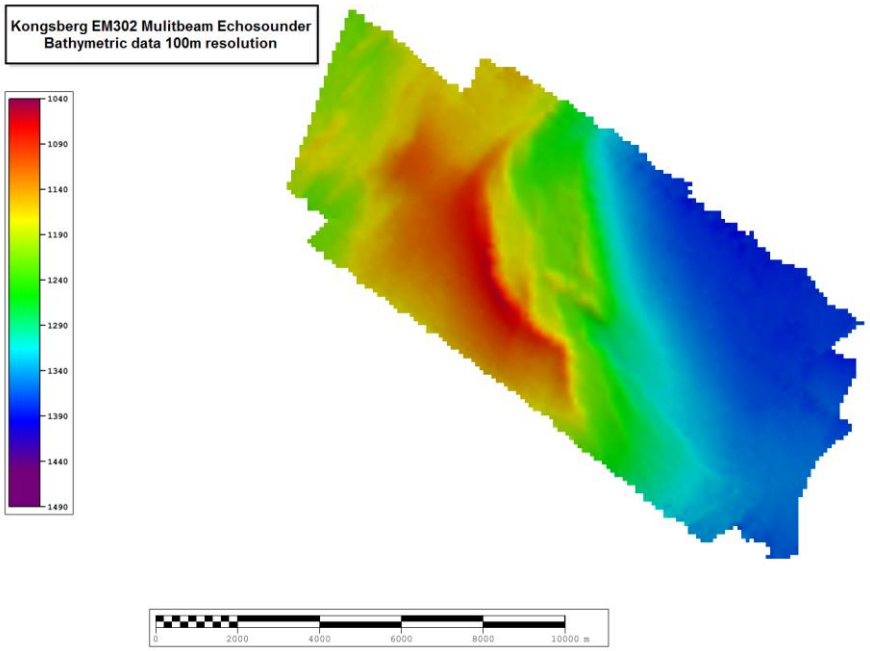


MBES – 50m Grid

Seabed 2030 – Can Decimated Data be Made Available?

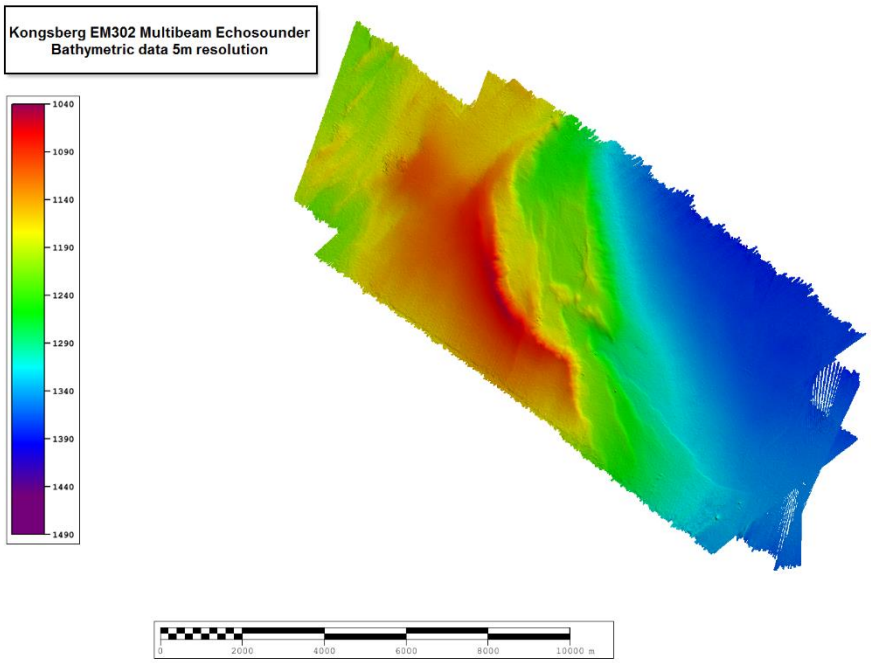


MBES – 5m Grid

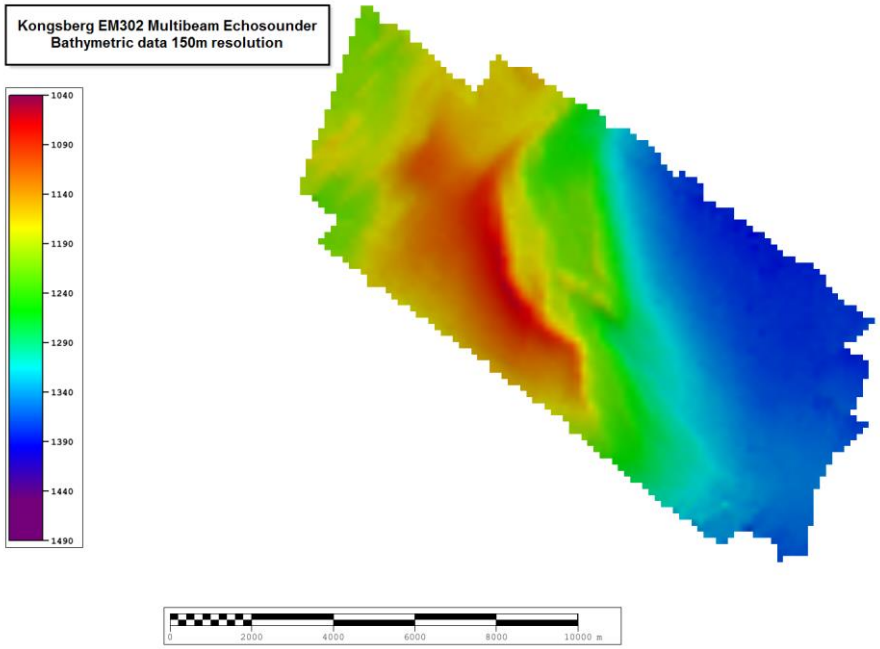


MBES – 100m Grid

Seabed 2030 – Can Decimated Data be Made Available?

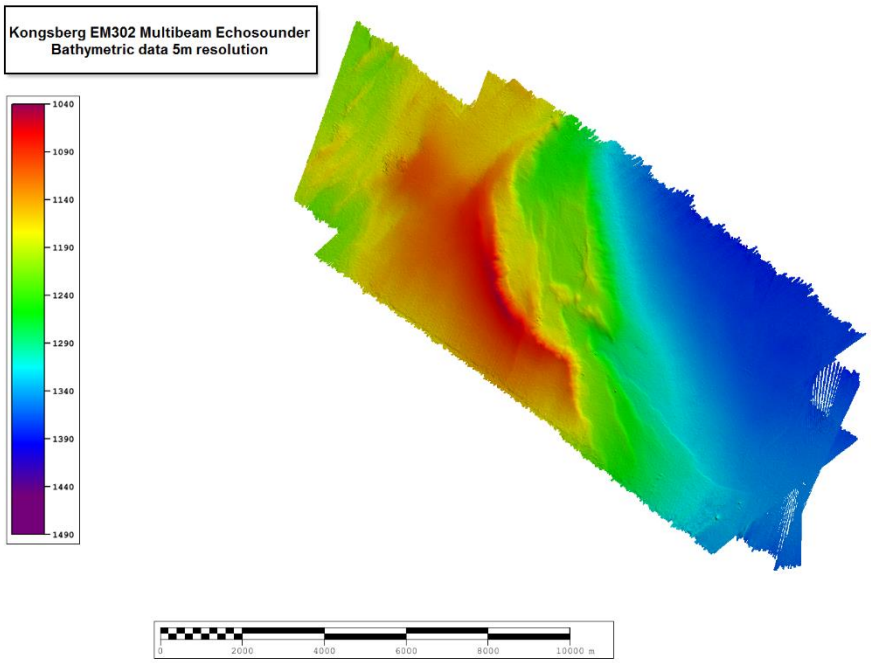


MBES – 5m Grid

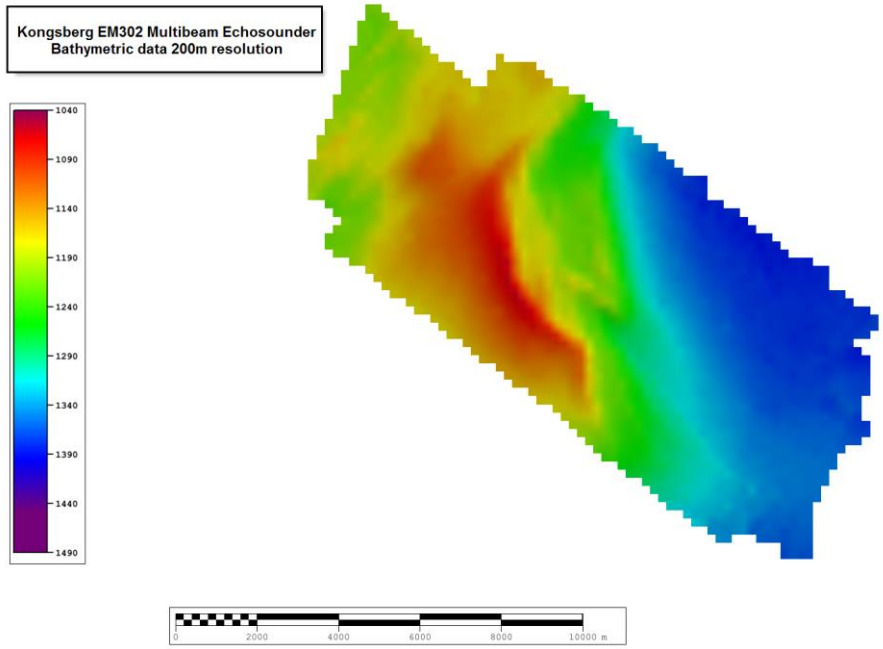


MBES – 150m Grid

Seabed 2030 – Can Decimated Data be Made Available?

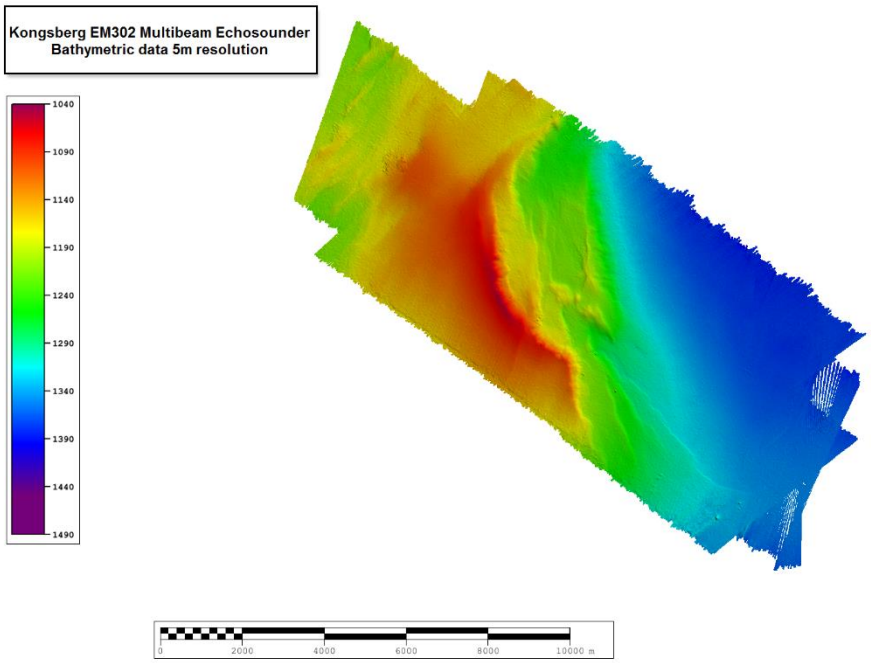


MBES – 5m Grid

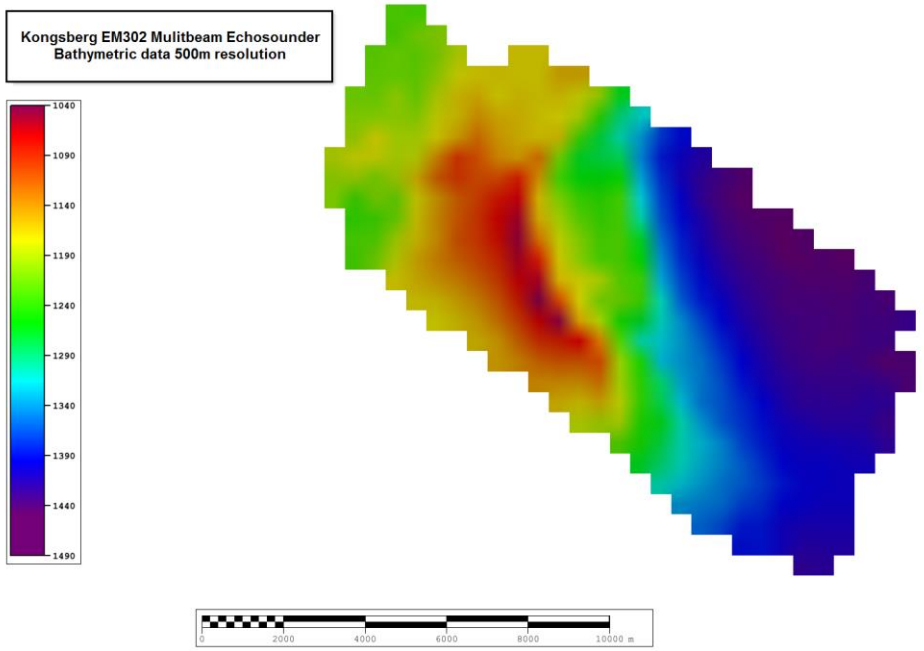


MBES – 200m Grid

Seabed 2030 – Can Decimated Data be Made Available?

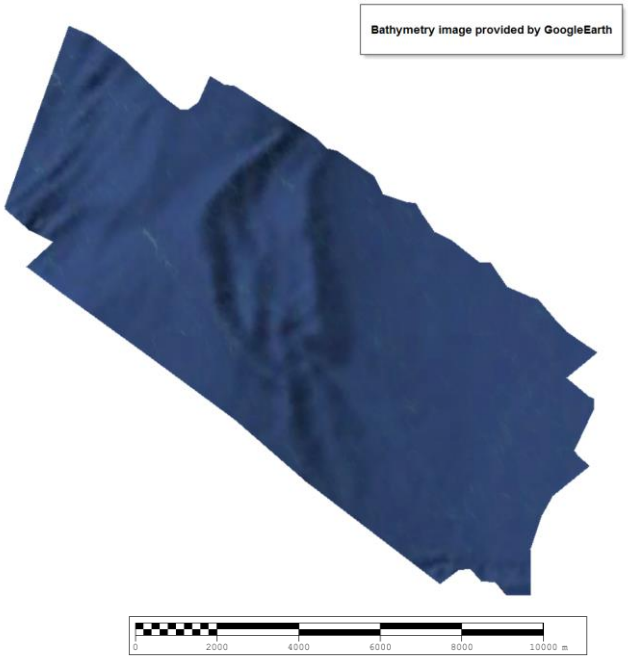


MBES – 5m Grid

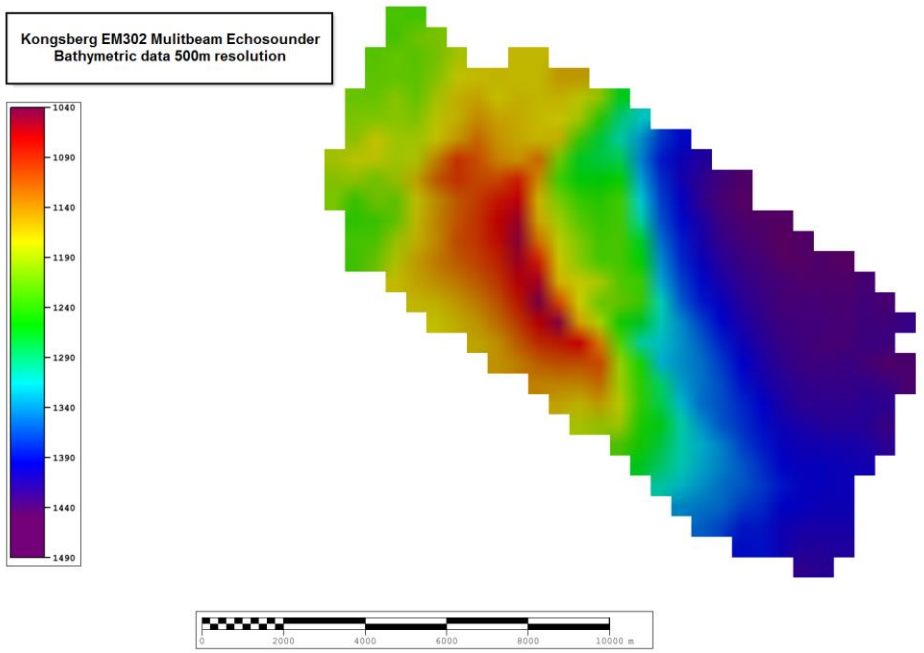


MBES – 500m Grid

Seabed 2030 – Can Decimated Data be Made Available?

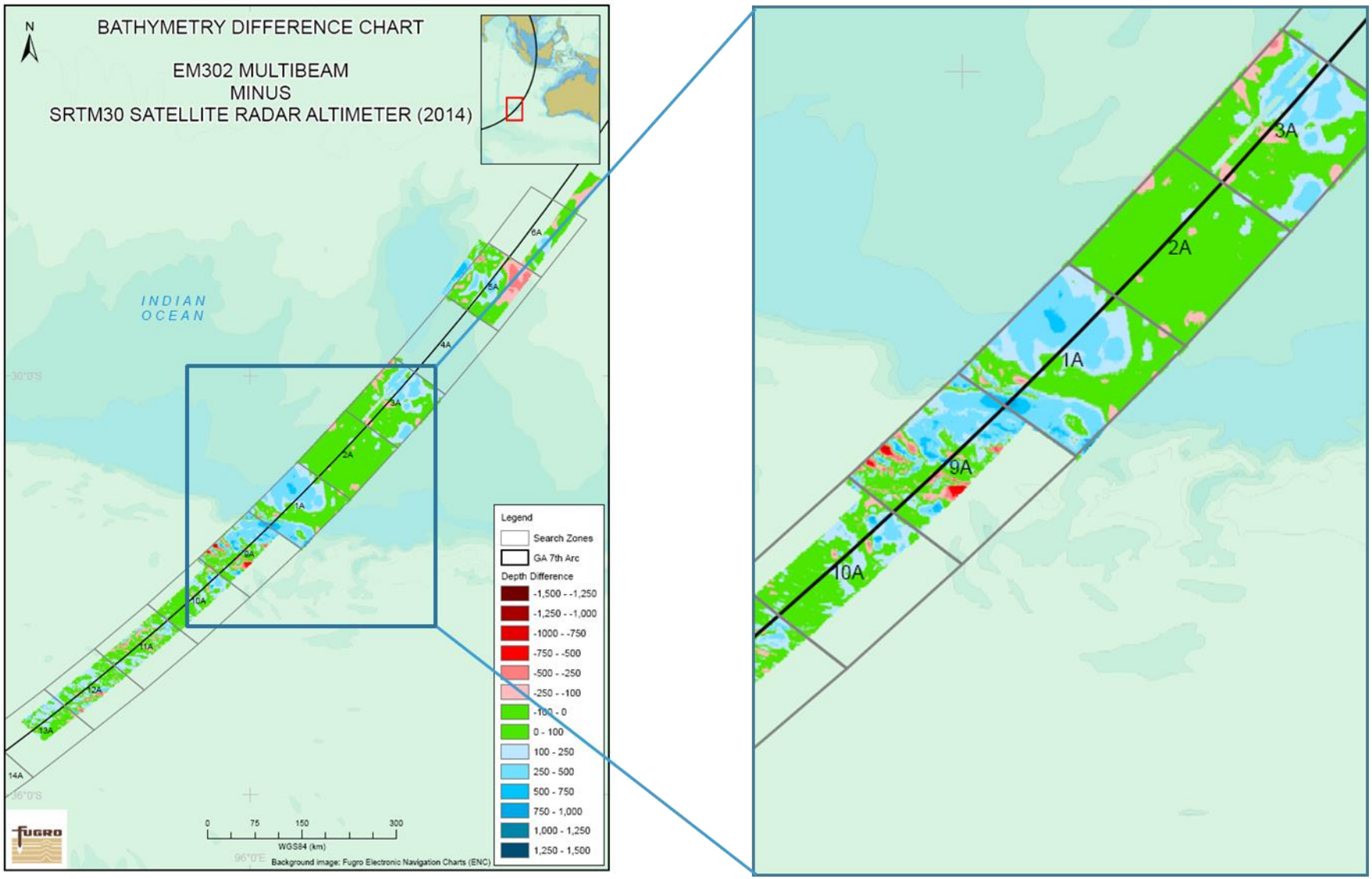


Google Earth



MBES – 500m Grid

Even Decimated Data will Improve Absolute Accuracy



Thank You

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