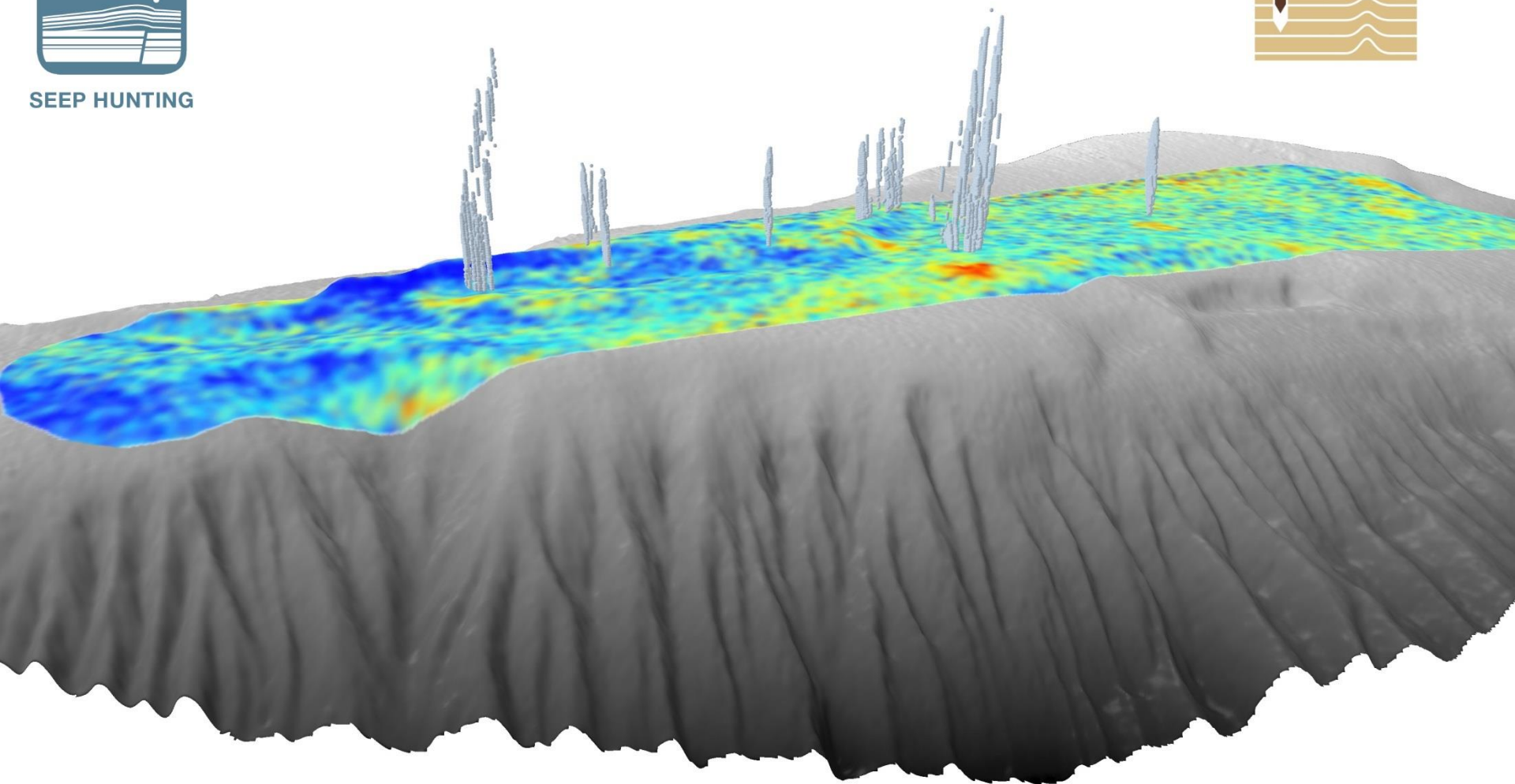




SEEP HUNTING



# Seep Hunting as an Effective De-Risking Exploration Tool

Offshore Geochemical Surveying & Its Use in Early Phase Exploration

APPEX London; Feb 2018

# Why are Seeps important for offshore exploration?

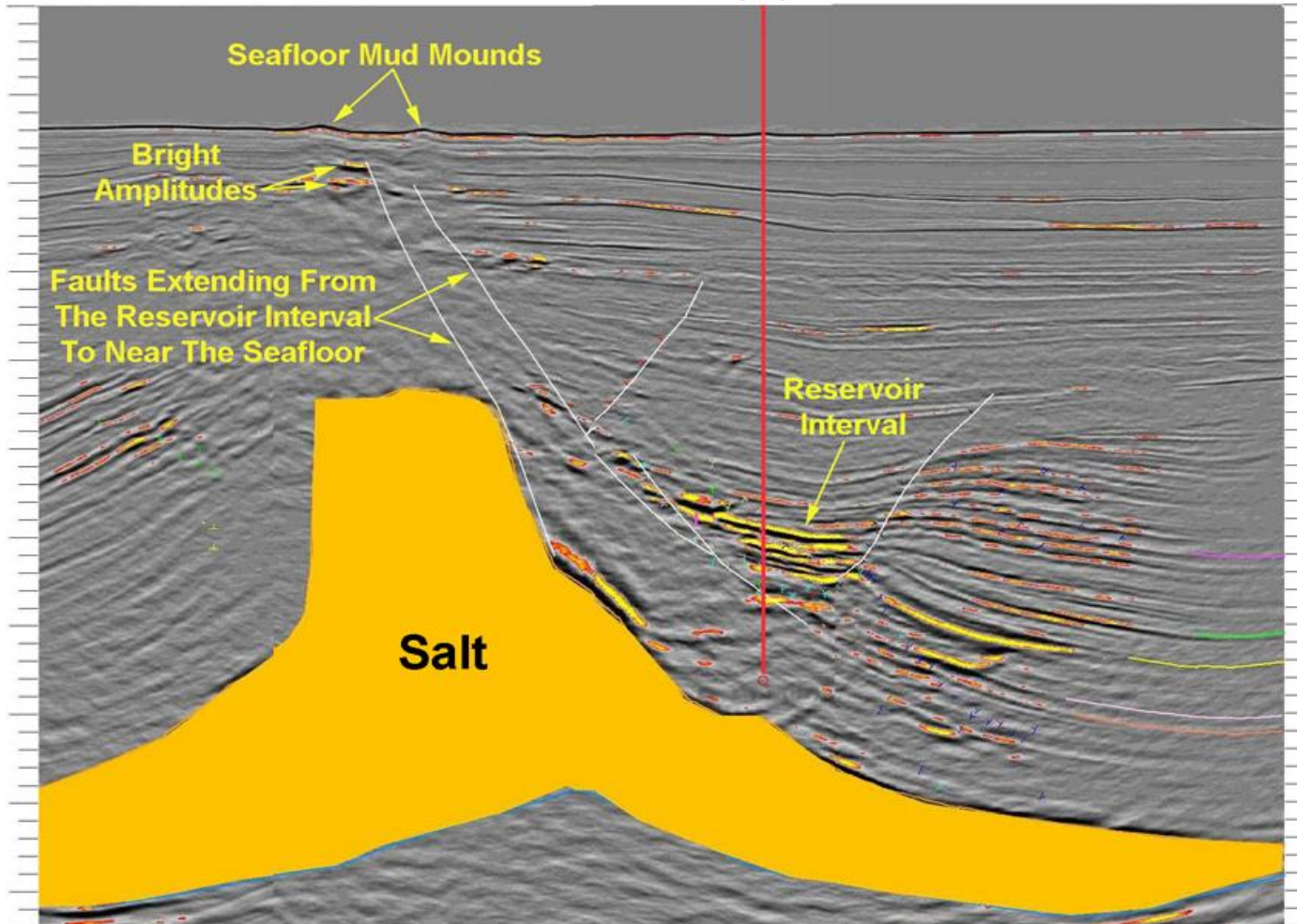


*Photo credit: Alfred-Wegener-Institut, 2004*



## 3-D seismic line in the Marco Polo area, Gulf of Mexico

Discovery  
Well



Faults extend up from the reservoir interval to near the seafloor. Shallow bright amplitudes and seafloor mud mounding suggest the potential for hydrocarbon seepage.

The **direct linkage** between the subsurface reservoirs, migration pathways, and seafloor seeps was confirmed in calibration tests (Abrams, 2011)

## 3-D seismic line in the Marco Polo area, Gulf of Mexico

Discovery  
Well

**FIND ME!**

Seafloor Mud Mounds

Bright  
Amplitudes

Faults Extending From  
The Reservoir Interval  
To Near The Seafloor

Reservoir  
Interval

Seeps extend up from the reservoir interval to the seafloor. Low bright amplitudes and seafloor mud mounding suggest the potential for hydrocarbon seepage.

The **direct linkage** between the subsurface reservoirs, migration pathways, and seafloor seeps was confirmed in calibration tests (Abrams, 2011)

**Seep-Hunting is hunting for the best location for taking geochemical samples**



# Finding Hydrocarbons

Finding seeps on land was one of the main tools throughout oil exploration's history. It was often accomplished by a field geologist who would explore the region on foot and take samples.

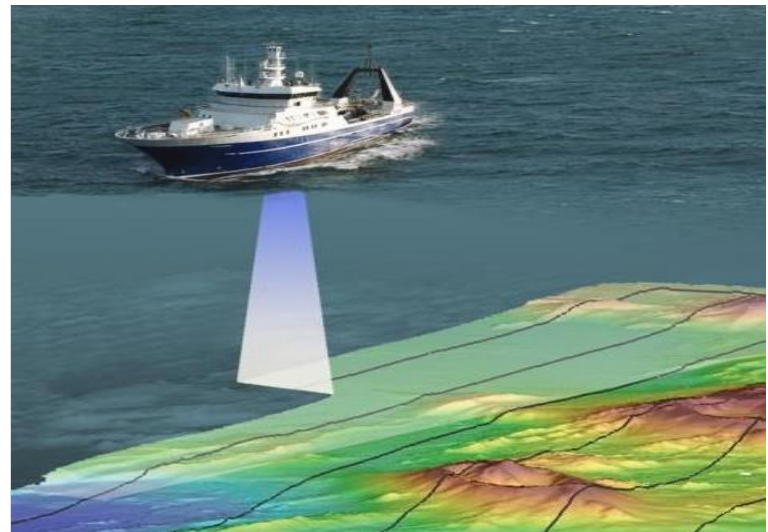
Image to right: Petroleum seep at Carpinteria State Beach, Carpinteria, Santa Barbara County, CA. Photo by S. Mulqueen (California Department of Conservation).



However, looking for seeping hydrocarbons in the marine environment has been a challenge, until recently.

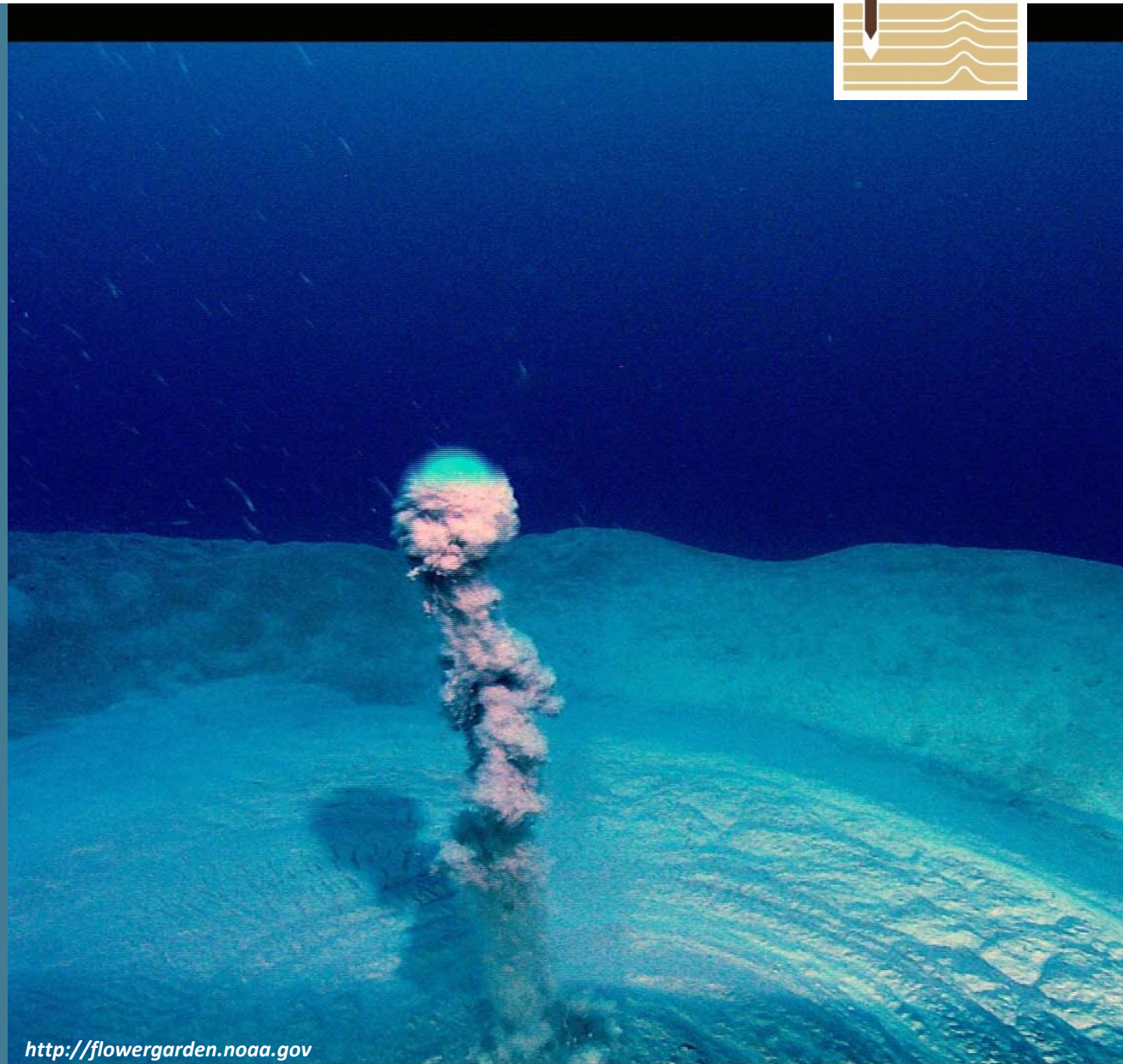
So, what is the equivalent of a field geologist when you are looking at a landscape that is hidden under thousands of meters water?

➤ Multibeam echosounder mapping.



## What is Modern Marine Seep Hunting?

The actual process of  
collecting geophysical  
data and interpreting  
it, so that we can  
identify the best sites  
for geochemical  
sampling



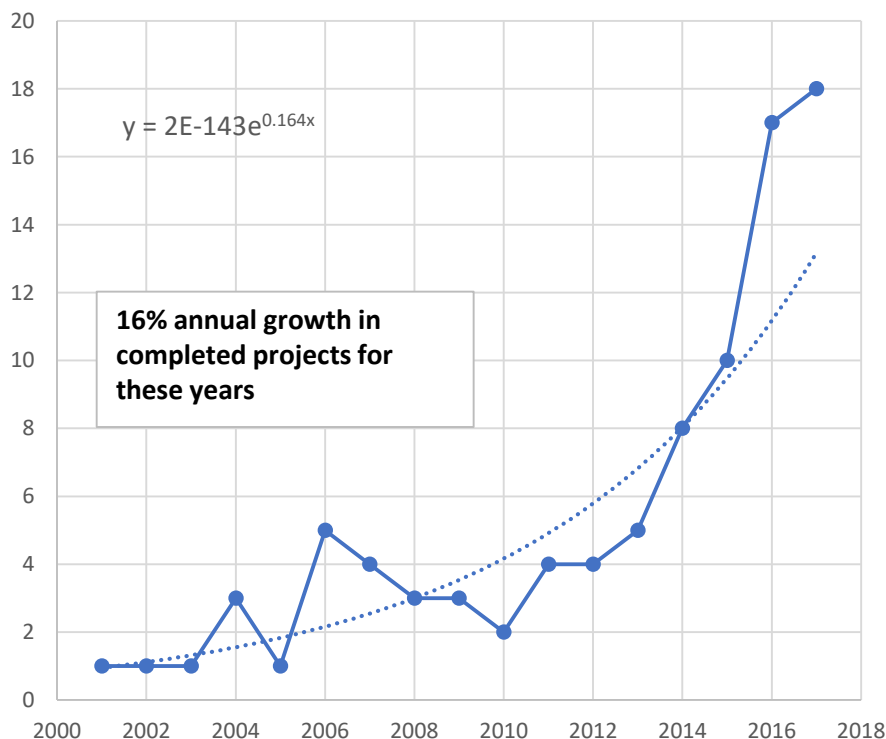


# Modern Seep-Hunting Campaigns –Industry Growth Curves

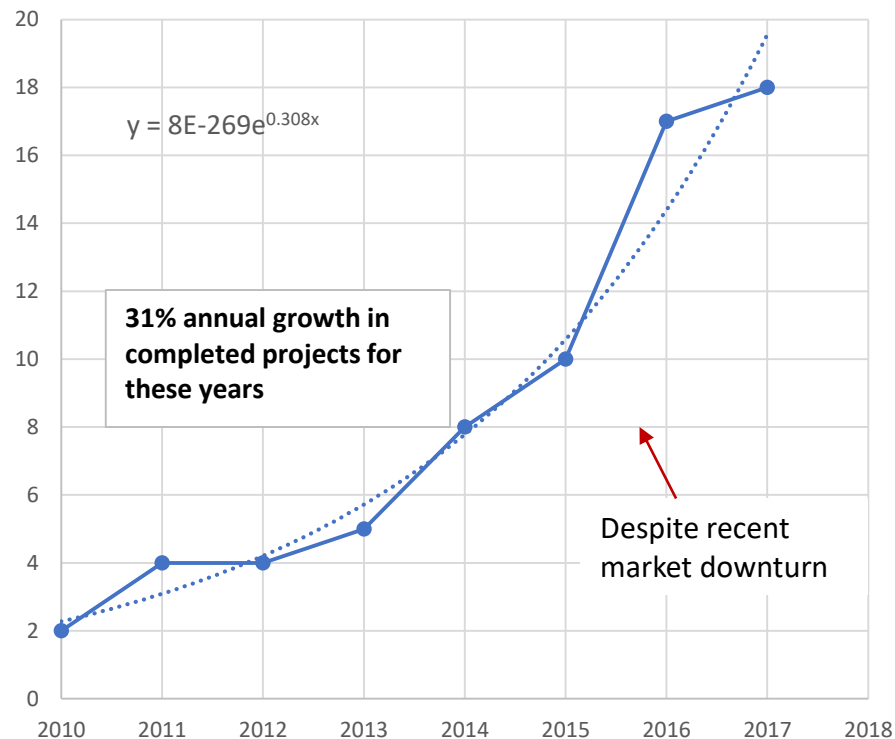
Projects grew annually by 16% from 2001-2017

Projects grew annually by 31% from 2010-2017

Seep Projects by year (2001 - 2017)



Seep Projects by year (2010 - 2017)



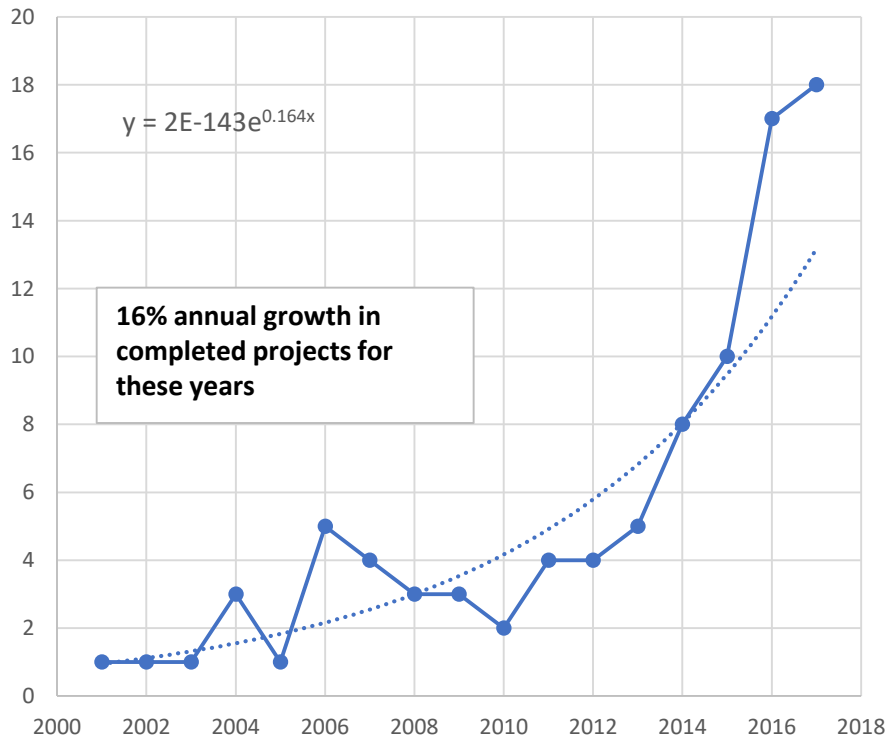
Fugro Seep-Hunting and Geochemical Projects Growth as a Business Line

# Modern Seep-Hunting Campaigns –Industry Growth Curves

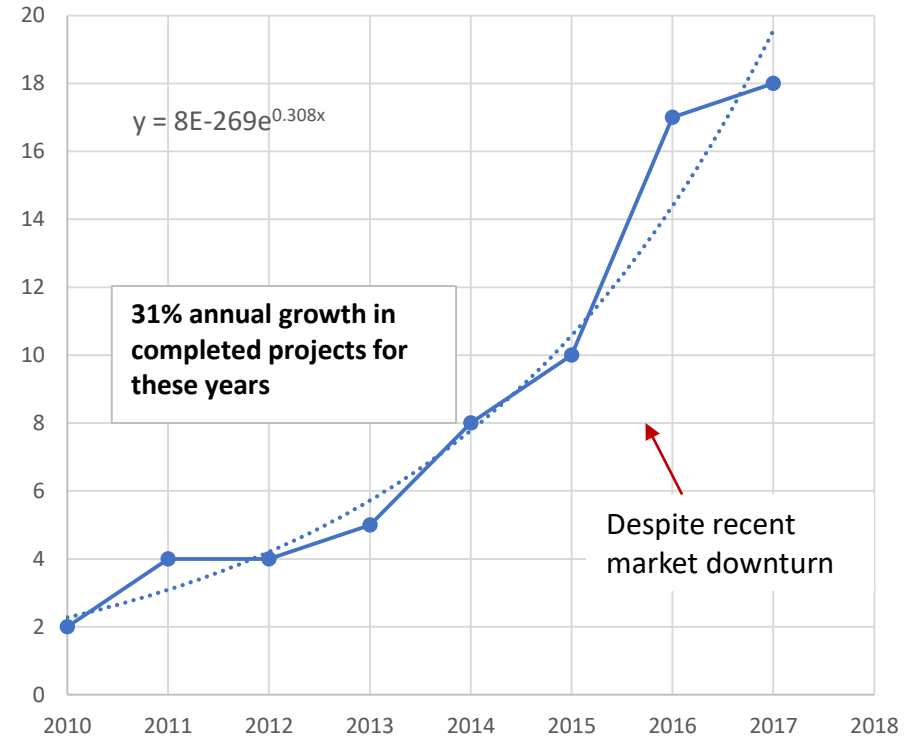
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Projects grew annually by 31% from 2010-2017

Seep Projects by year (2001 - 2017)



Seep Projects by year (2010 - 2017)



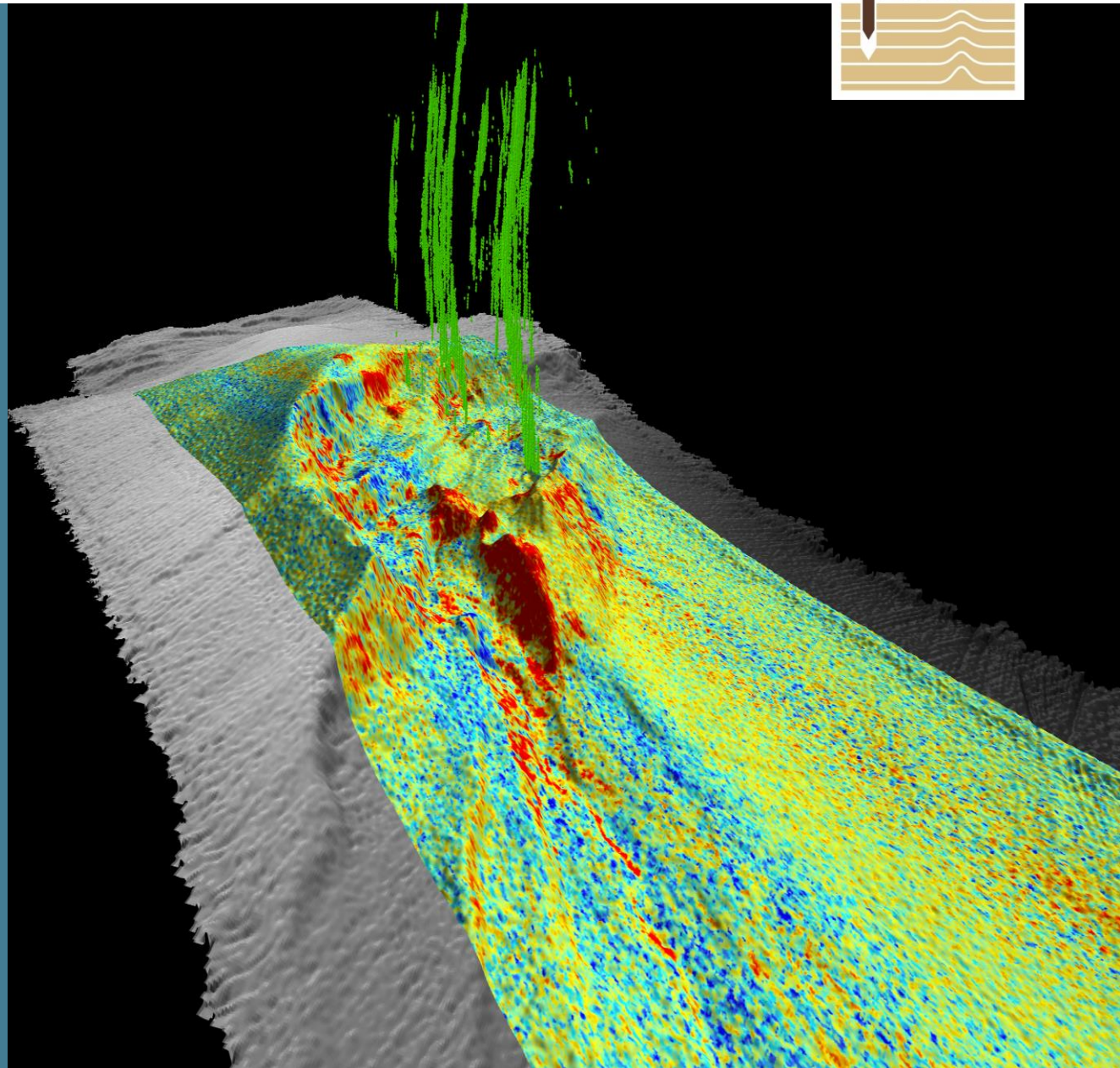
Fugro Seep-Hunting and Geochemical Projects Growth as a Business Line

**Over these years we have 4 essential learnings for the best practices...**



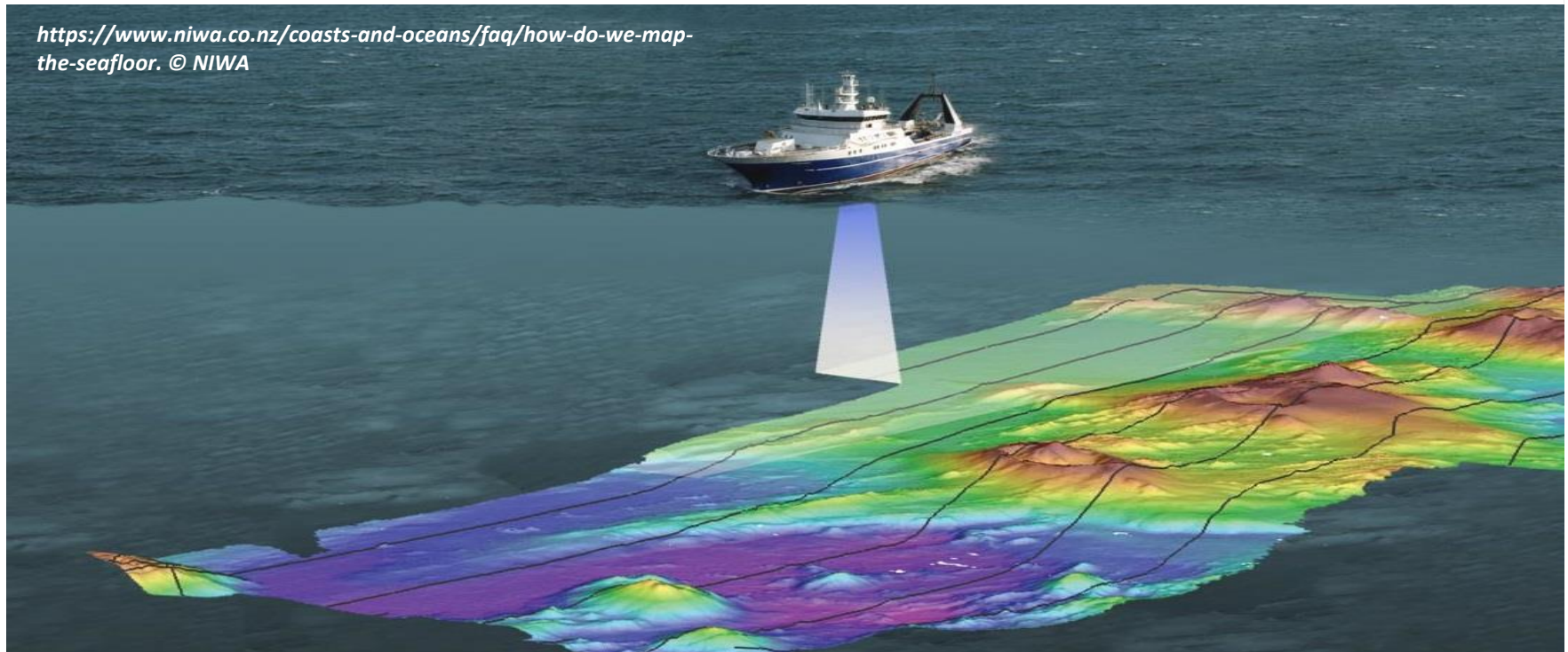
## LEARNING #1

Multibeam Data:  
The Driver for  
Modern Marine  
Seep Hunting



# Modern High-Resolution Multibeam Mapping of the Seafloor

- Strongest recent technological driver is the ability to map the seafloor
- High-resolution multibeam echosounder data allows detailed identification of seafloor features indicative of hydrocarbon seepage.
- Experienced geoscientists interpret the relationship between potential reservoirs and the seabed using the geomorphology data available from modern multibeam systems.
- This is the equivalent of a field geologist prospecting for seeps as was once done on land in the early days of oil exploration.

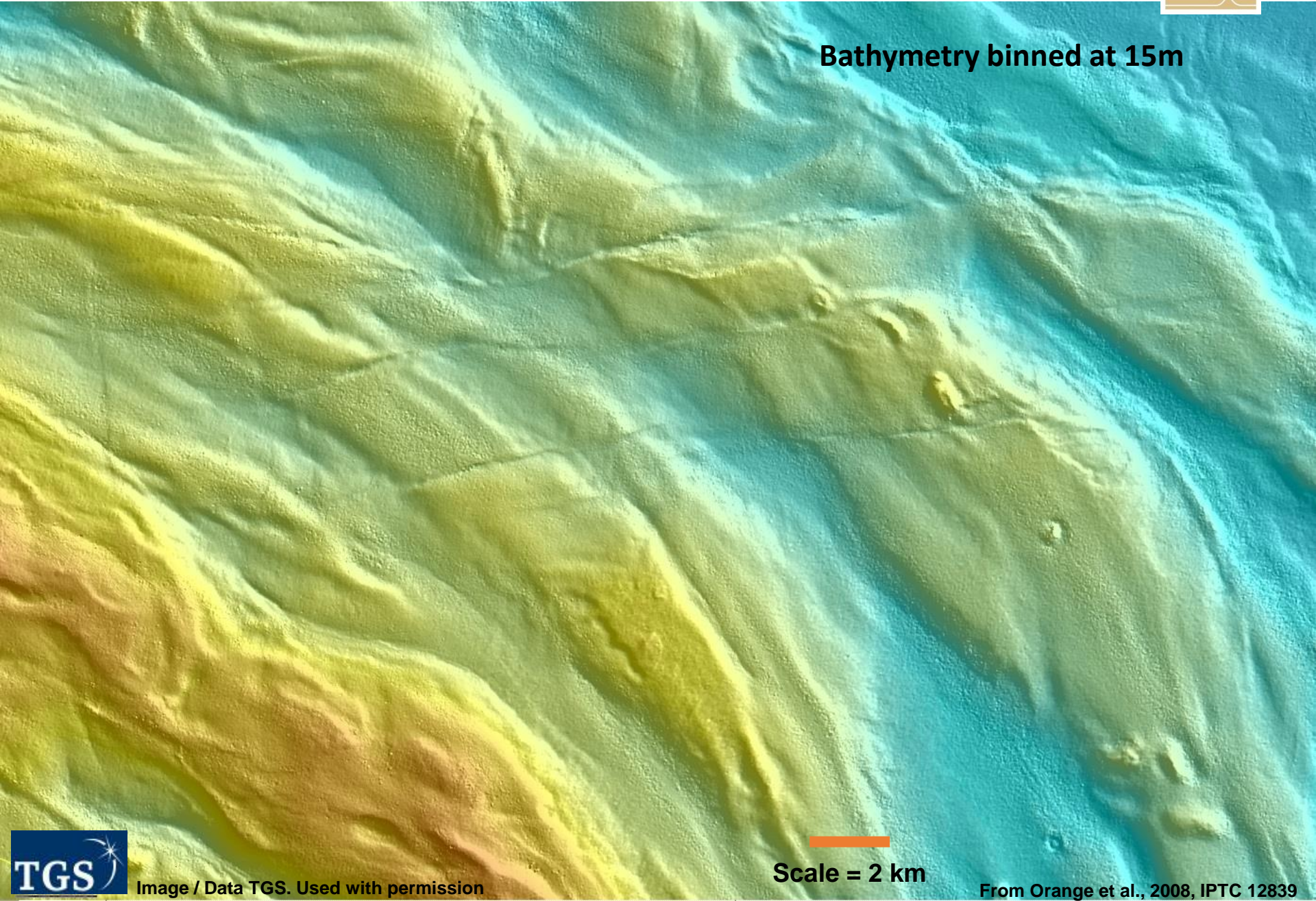




# Bathymetry



Bathymetry binned at 15m



Scale = 2 km



Image / Data TGS. Used with permission

From Orange et al., 2008, IPTC 12839



# Backscatter



Backscatter binned at 5m

6 cores were taken here, 5  
hydrocarbon hits

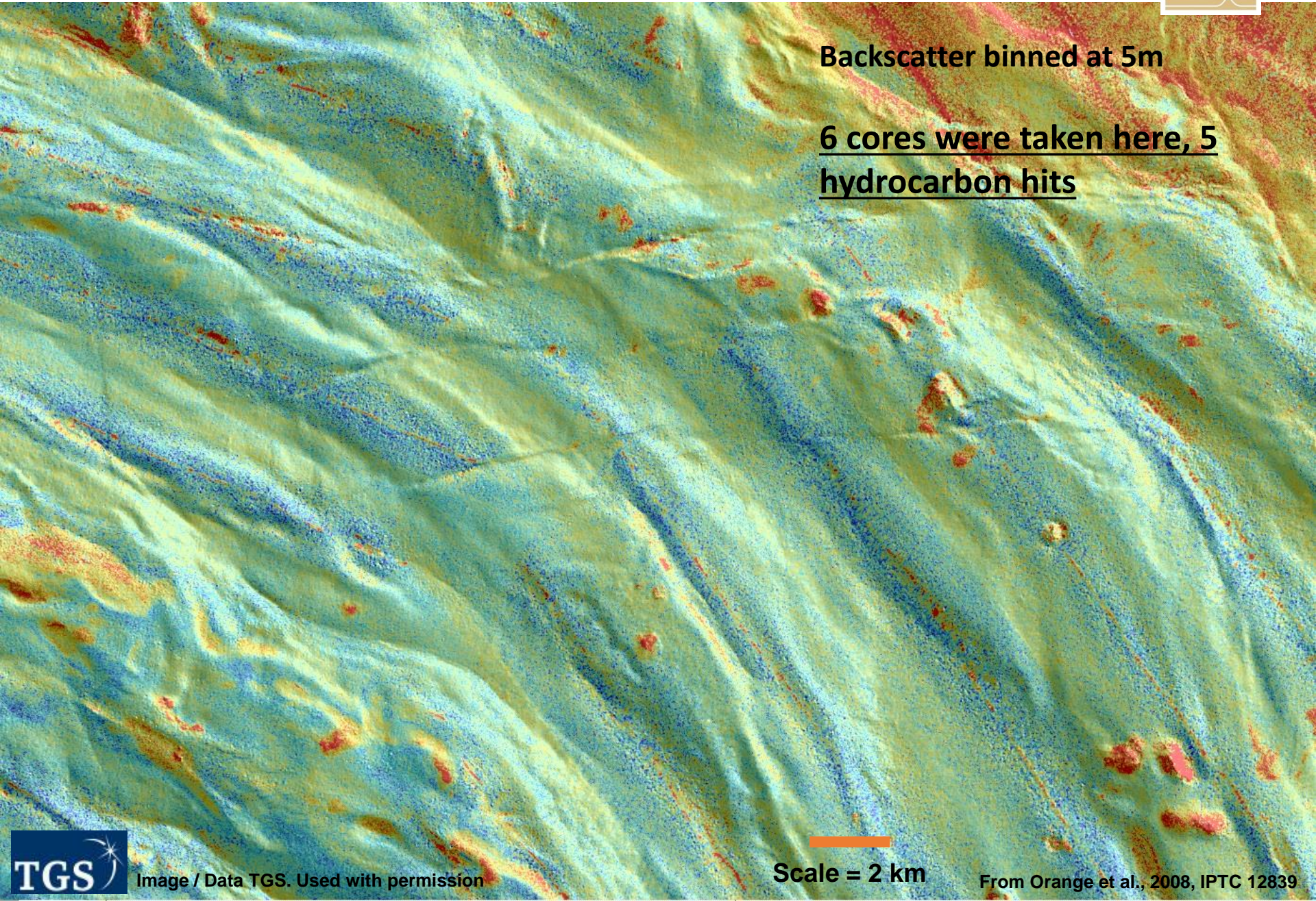


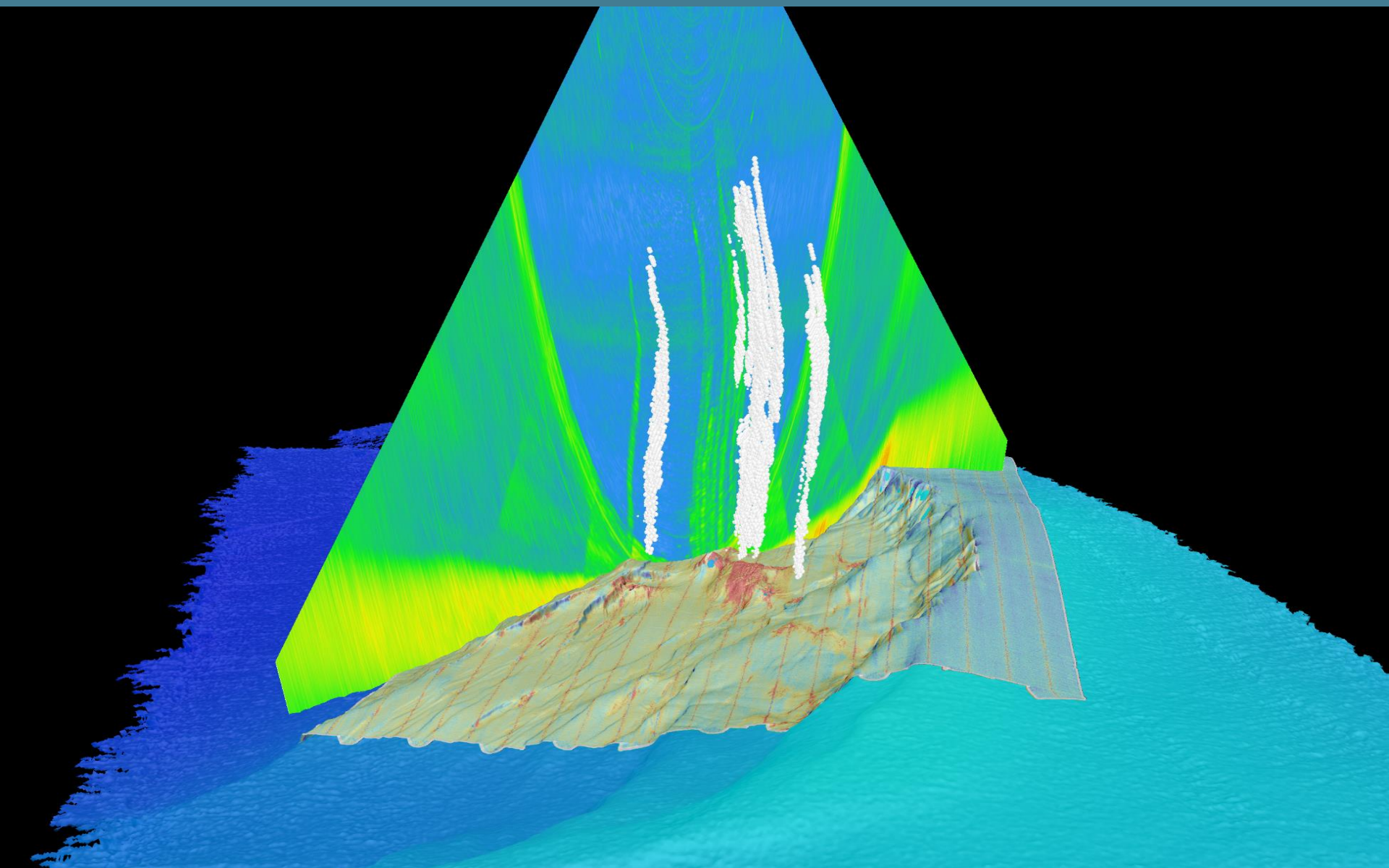
Image / Data TGS. Used with permission

Scale = 2 km

From Orange et al., 2008, IPTC 12839



# Extraction of Water Column Targets

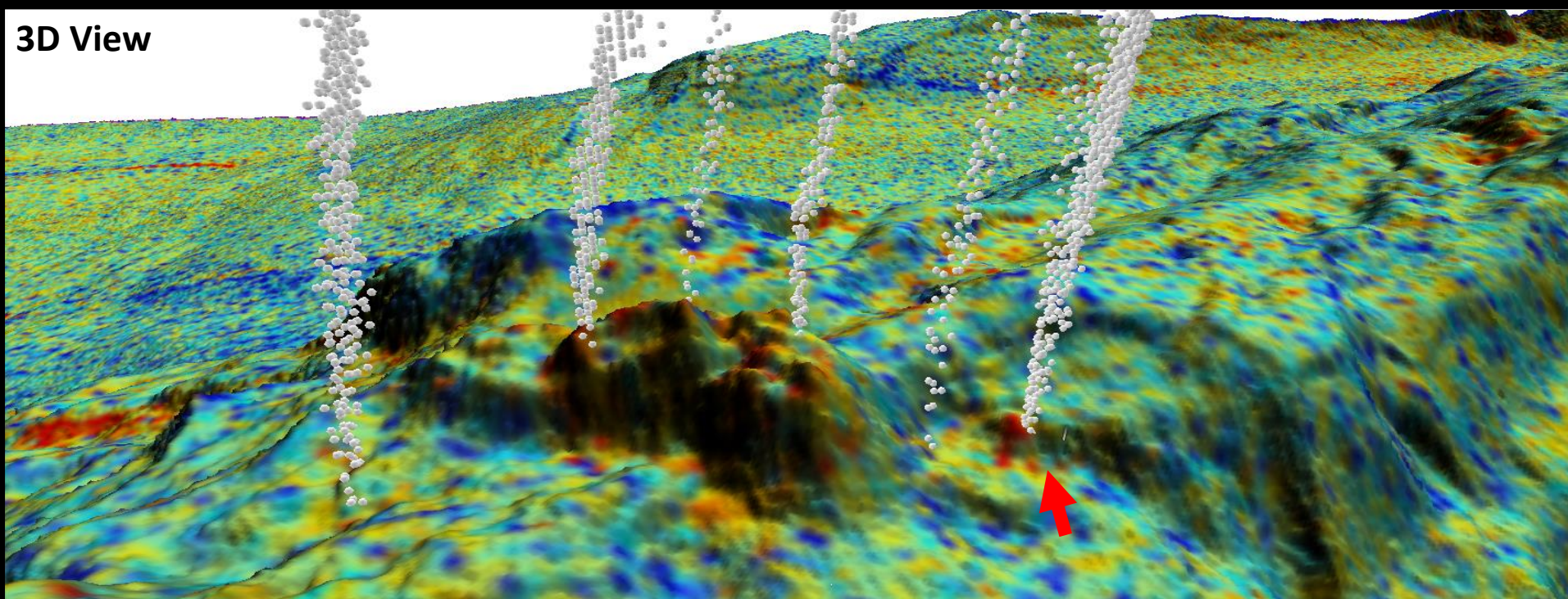




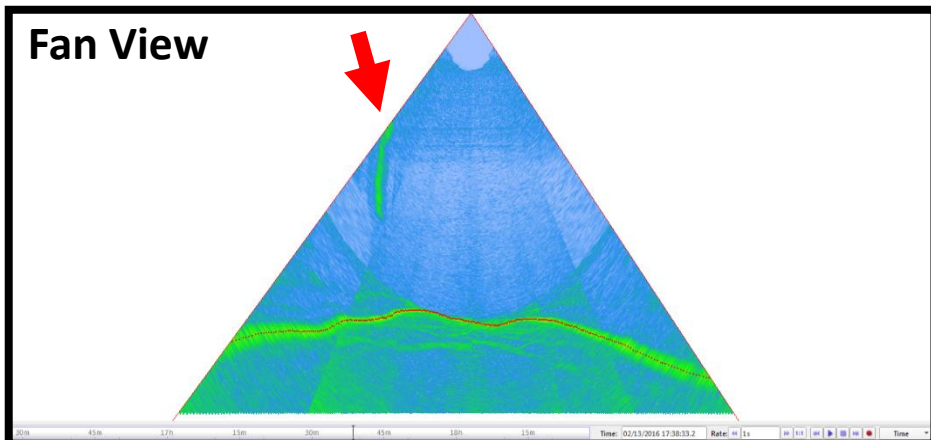
# Using Bathymetry, Backscatter, and Water Column Plume Analysis



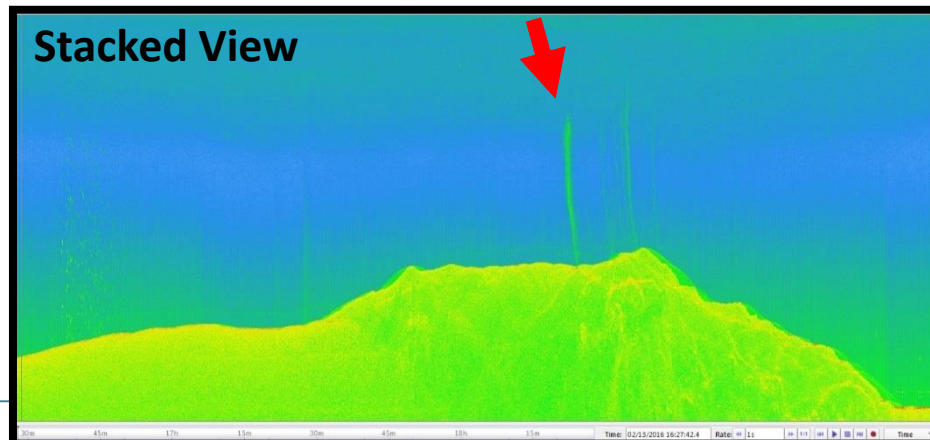
**3D View**



**Fan View**

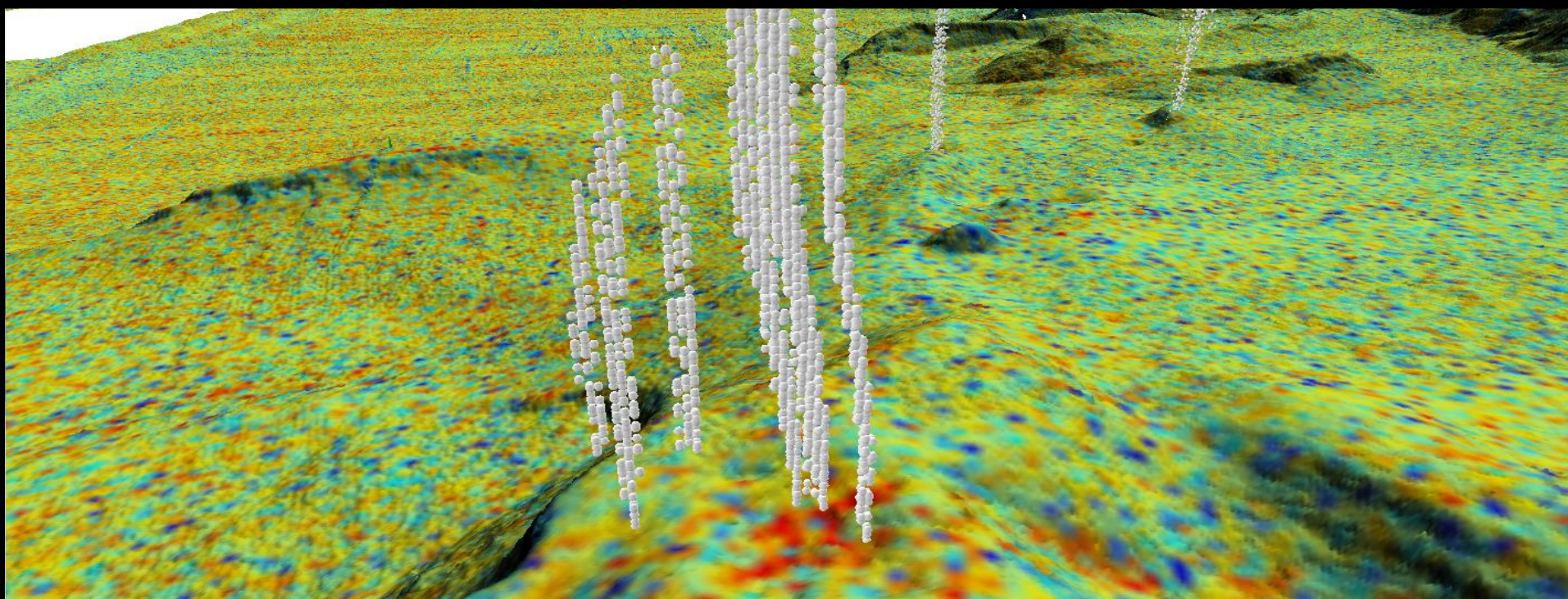


**Stacked View**

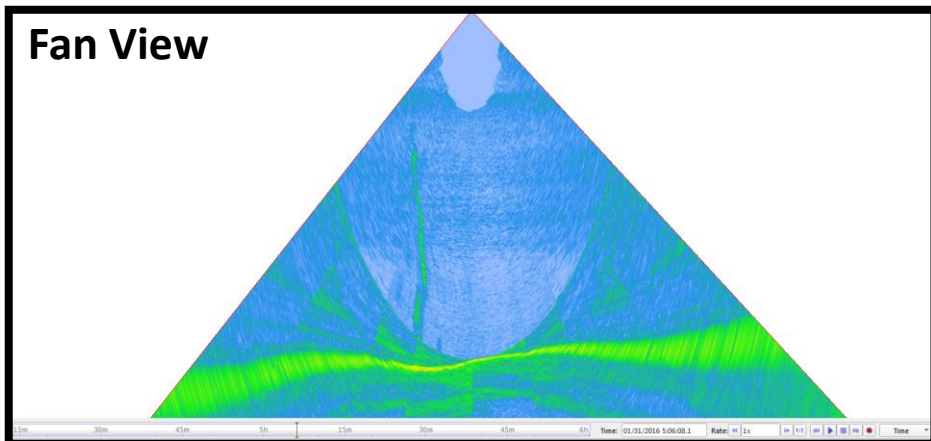




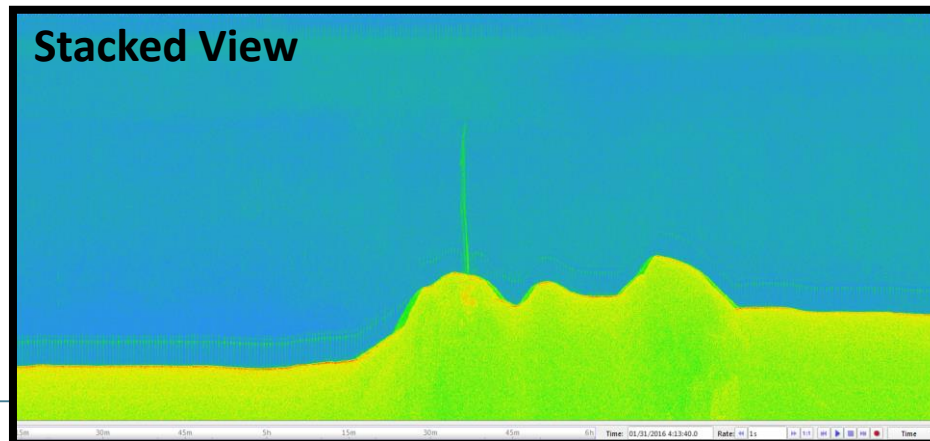
# Using Bathymetry, Backscatter, and Water Column Plume Analysis



**Fan View**



**Stacked View**





## LEARNING #2

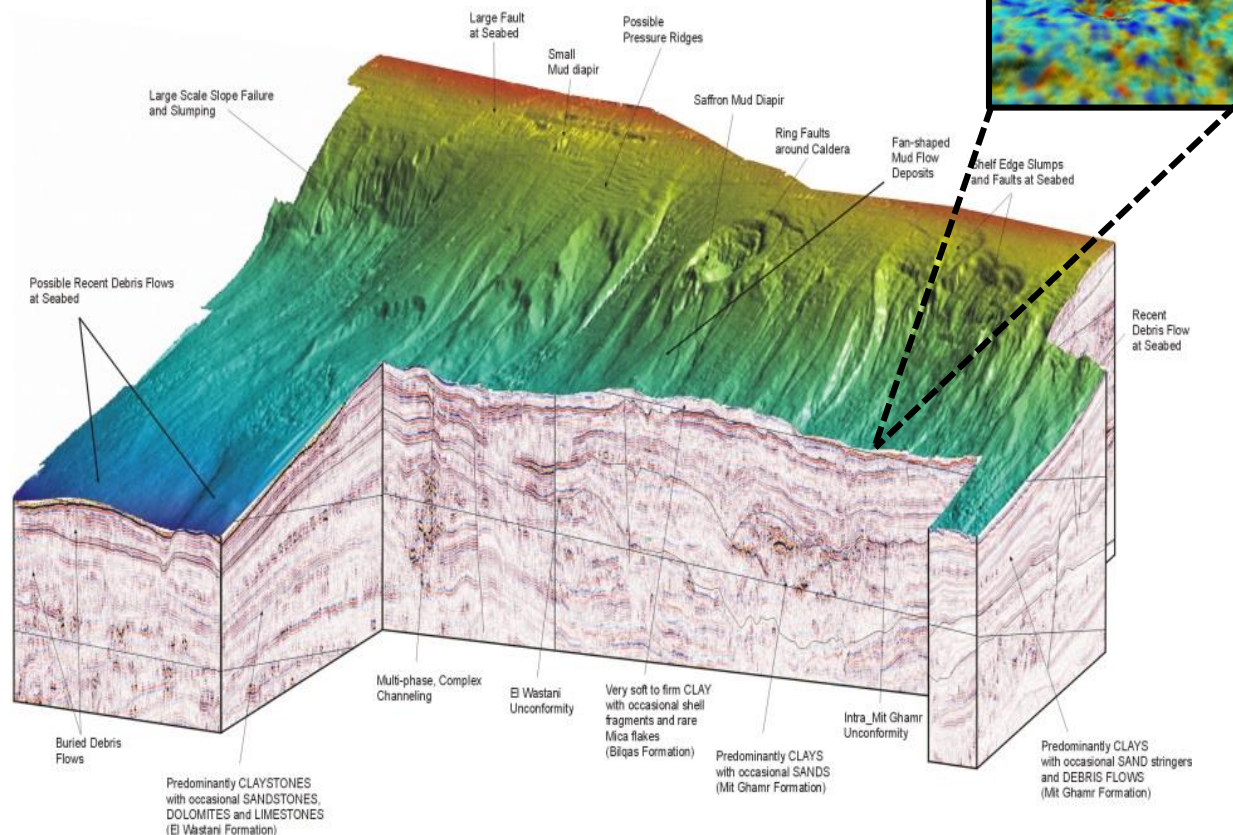
### Interpreting the Geology: The Key to Seep Hunting

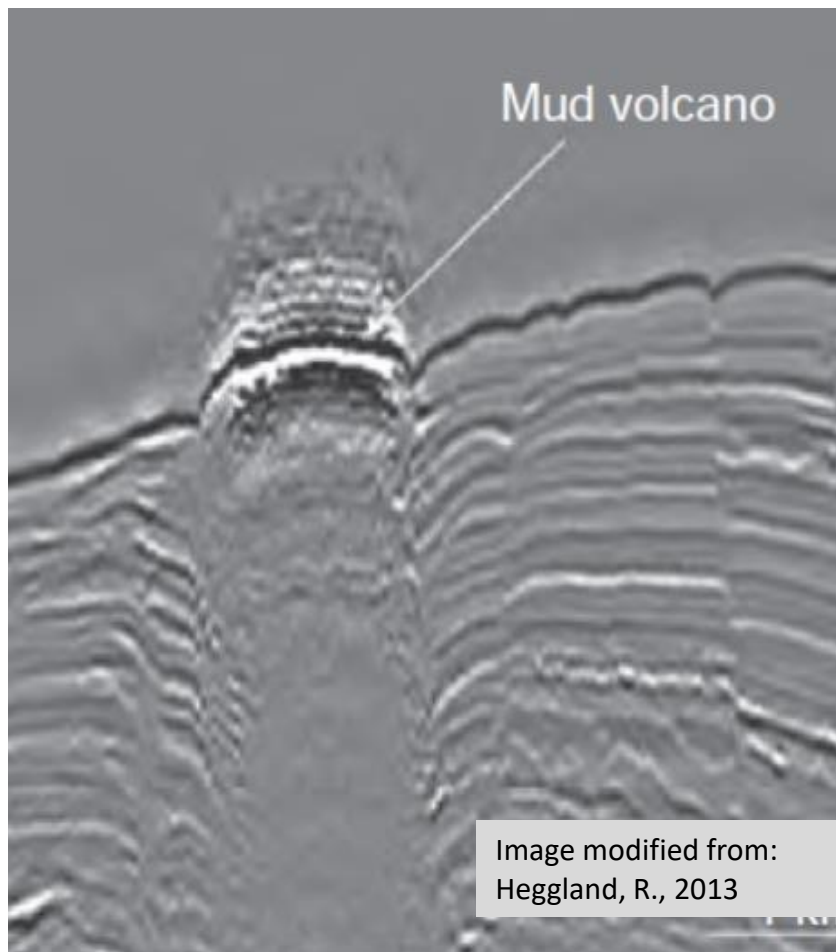


## What is THE MOST IMPORTANT PART OF Modern Marine Seep Hunting?

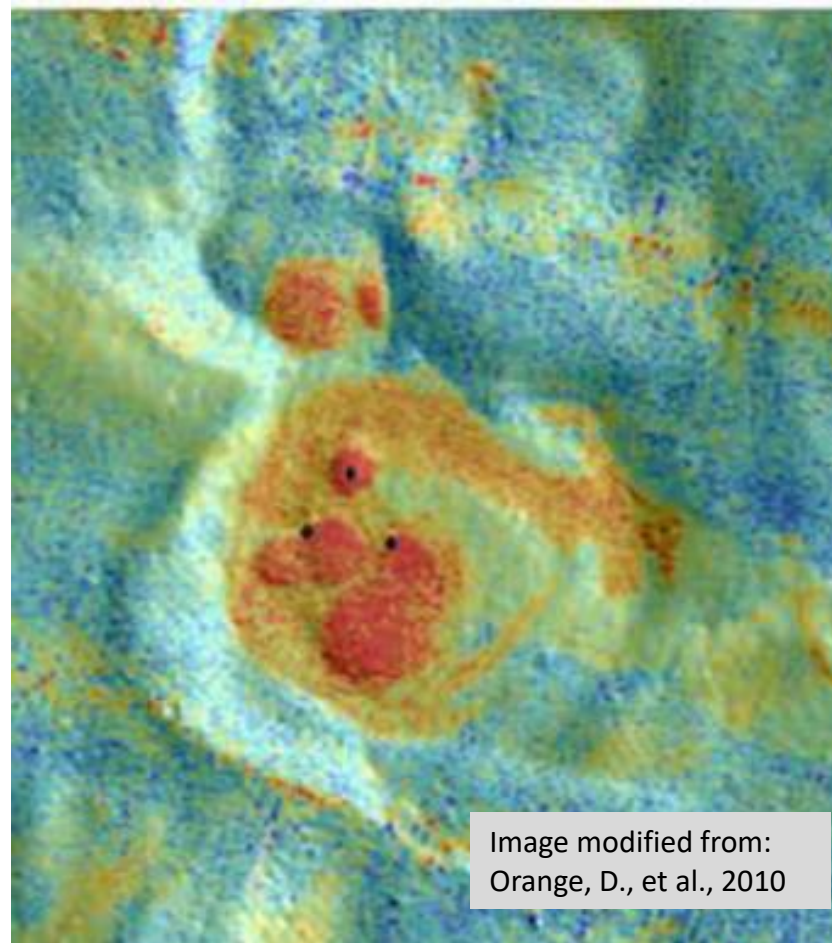
... Interpreting an integrated dataset using skilled geoscientists to figure out where to sample.

1. You don't know if your seep is tapping into your prospect without knowing the plumbing (exploration seismic)
2. You can't find the seep on the seabed accurately to sample it without high resolution mapping
3. You can't get a sample unless you know good geochemical sampling practices (geochemical sampling, after the seep hunting is done...)





*A good place to take a sample!  
... but where is the best place within this good place??*



*Added complexity of 3 resurgent domes within a nested caldera visible with multibeam.*

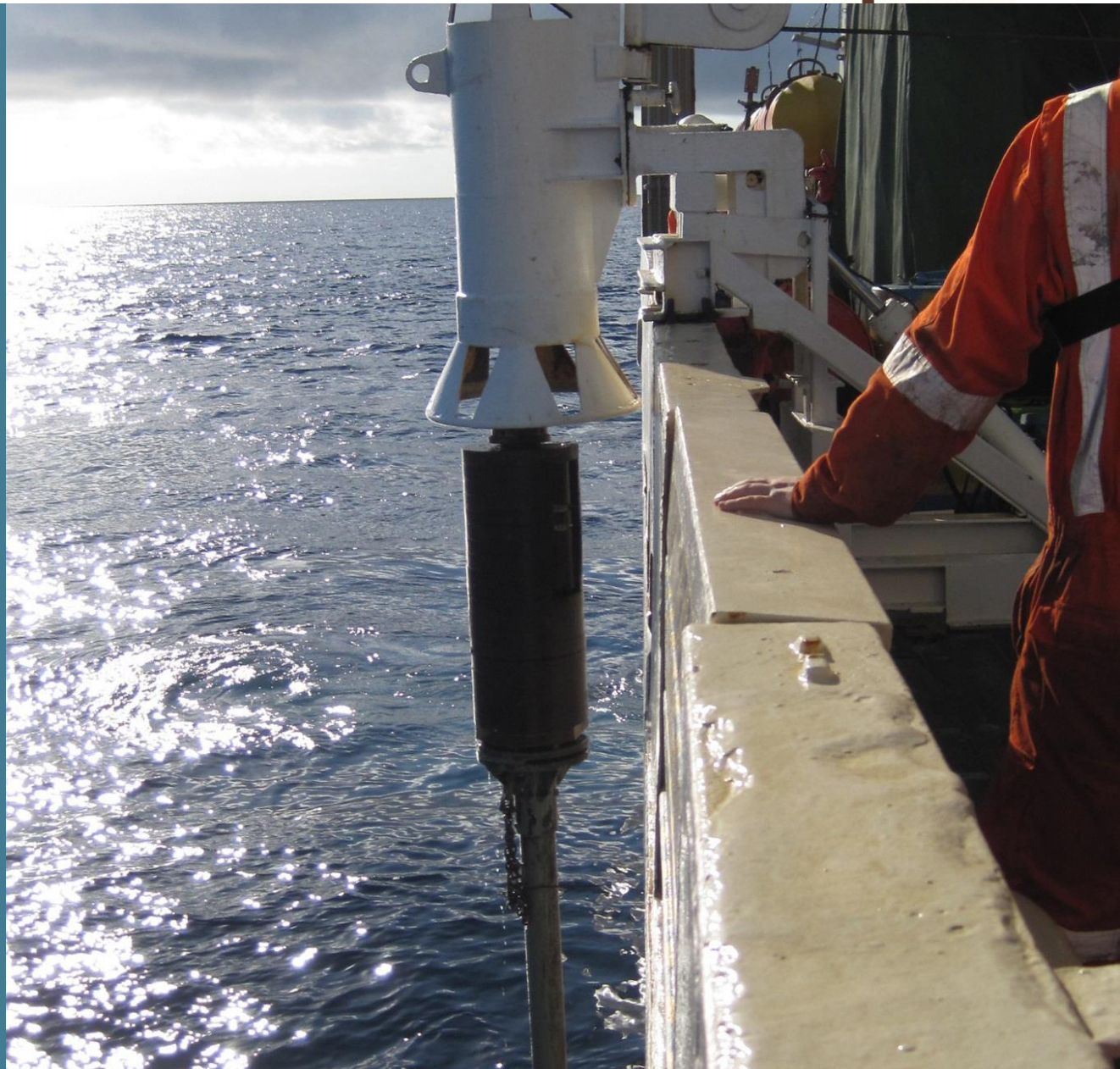


## LEARNING #3

The objective is  
not just taking  
the core...  
...it is getting the  
right sample



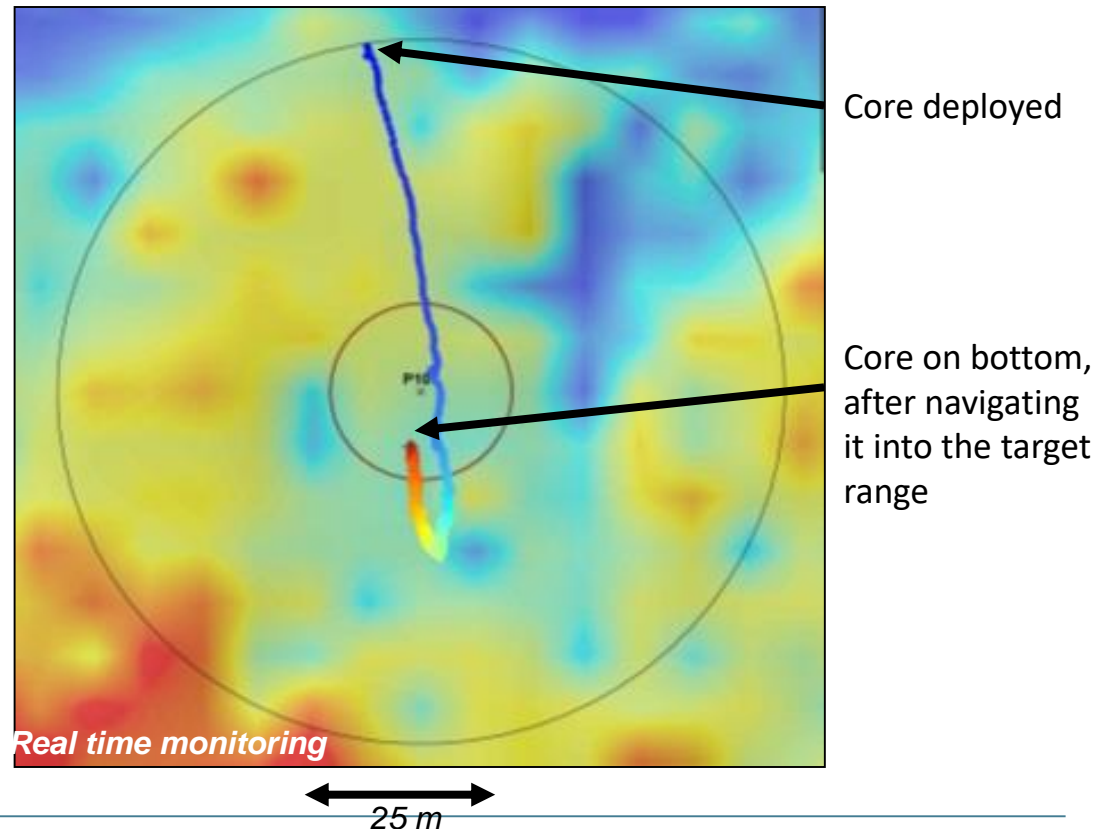
Navigate the  
core to the  
target accurately





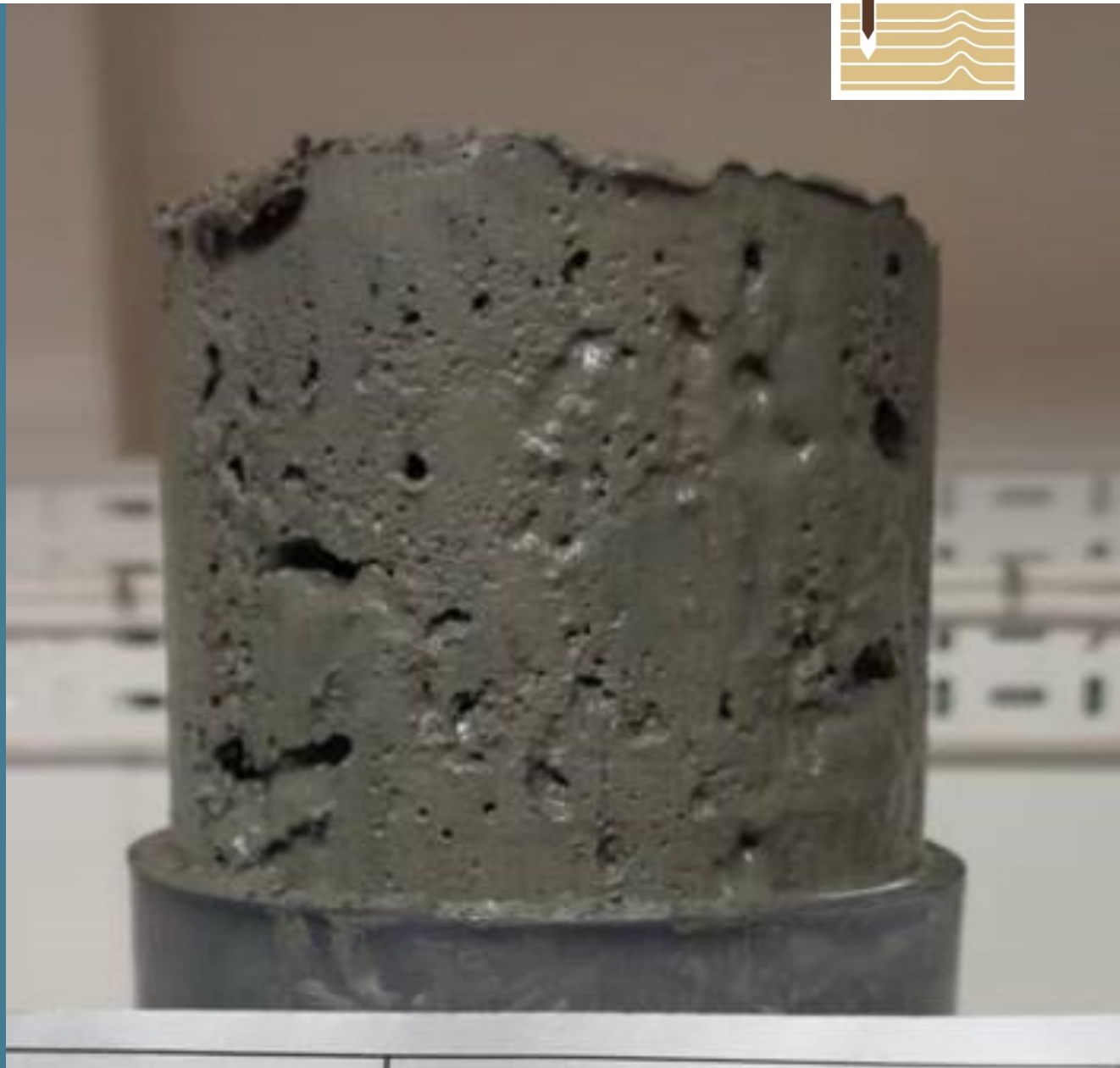
# The objective is not just taking the core...it is getting the right sample

- Missing the target by as few as tens of meters can lead to an inconclusive geochemical result.
- May lead to erroneous conclusions about the potential of the reservoirs in the block and can be problematic for the entire program.
- If you don't navigate to the target, you might as well be dropping the core over the side of the ship blindly with no knowledge of the seabed beneath you.





Sample it again  
if you need to!  
And again!



The objective is not just taking the core...it is getting the right sample

If you bring up a handful of crushed shells, you've likely hit a seep... Sample again! And again!

Some of the best cores I've ever recovered, with oil dripping from them, have been 20-40 cm's long.

If you have found a seep, get a sample from it.



Core recovery with seep-related hardgrounds at the base.



Bubbling Gas Hydrates

Seep-related authigenic minerals and partial Calyptragenid shells.





You got this  
sample, and it  
was a lot of  
trouble to get...

Do NOT let it get  
contaminated on  
the ship!!



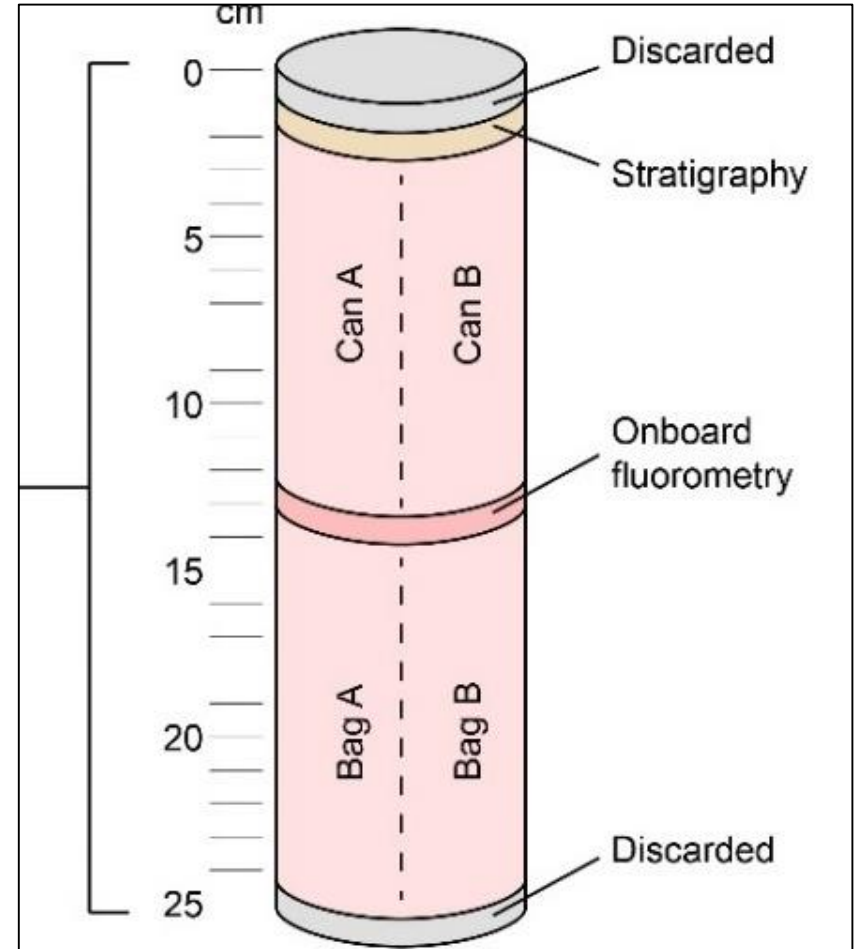
# The objective is not just taking the core...it is getting the right sample

- Clean and transparent core liners should always be used. Clean procedures are always used. Everything is photographed. Everything is labelled. Everything gets cleaned between each sampling event.
- Make sure the team is clean, not sloppy with labeling, and takes duplicates
- A good geochemist is an obsessive-compulsive geochemist!





The objective is not just taking the core...it is getting the right sample



*Samples are processed for storage in -80°C freezers and shipment to shore-based laboratories for a complete suite of analyses to be performed at a later date... and onboard preliminary geochemical analyses (headspace and total scanning fluorescence) to be performed while the vessel is still in operation.*

## LEARNING #4

Onboard  
Geochemistry to  
guide your  
sampling plan!





# Shipboard Geochemical Screening

## Headspace gas for C1-C6

- Taken immediately when core is cut open
- Gas chromatography results ready within hours

## Total scanning fluorescence for aromatic hydrocarbons

- Taken from clean portion of the core
- Dried, powdered, and extracted
- TSF results are ready in ~48 hours

## Analyses help optimize operations while on site

- Additional sampling in areas with positive results
- Sampling campaign is modified while the vessel is still mobilized.

## Shipboard analyses speed up shore-based results

- Promising samples for advanced analyses are identified before leaving the vessel
- Greatly reduced risk in countries where sample shipment may be problematic

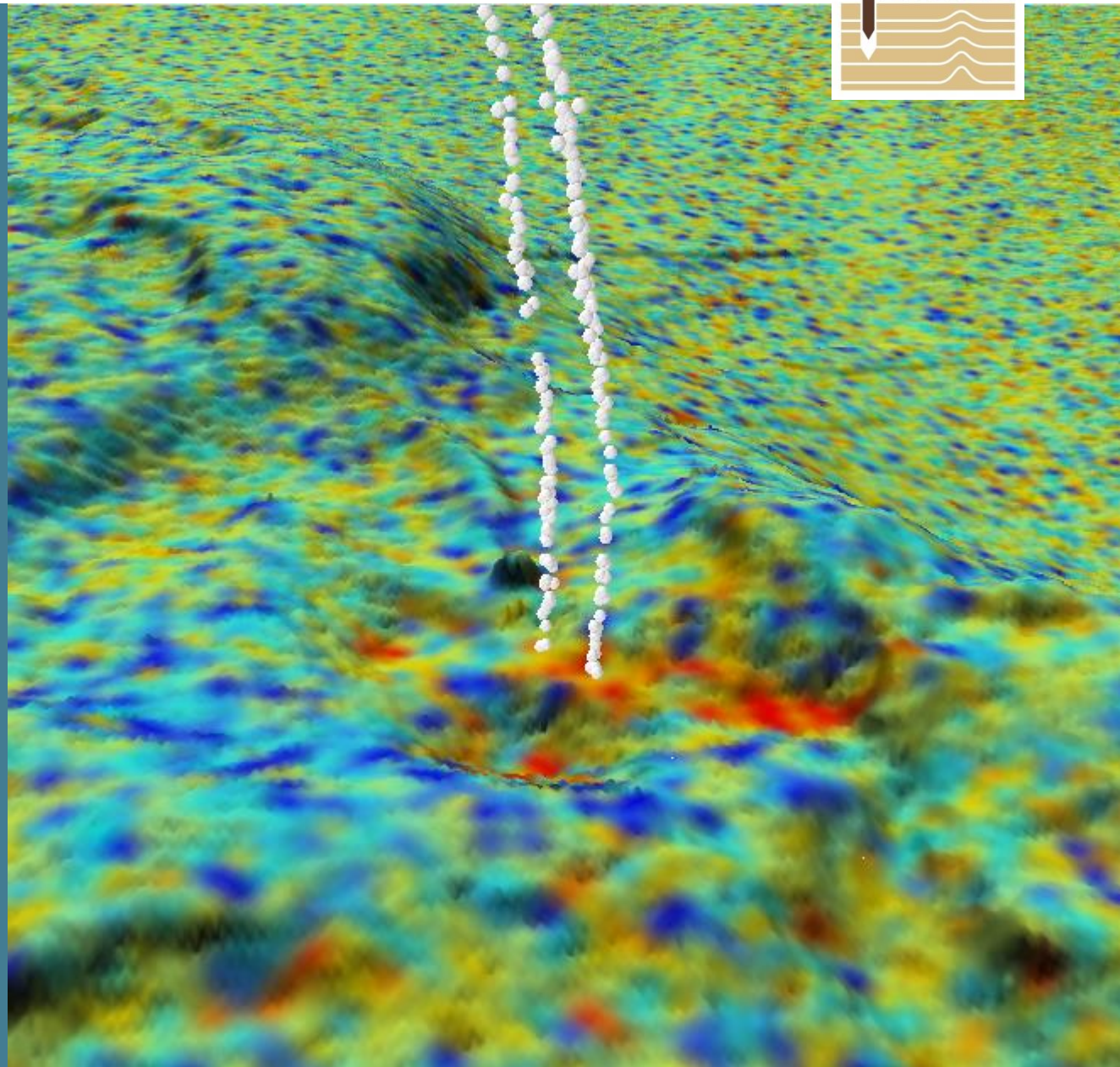


*Head space gas samples are taken after core recovery.*



*Samples for TSF analysis are dried, powdered, and extracted.*

# Seep-Hunting... So what?





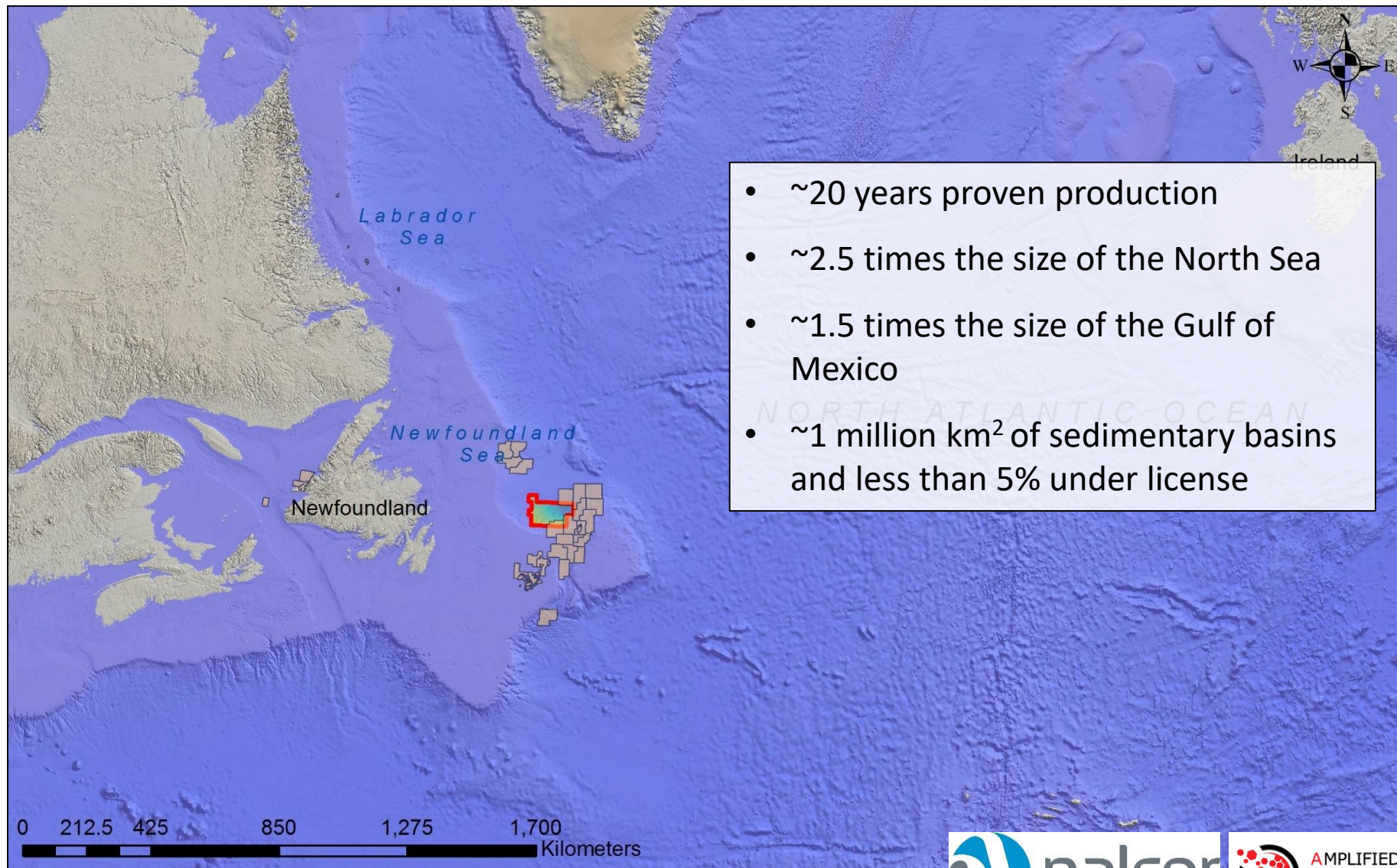


# PRELIMINARY Seep Hunting and Geochemical Piston Coring Results Orphan Basin





# Newfoundland and Labrador's Frontier Basins

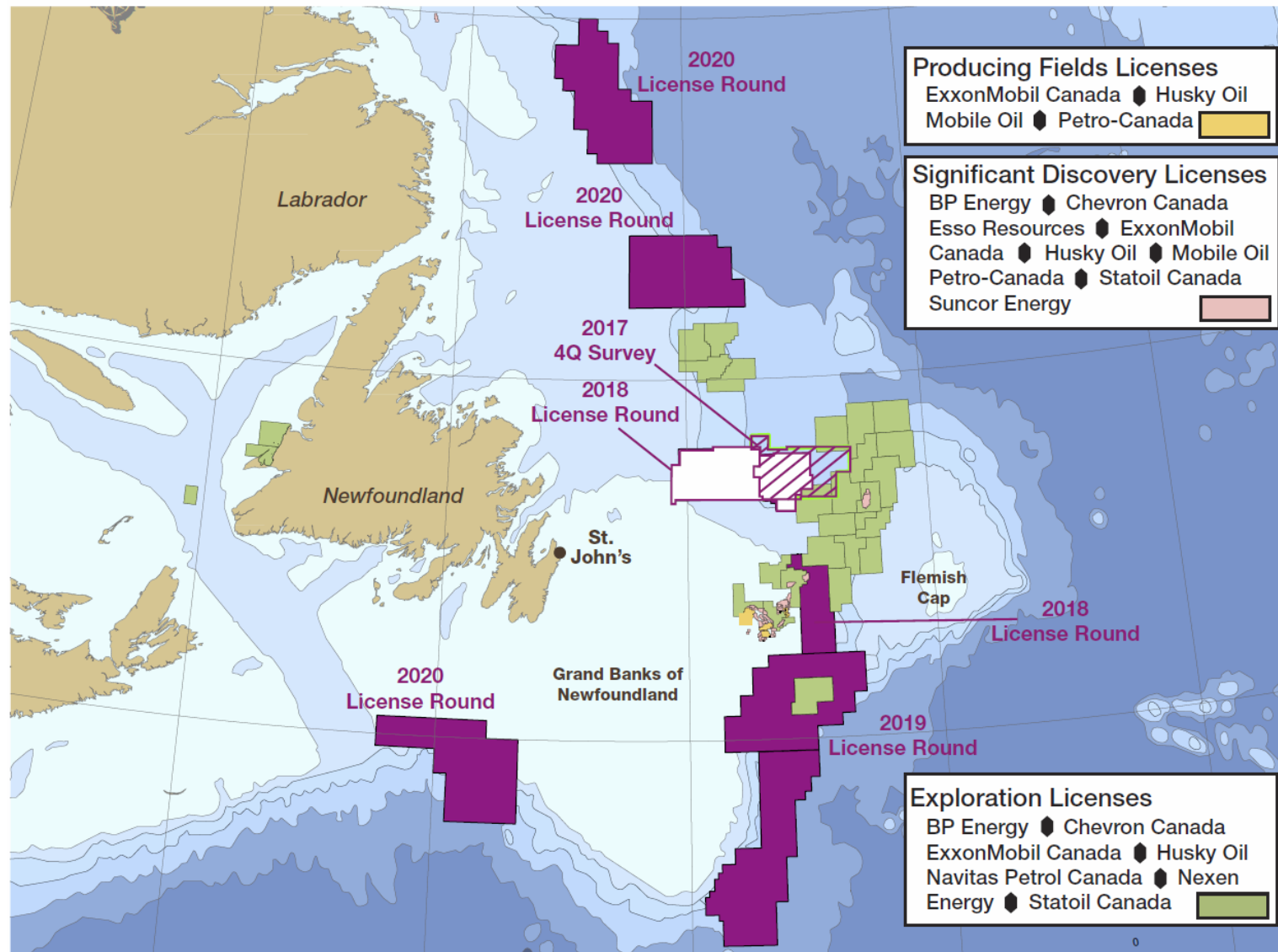


- ~20 years proven production
- ~2.5 times the size of the North Sea
- ~1.5 times the size of the Gulf of Mexico
- ~1 million km<sup>2</sup> of sedimentary basins and less than 5% under license





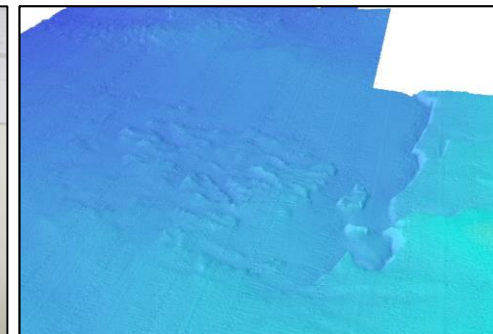
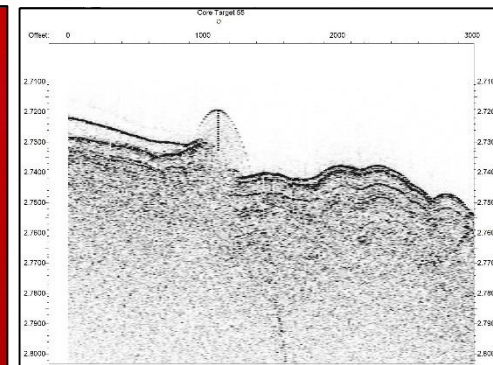
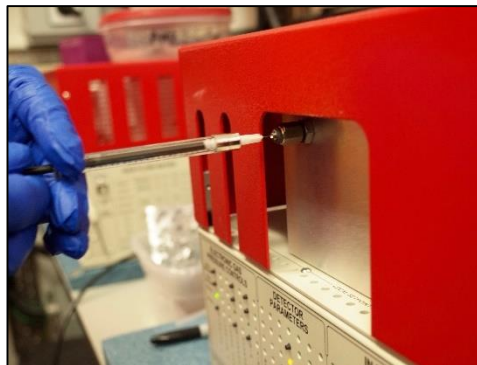
# Newfoundland and Labrador's Frontier Basins



# Scope of Seep Hunting Survey



- **Scope of Survey**
- Geophysical Data
  - Bathymetry
  - Backscatter
  - Sub-bottom profiles
- Heat Flow Data
- 99 Piston Cores Sampled
- Onboard Geochemistry
  - Gas Chromatography
  - Total Scanning Fluorescence
- Shore-based Advanced Geochemical Analyses





# Bathymetry and Backscatter Data Collected



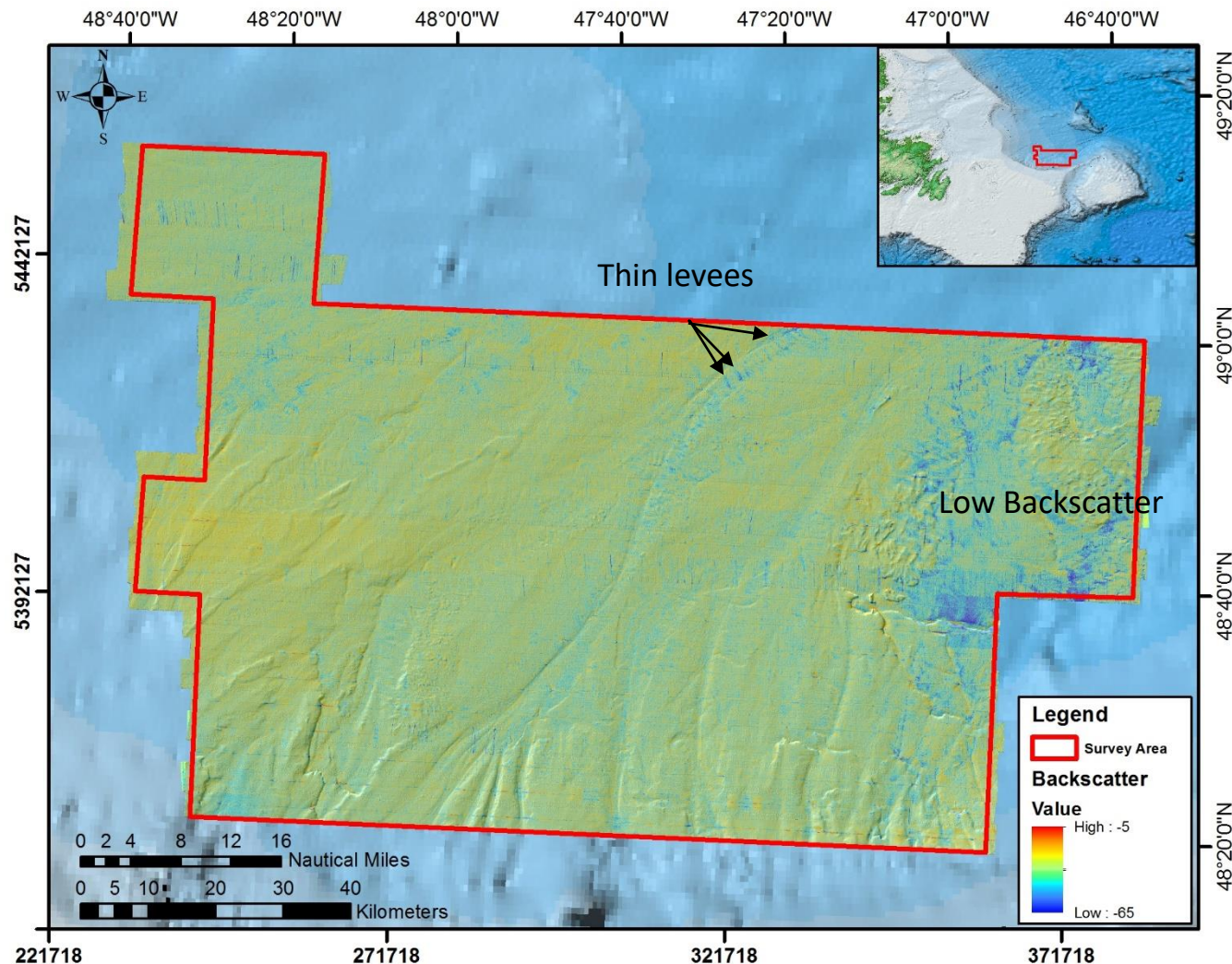
- Within the Orphan Basin Survey Area on Fugro Discovery
- 10,583 km<sup>2</sup> total survey area
- Depths from 1,324 to 2,850 m
- Acquired with a Kongsberg EM122 (1°x2°) using dual-pinging Deep Mode
- Bathymetry gridded to 15 m resolution and Backscatter gridded to 5 m resolution

# Backscatter Observations

## Channels and Escarpments



- Low seafloor reflectivity is associated with thin levees along the edges of these broad downslope channels
- This indicates the presence of muddy overbank turbidites
- Suggests these channels are active sediment conduits.



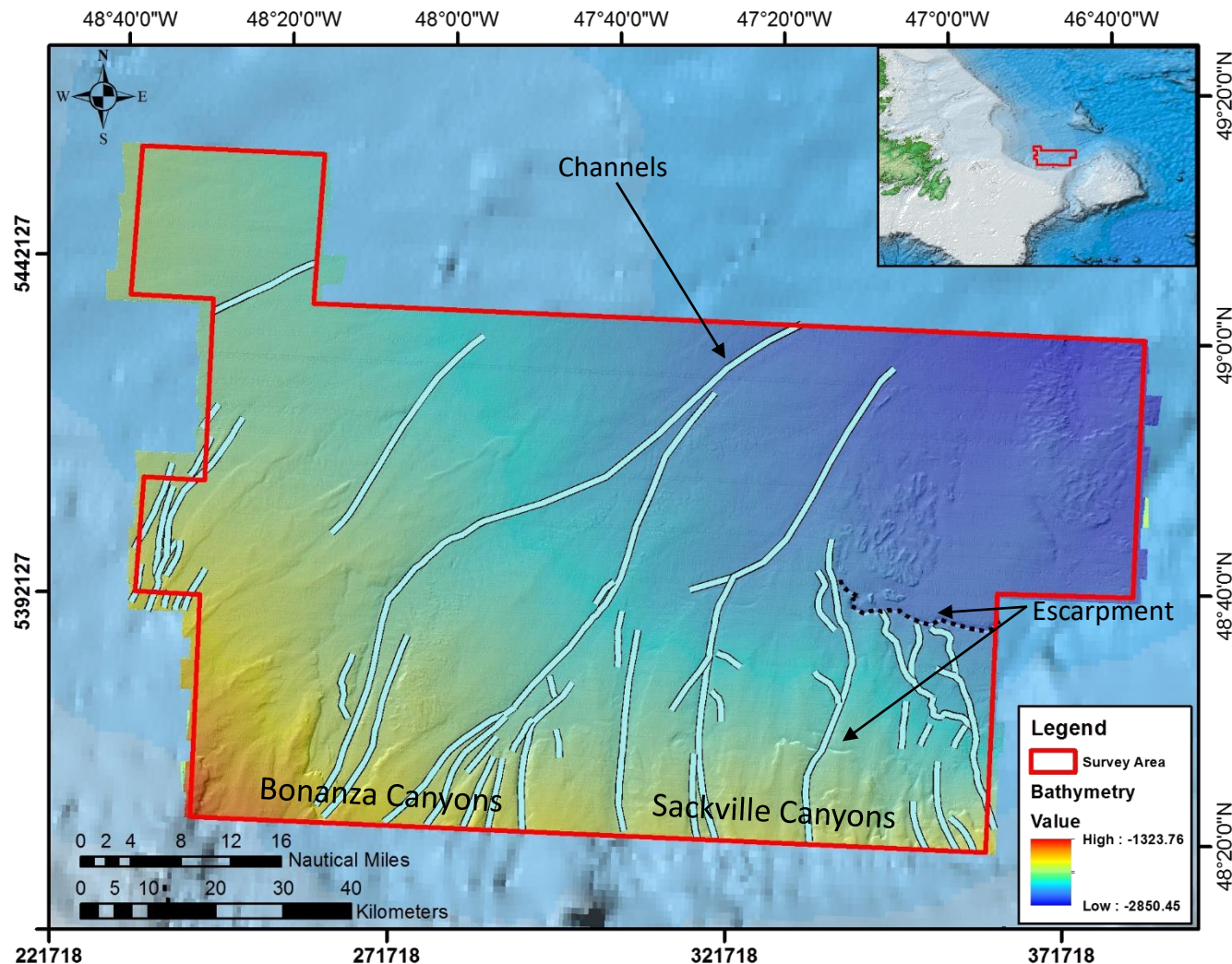


# Bathymetry Observations

## Channels and Escarpments



- Channels range from 2-4 km across, depths of 20-80 m, and run downslope towards the NE into broader and shallower channels.
- Erosional escarpments with up to 100 m of relief are located in the southern and eastern sections of the area.

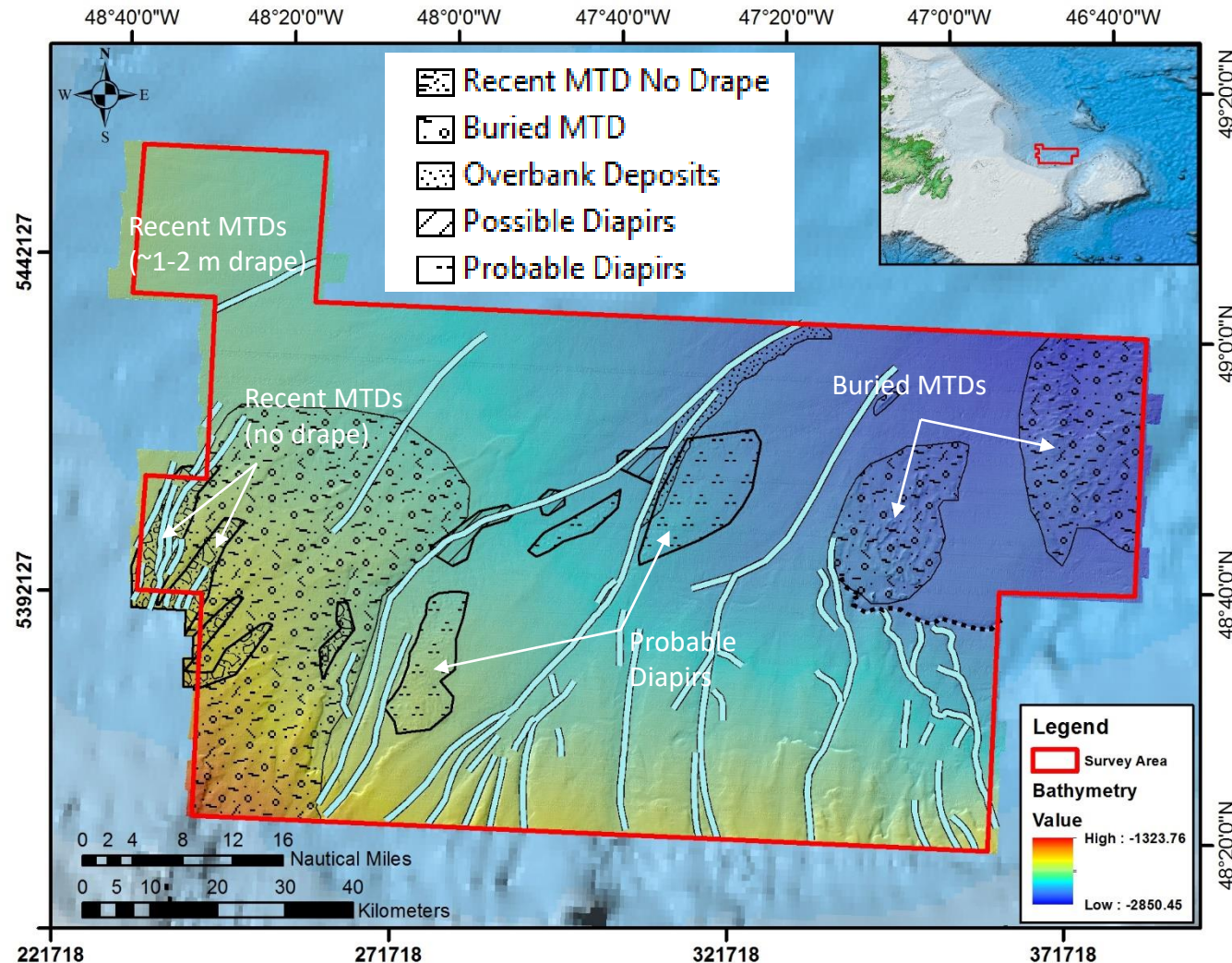


# Bathymetry Observations

## MTDs and Diapirs



- MTDs of varying thicknesses present within the area
- Hemipelagic drape of MTDs range from
  - No drape
  - 1-2 m of drape over recent MTDs
  - Buried MTDs with up to 30 m of drape.
- Laterally-extensive areas of hummocky seafloor are prominent in the eastern and northeastern areas and are interpreted to be the surface expression of buried MTDs.



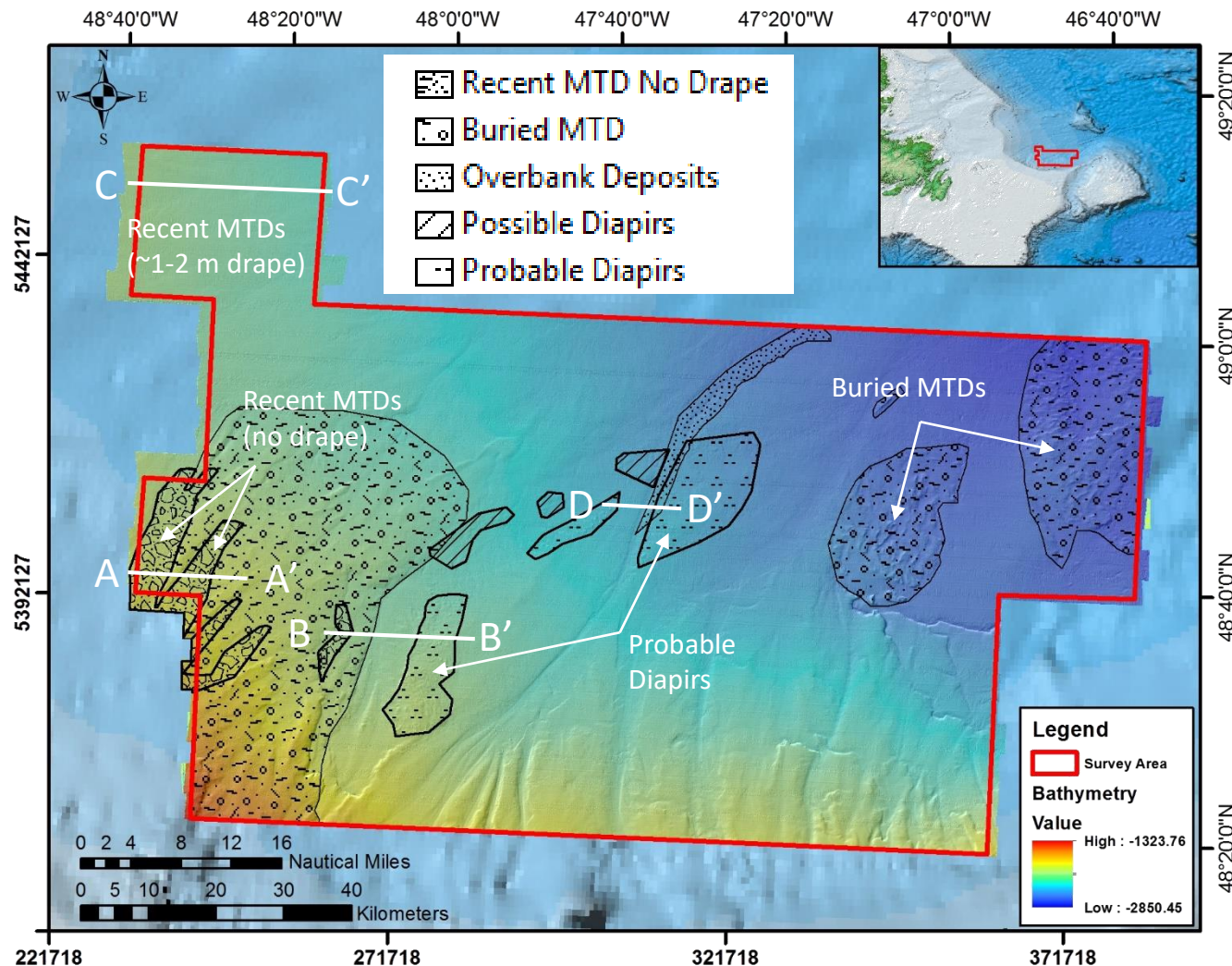


# Bathymetry Observations

## MTDs and Diapirs

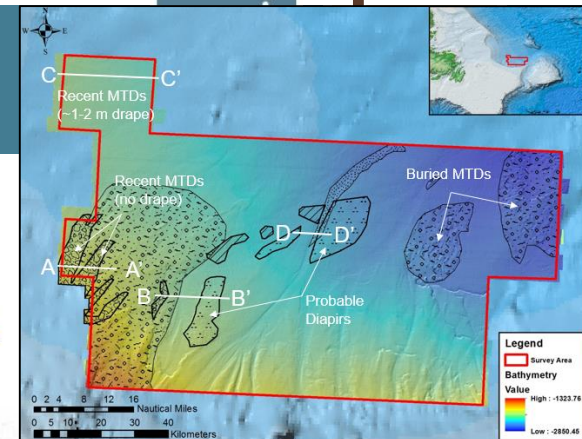
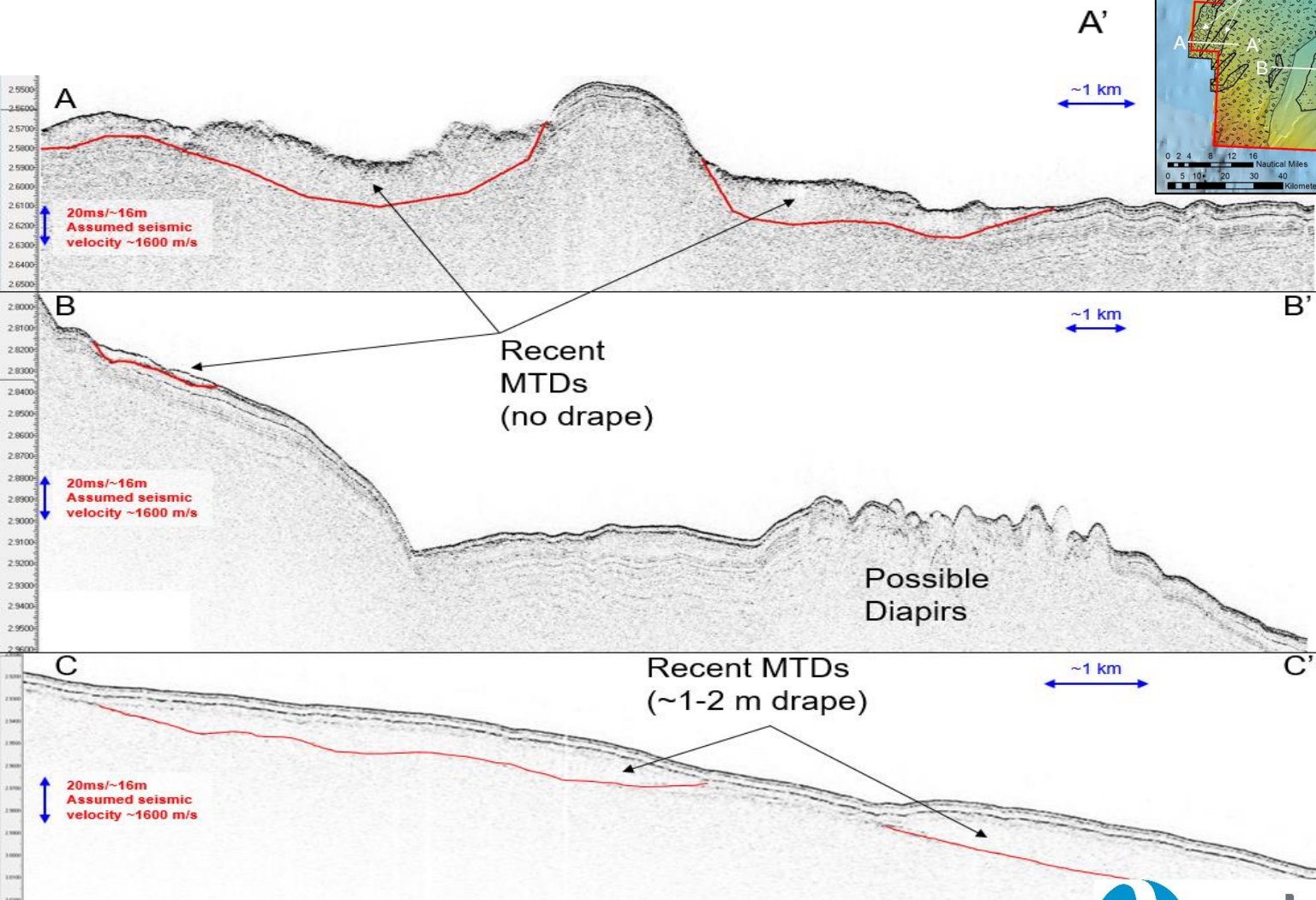


- A zone of low positive relief features interpreted to be diapirs are located in the south-central area of the survey block.
- These circular, mounded features have diameters up to 300 m across with 10 m of relief in 2,400 m water depth.



# Subbottom Profiler Data

## MTDs and Diapirs

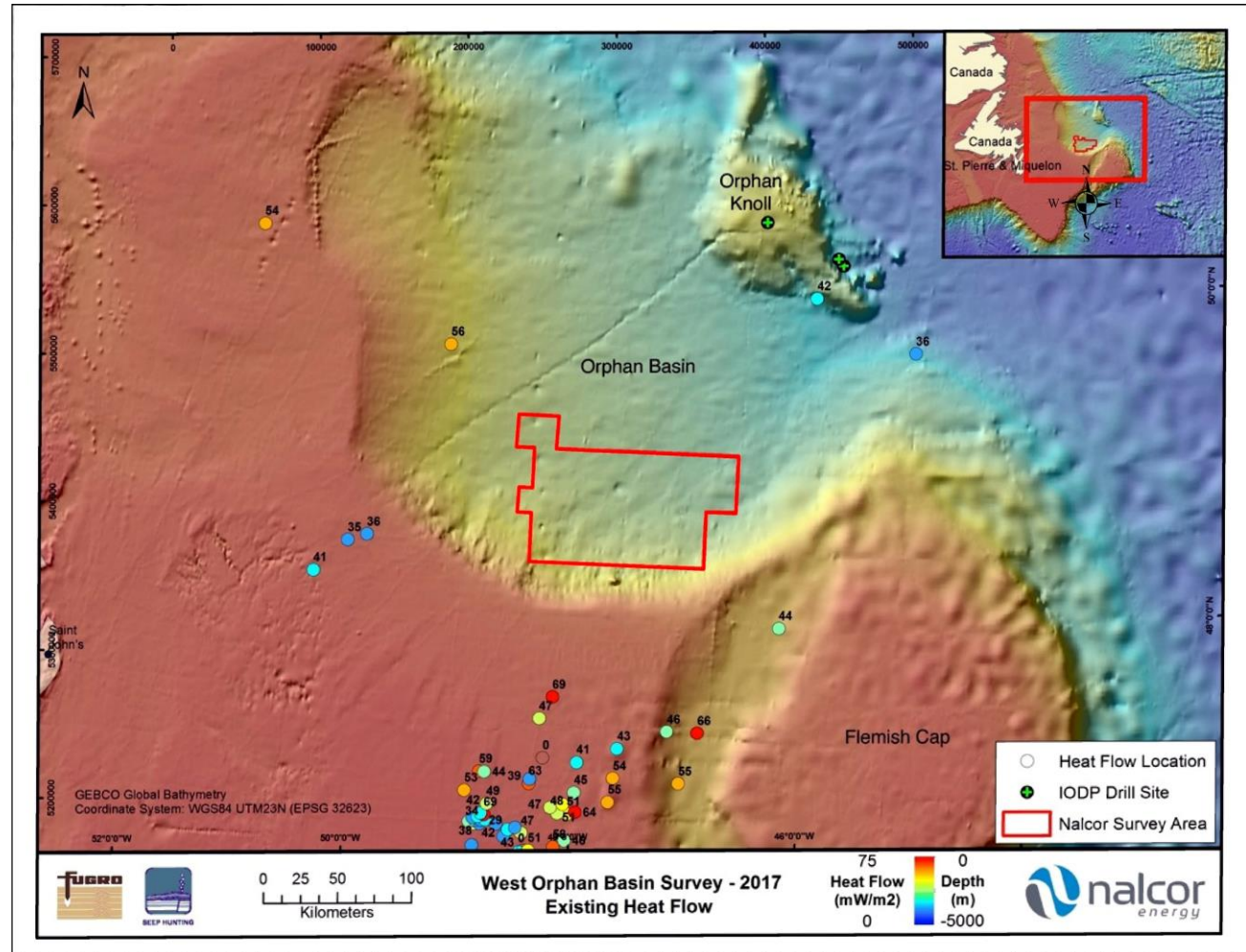




# First Major Orphan Basin Heat Flow Campaign



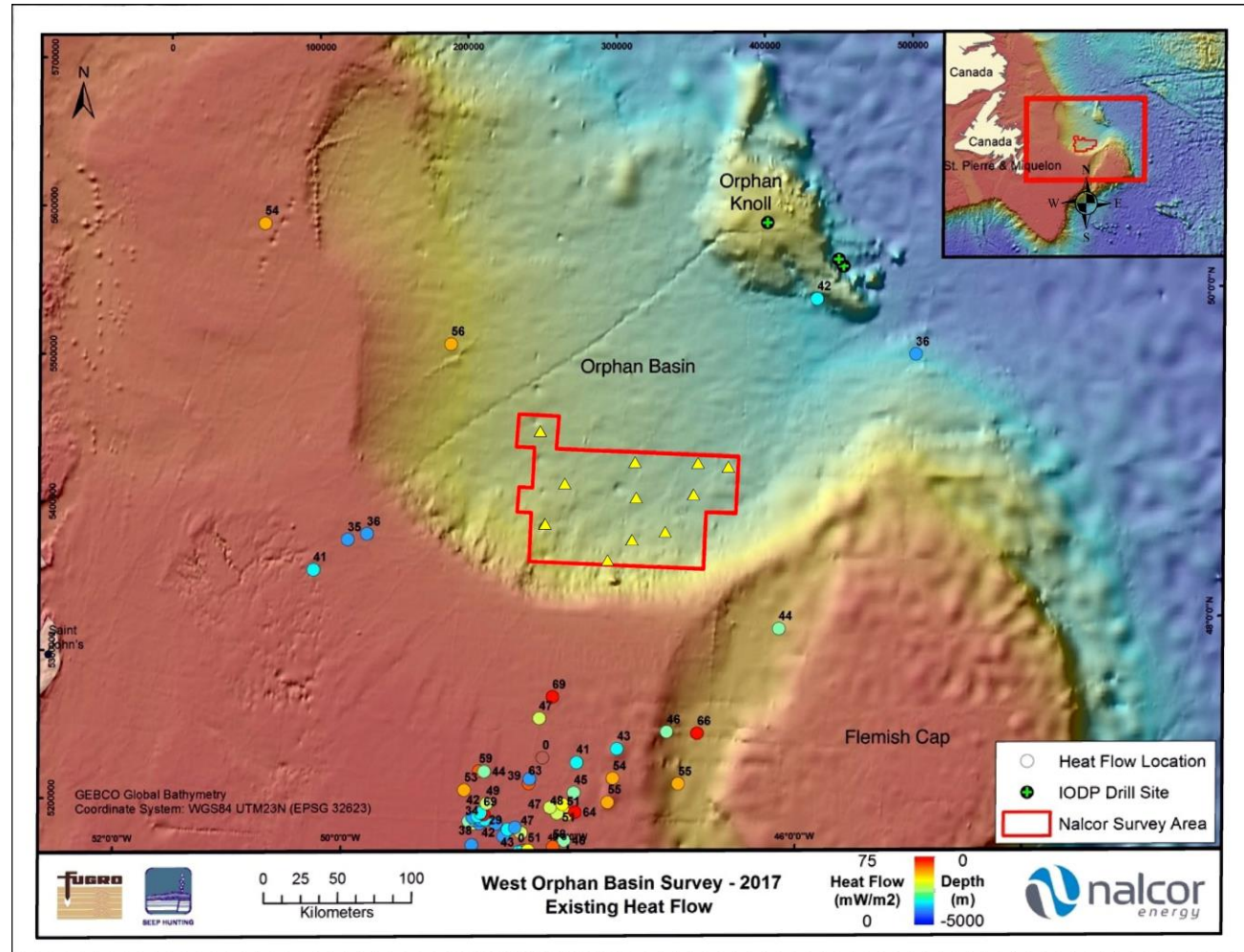
- 3 measurements exist in Orphan Basin
- Most other measurements are along the margin above the shelf break
- Lack of thermal data within the Orphan Basin prevent definitive determination of thermal conditions
- Collection of additional data necessary



# First Major Orphan Basin Heat Flow Campaign

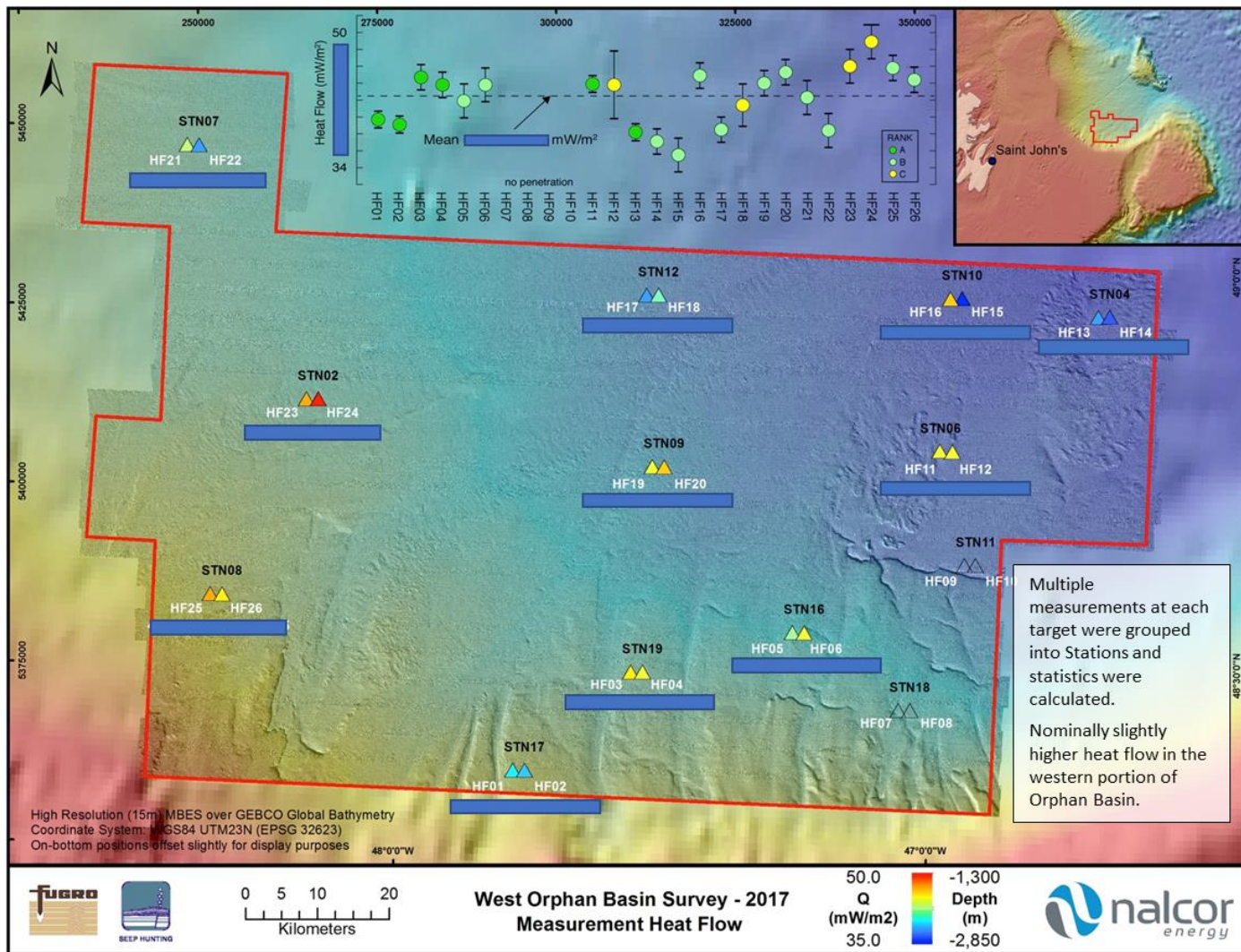


- 3 measurements exist in Orphan Basin
- Most other measurements are along the margin above the shelf break
- Lack of thermal data within the Orphan Basin prevent definitive determination of thermal conditions
- Collection of additional data necessary
- 22 Heat flow measurements acquired and analyzed in Study Area





# First Major Orphan Basin Heat Flow Campaign

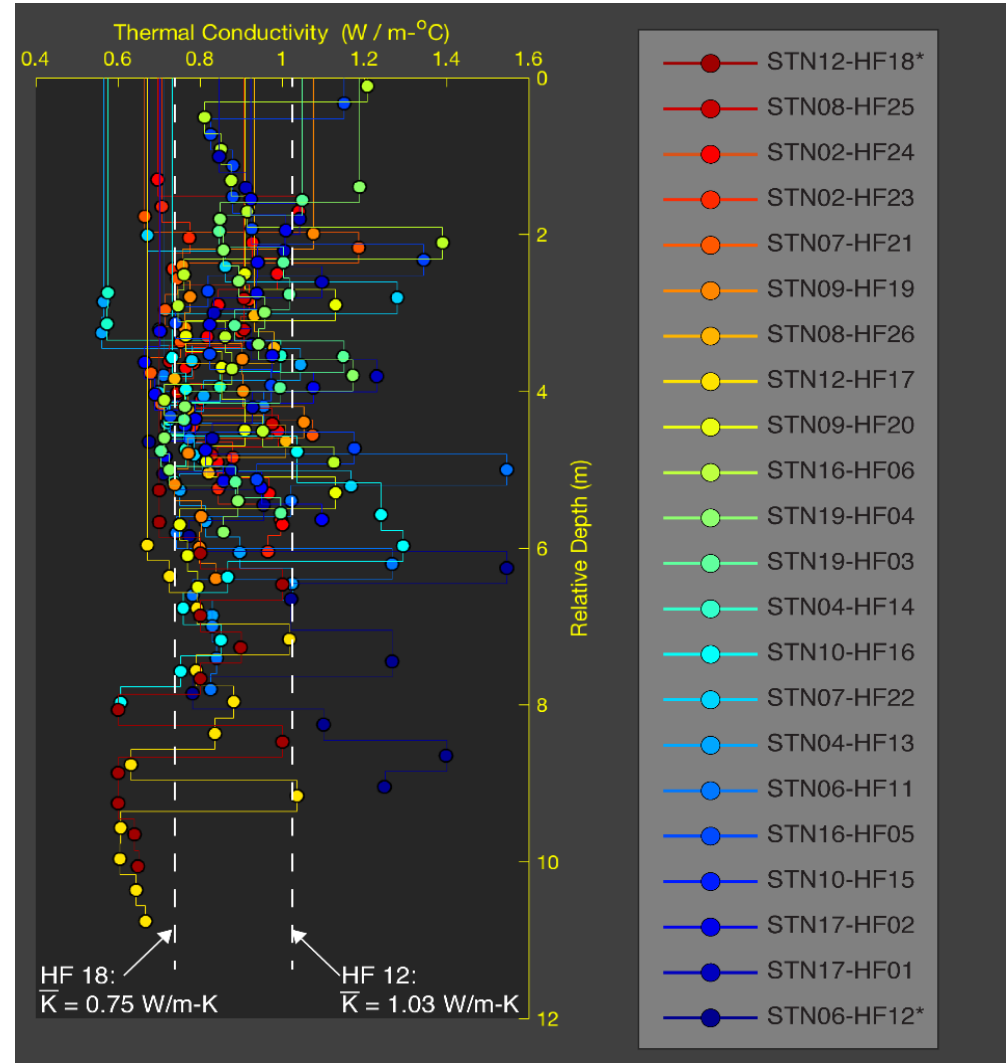


# Heat Flow

Turbidity Flows or MTDs



- Distinct layering of inferred sandy deposits (conductivity  $> \sim 1.1 \text{ W/m-K}$ ) was recorded at most measurement locations
- Results consistent with episodic turbidity flows or mass transport deposits.

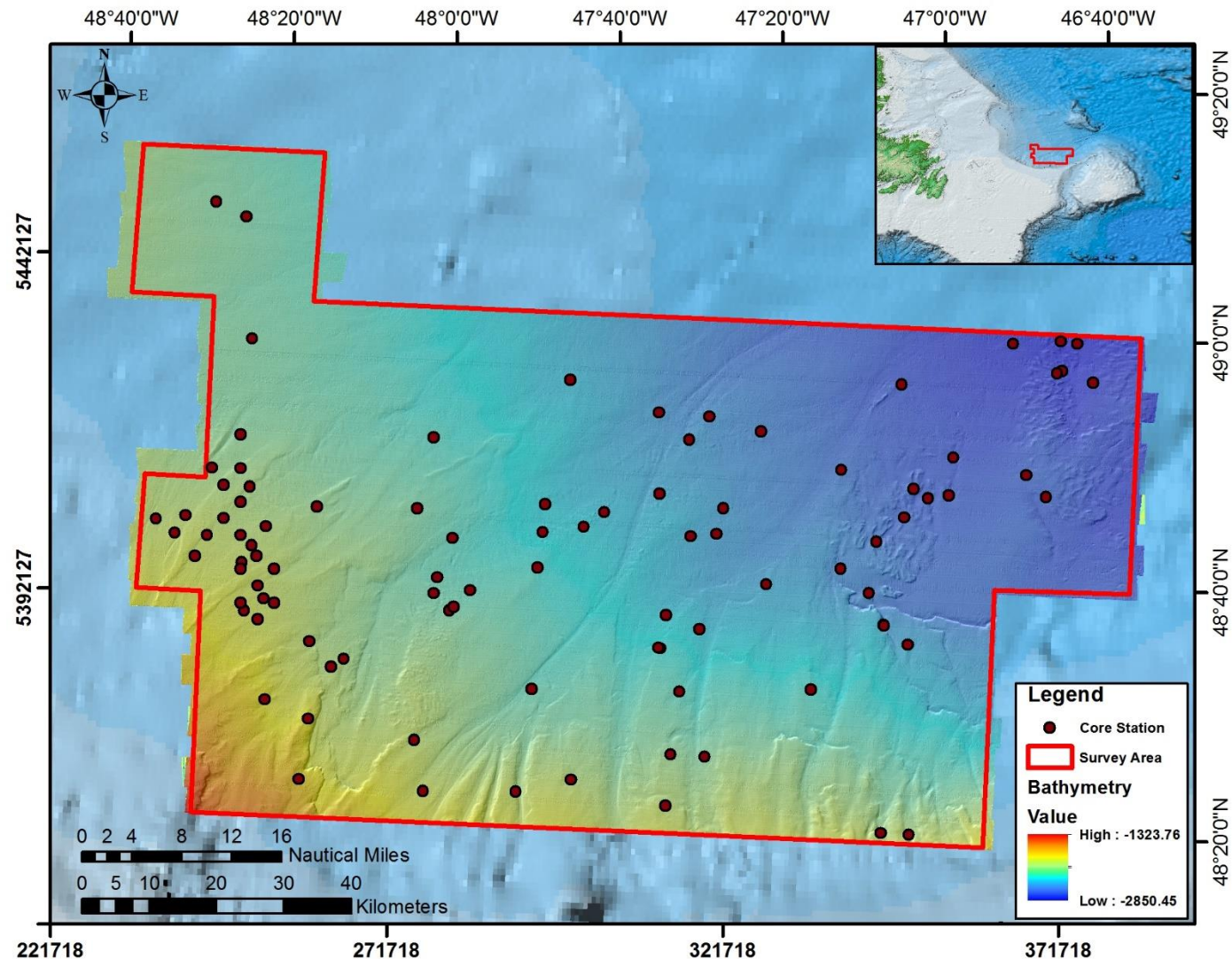




# Geochemical Piston Cores



- 99 geochemically sampled cores
- 547 onboard geochemical samples
- 778 samples (primary and backup) for shore-based geochemical analyses
- 101 AGI samples



# Shipboard Geochemical Screening



## Headspace gas for C1-C6

- Taken immediately when core is cut open
- Gas chromatography results ready within hours

## Total scanning fluorescence for aromatic hydrocarbons

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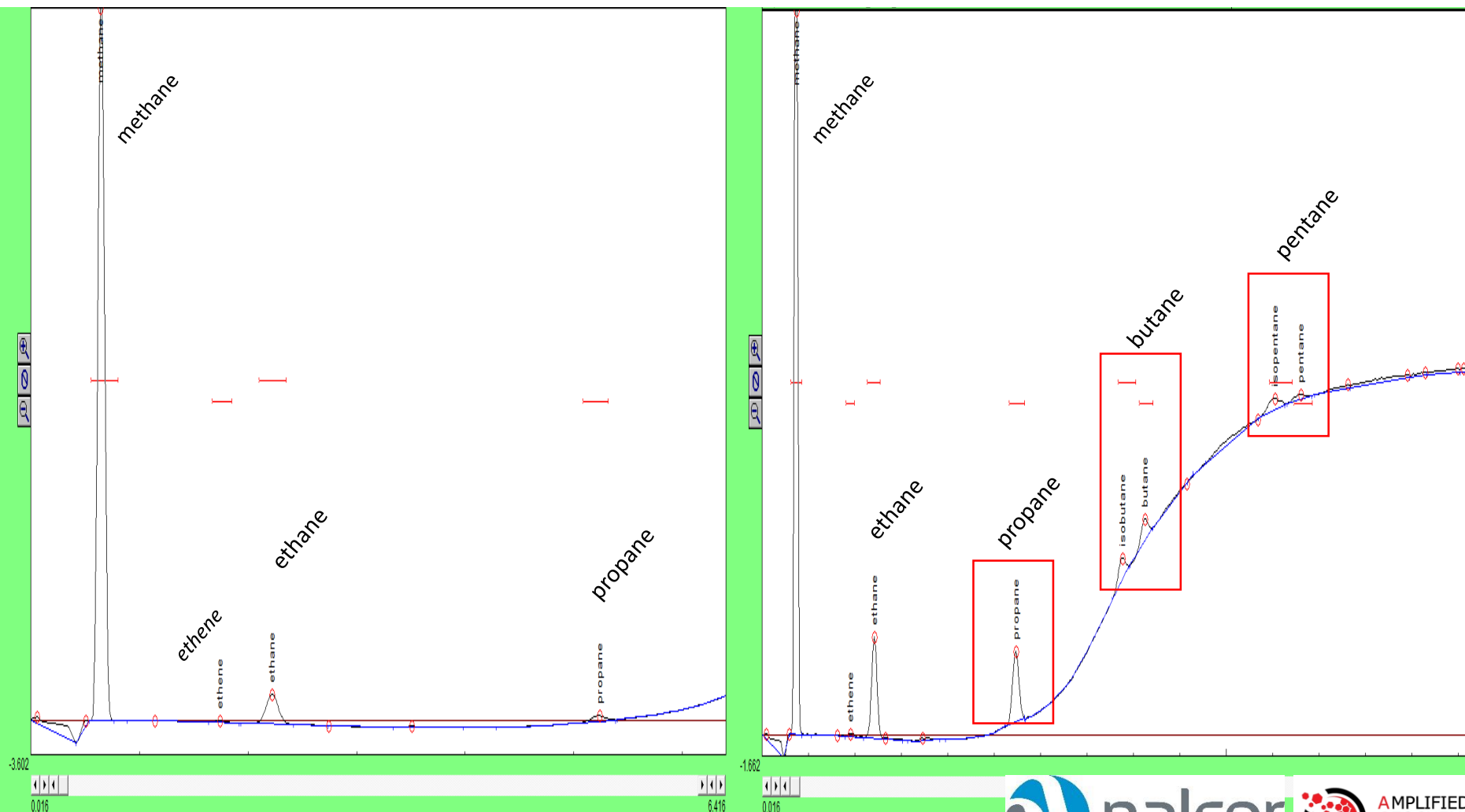
*Samples for TSF analysis are dried, powdered, and extracted.*



# Shipboard Headspace Analyses



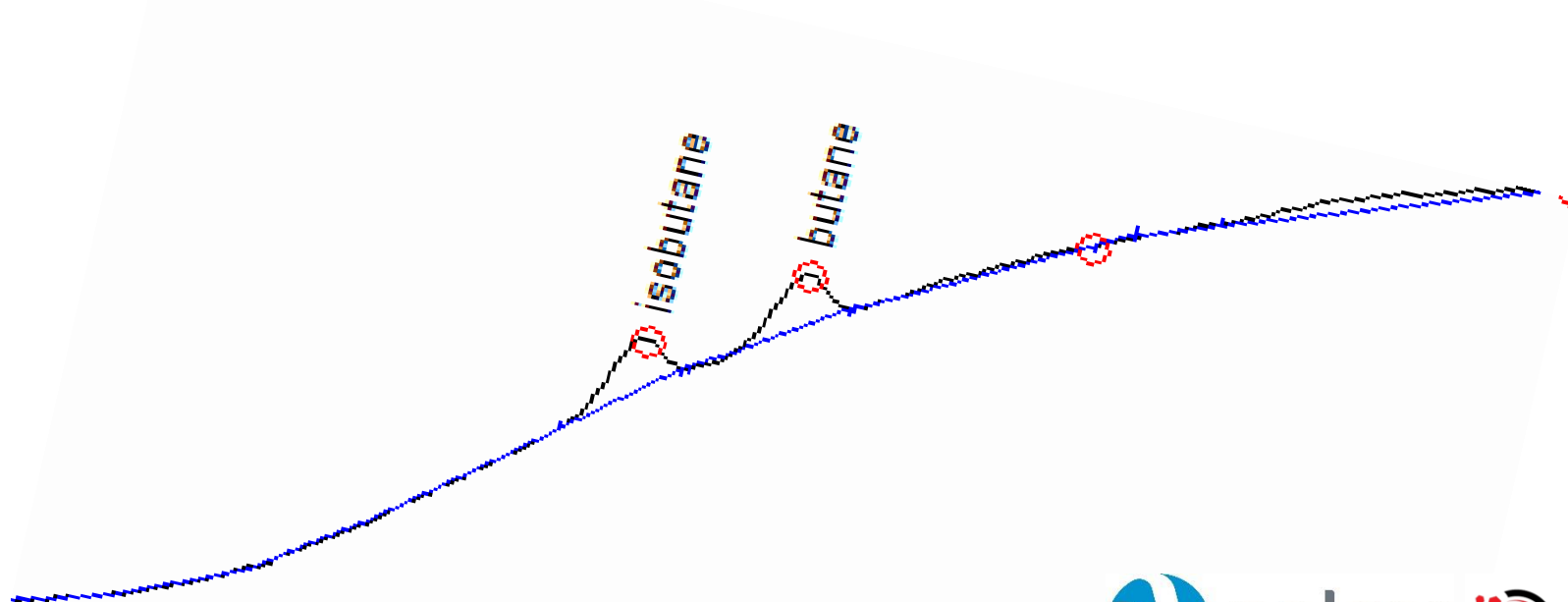
Propane and butane, albeit in low concentrations, were observed onboard in the gas chromatography results.



# Shipboard Headspace Analyses

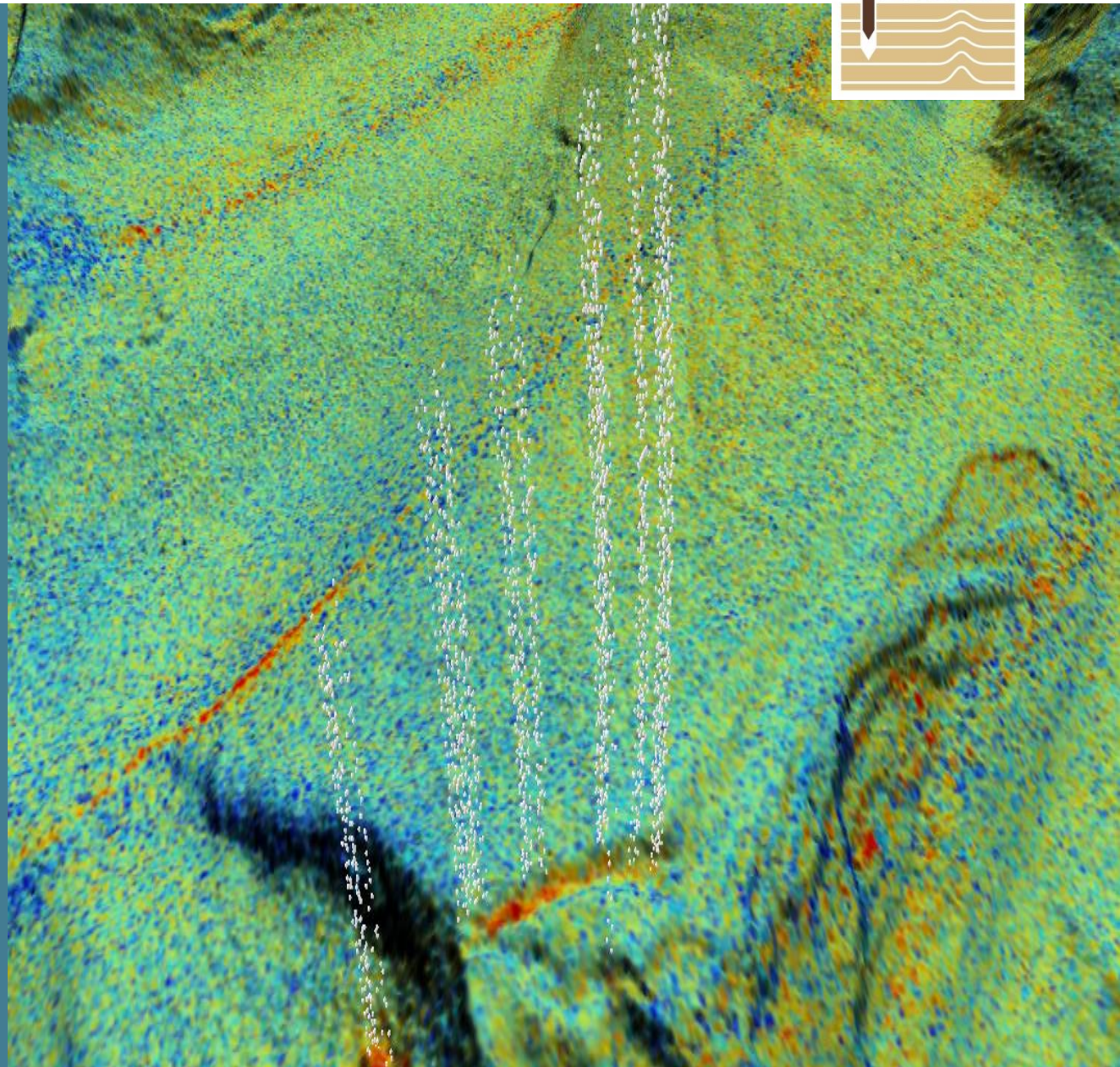


- There appears to be a small concentration of butane.
- It is clearly well above the baseline and where butane was expected, which was calibrated daily.
- Multiple verifications of these peaks were run while out there. Some of the higher butane samples were re-injected to confirm the results and always measured the same content in the re-injection of the same sample.
- When you look at the overall pattern of higher ethane and propane, and the presence of isobutane, there is good confidence that this was naturally-occurring butane.





# Conclusions: (in context of Orphan Basin Study)



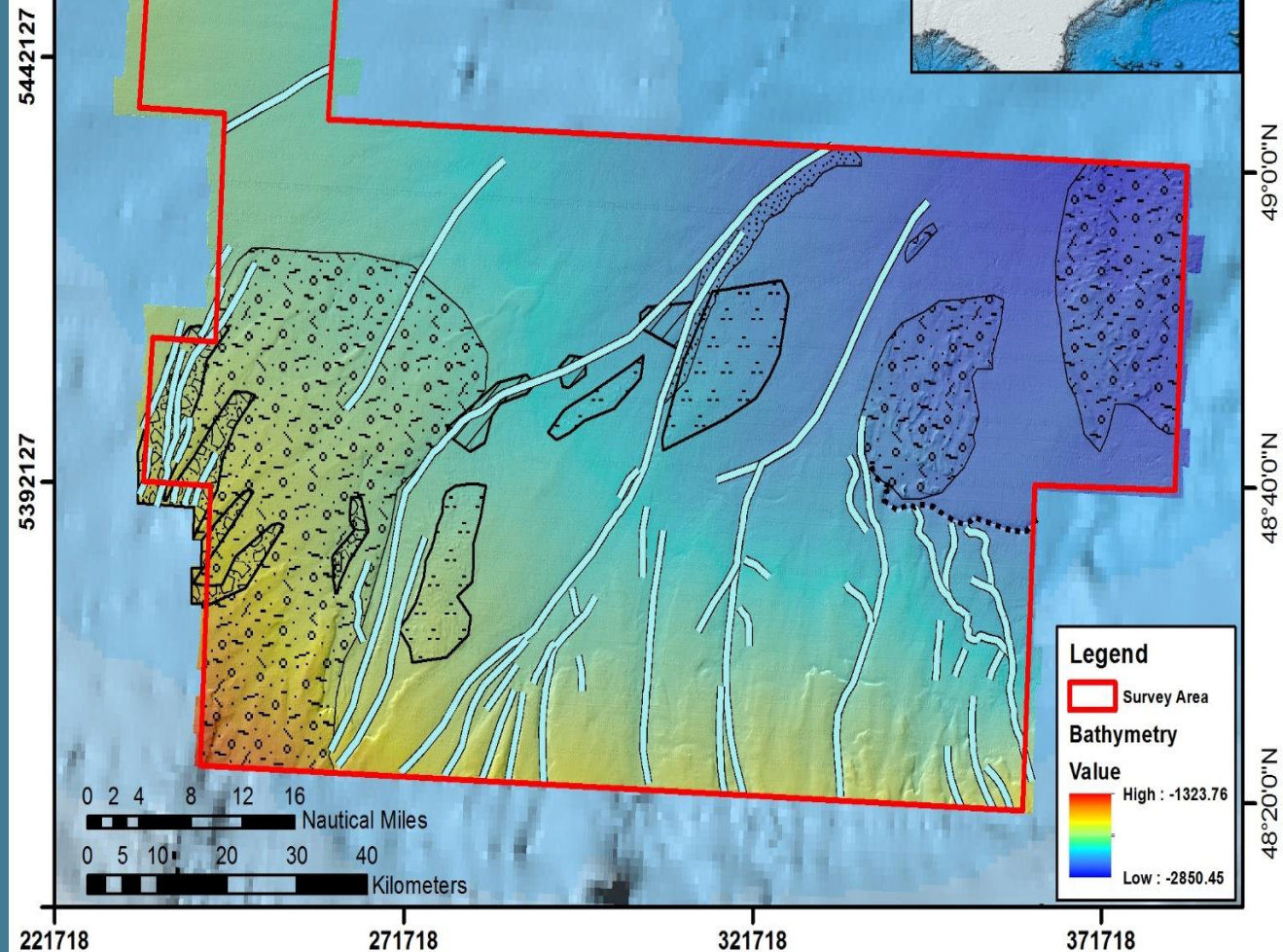


High quality of the bathymetry and backscatter datasets allowed for robust geomorphic interpretations. These can be used not only for exploration (and best positions for geochem samples to be take), but also later purposes such as geohazard assessments, pipeline routing, environmental studies, etc.



## LEARNING #1

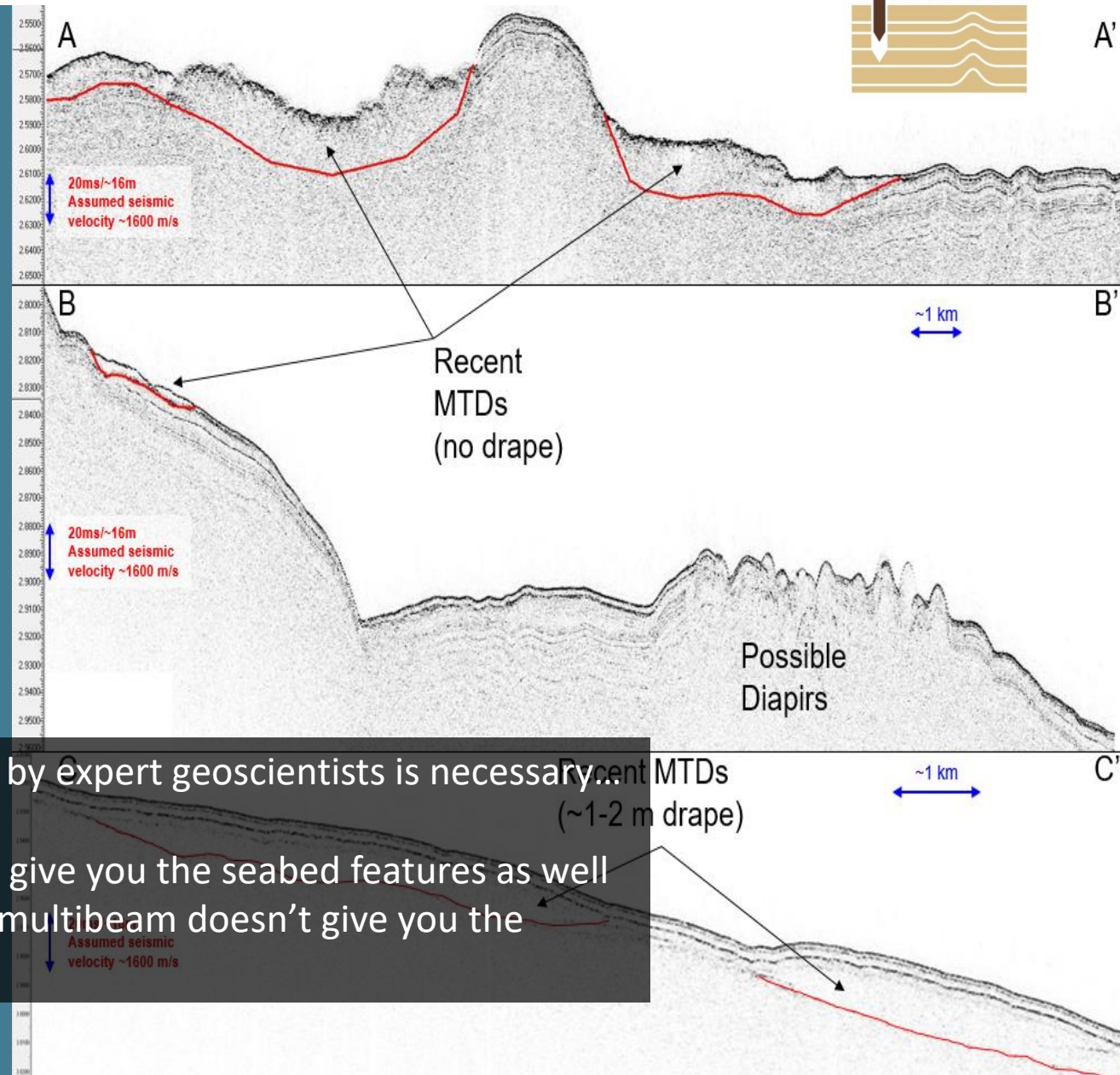
### Multibeam Data: The Driver for Modern Marine Seep Hunting





## LEARNING #2

### Interpreting the Geology: The Key to Seep Hunting



Integrating the datasets by expert geoscientists is necessary...

... Seismic alone doesn't give you the seabed features as well as multibeam data, but multibeam doesn't give you the subsurface geology.

Not all vessels can perform this work, and coring blindly will likely get you meaningless data (statistically-speaking).

Also the processing and preparation of the samples are critical, if you want good data.

## LEARNING #3

The objective is  
not just taking  
the core...  
...it is getting the  
right sample





## LEARNING #4

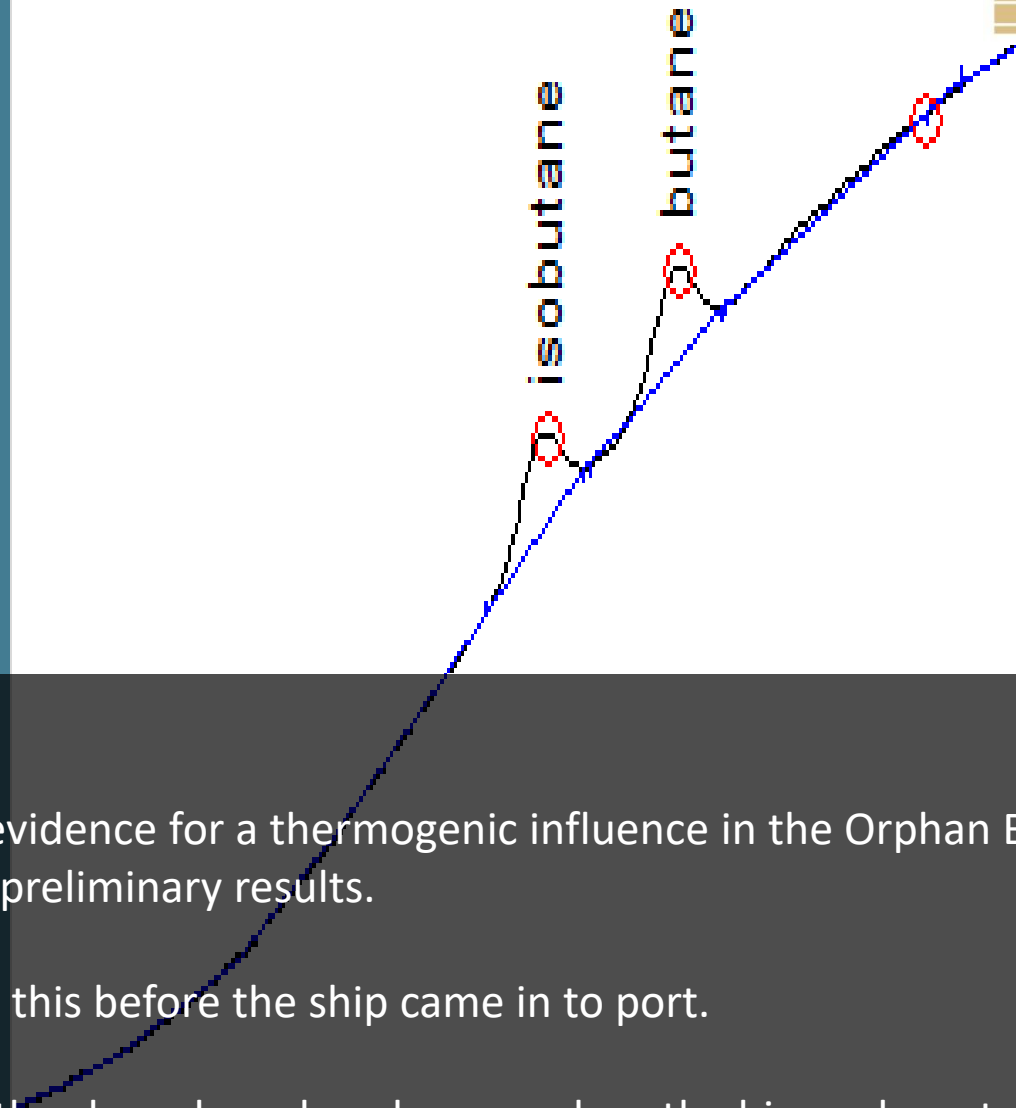
### Onboard Geochemistry to guide your sampling plan!

This is good data.

There is geochemical evidence for a thermogenic influence in the Orphan Basin survey area, based on preliminary results.

We were able to know this before the ship came in to port.

(And now we wait for the shore-based analyses, such as the biomarkers, to be completed to get the complete picture)



## Recap – How To Find Seeps for your Geochemistry Programs

- Use **robust science** every step of the way.
- **Evolve** as the **technology** improves; *seep exploration is technology-limited so therefore it is improving every year.*
- Involve **key personnel** who are qualified and experienced with this work; *the cost of added personnel who can make the program a success is background noise compared to the cost of a mobilized vessel... or to the cost of a failed program.*
- **Optimize** the program **in real-time**. *Adaptive plans with room to react based on what is happening 'on the ground' will improve the program's chances of success.*





Thank you.

For more information, please contact

Jim Gharib; Fugro Global Product Manager for Seep Studies

[jgharib@fugro.com](mailto:jgharib@fugro.com)