Photo credit: Dallas Dunlap, BEG

Growing Experience with HR3D Marine Seismic

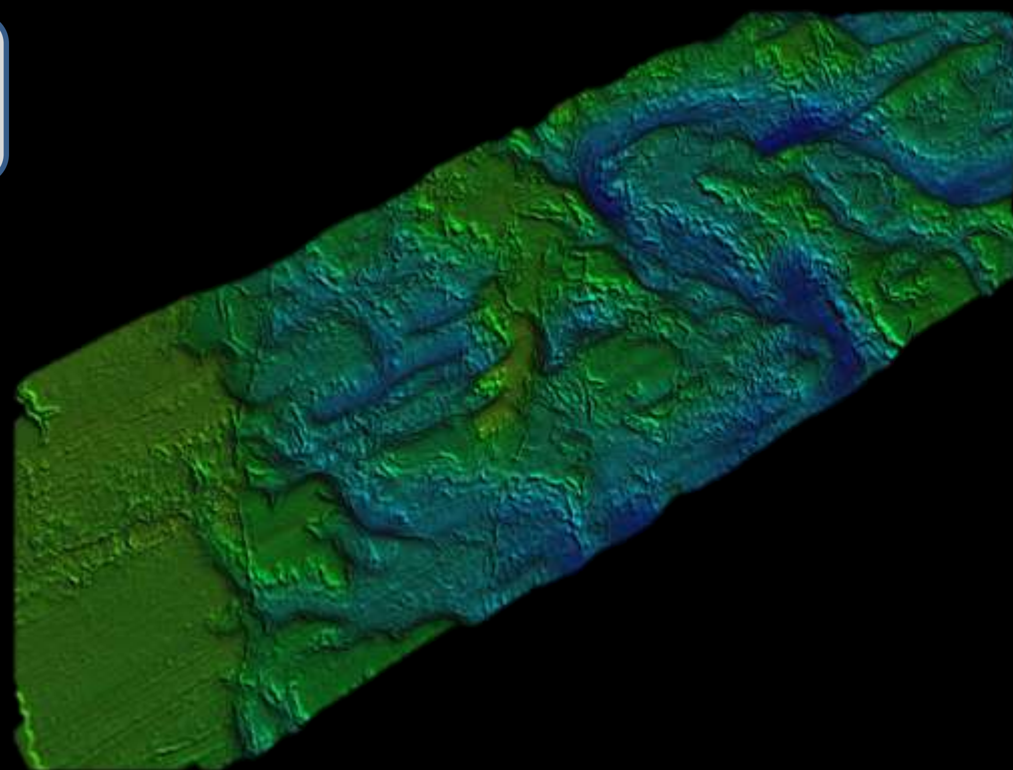
TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences

BEG

UTIG

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

NETL



SUMMARY

- **HR3D is a mature but evolving technology capable of addressing a range of geoscience topics.**
  - Learnings from UT: 150 sq. km. surveys in GoM; Japan
  - Many others (Tromso, Geomar, Southampton, etc.)
    - Vessel, mobilization, deployment, positioning, array geometry, source, processing.

- **Technology & datasets can evaluate geologic history and/or active processes:**

  Characterization: Success imaging overburden in detail.

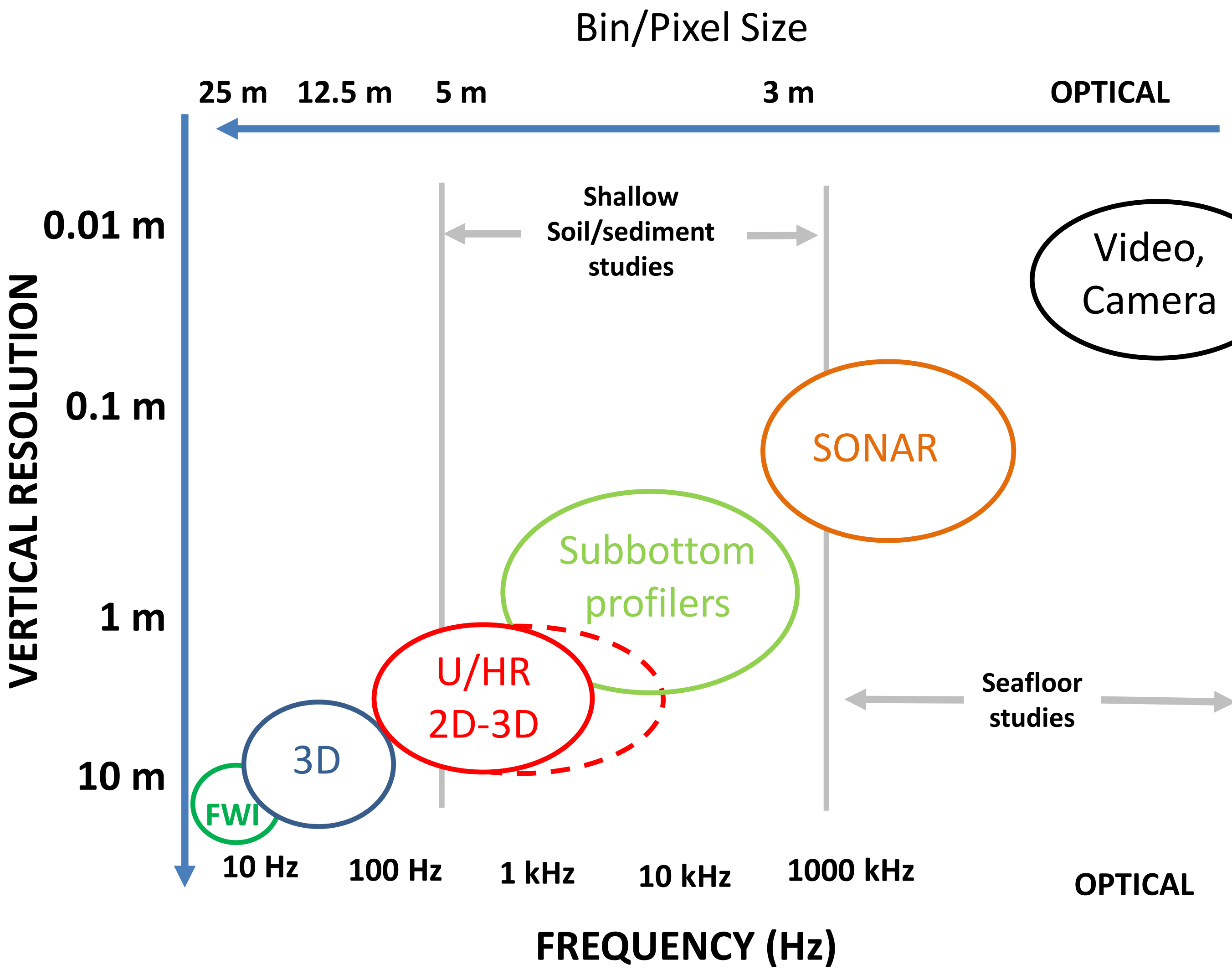
  1) **GEOLOGY**: Well-resolved faults and stratigraphy down to 1+ sec (90 cu. in. source)
     - Complex stratigraphic heterogeneity (inner shelf)
     - Subtle fault expression toward seafloor.
  2) **FLUIDS**: Identification of leaky/non-leaky geo-systems.
     - Potential migration pathways & re-accumulations not seen in conventional data.
     - Integration with Coring, CPT, EM, etc.

OVERVIEW

- The Pcable™ HR3D system (there are others)
  - Intro: what defines HR3D?
    - Resolution -> applications
  - System geometry & specifications.
  - Operations: HSE, weather tolerance, production rates.

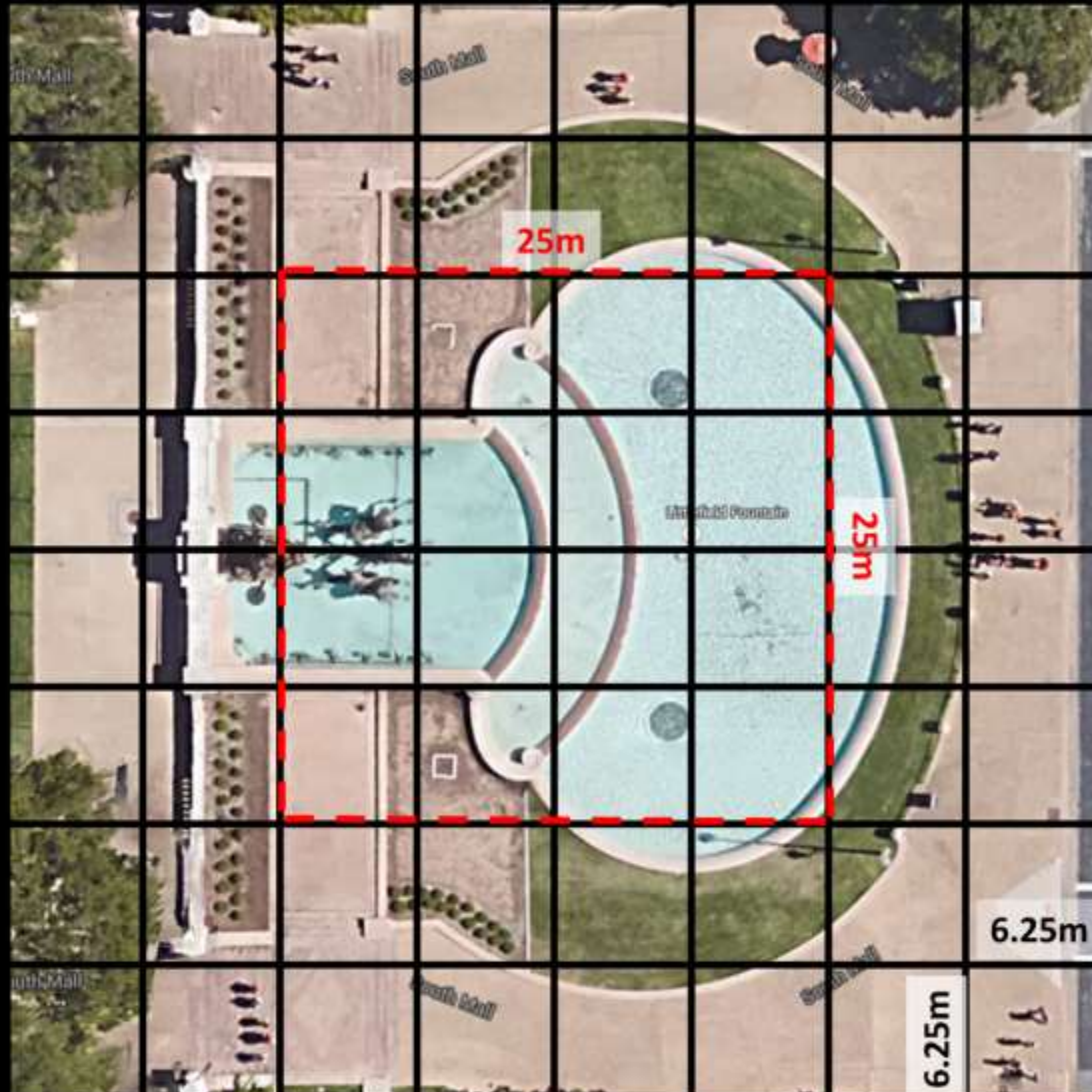
- Data examples – inspirational
  - Stratigraphy & structure
  - Gas anomalies
  - Integrated sediment coring
  - Nested geophysical observations - Faulting
  - Mass transport deposits

- [*Processing aspects*]
- FORWARD PLANS



Exploration	30 - 75 Hz
High-resolution	80 - 375 Hz
Very high	375 - 1500 Hz
Ultra-high	1.5 – 14 kHz

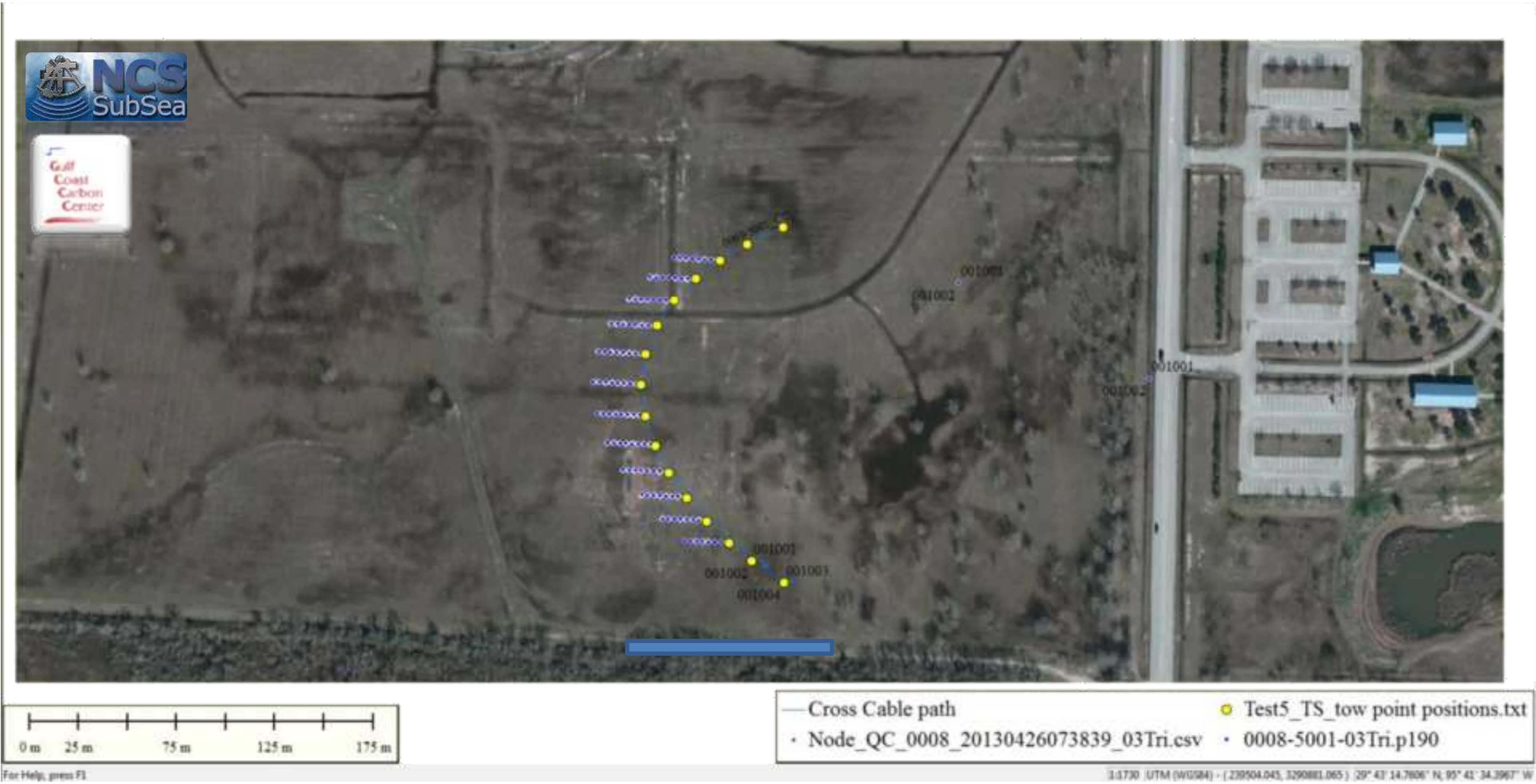
Modified from Hill et al., 2015, Leading Edge
http://dx.doi.org/10.1190/tle34040380.1


South Mall
25m
25m
6.25m
6.25m


50m
50m
50m

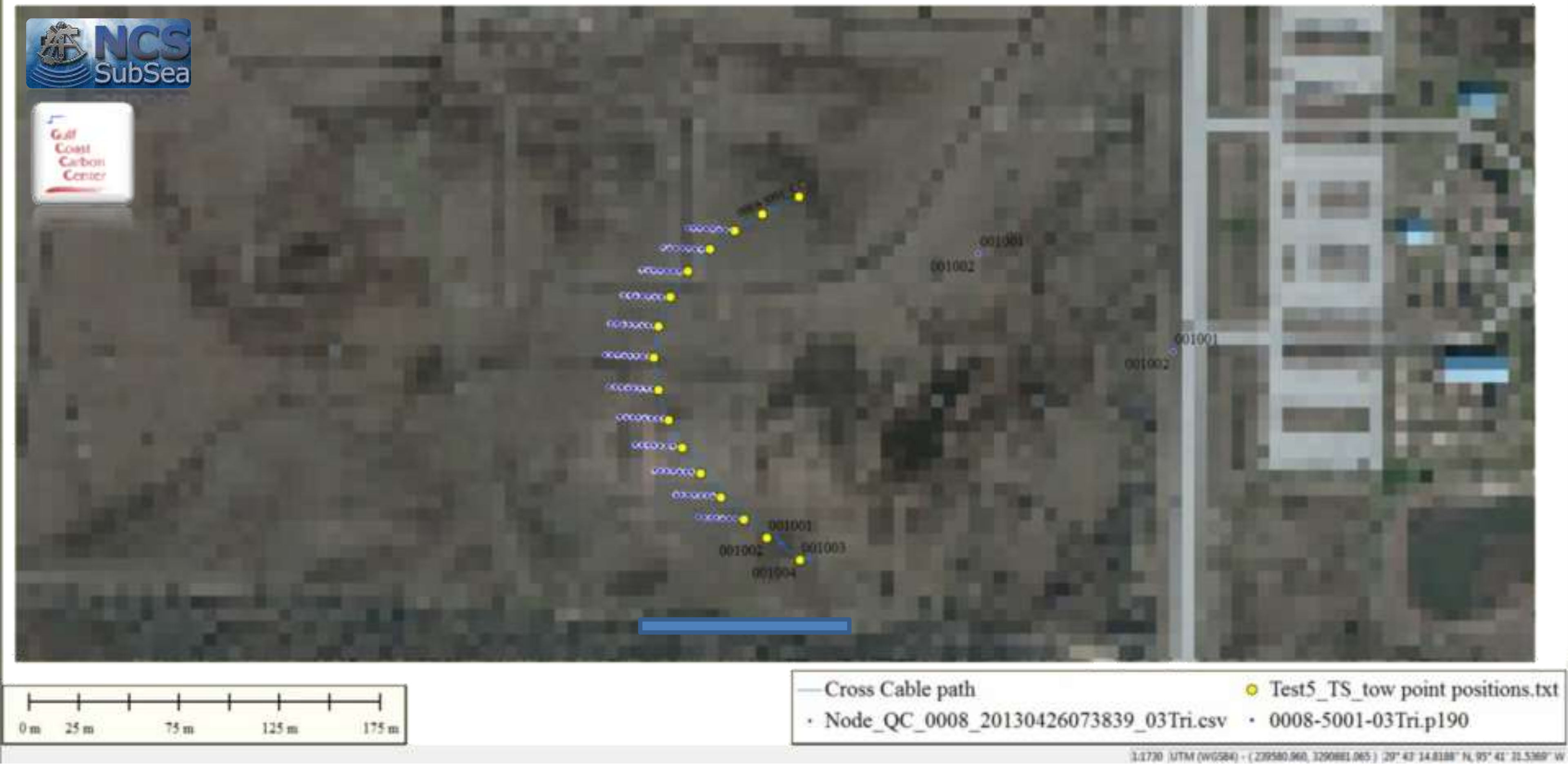
REC Position Accuracy

Pixels 0.5 m x 0.5 m



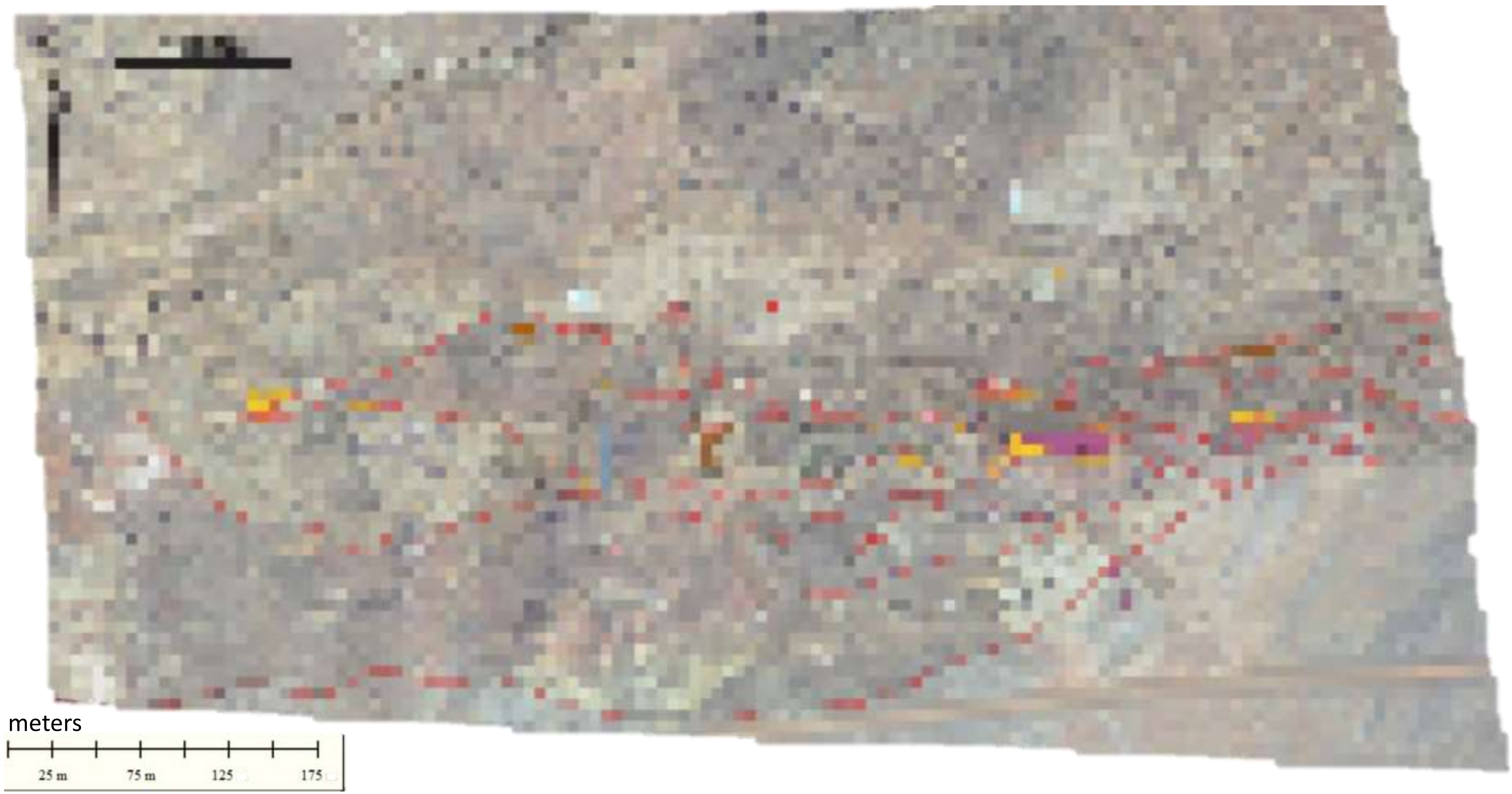
Horizontal Resolution?

Pixels 6.25 m x 6.25 m
Survey bin size



Urquhart (2011) MS Thesis, UT-Austin:
Structural controls on CO_2 leakage and diagenesis in a natural long-term carbon sequestration analogue : Little Grand Wash fault, Utah

Little Grand Wash Fault System:
~6.25 m pixel resolution



Those features may be visible in overburden
Function(depth, frequency, Fresnel Zone, Moduli, etc.)

Conventional 3D

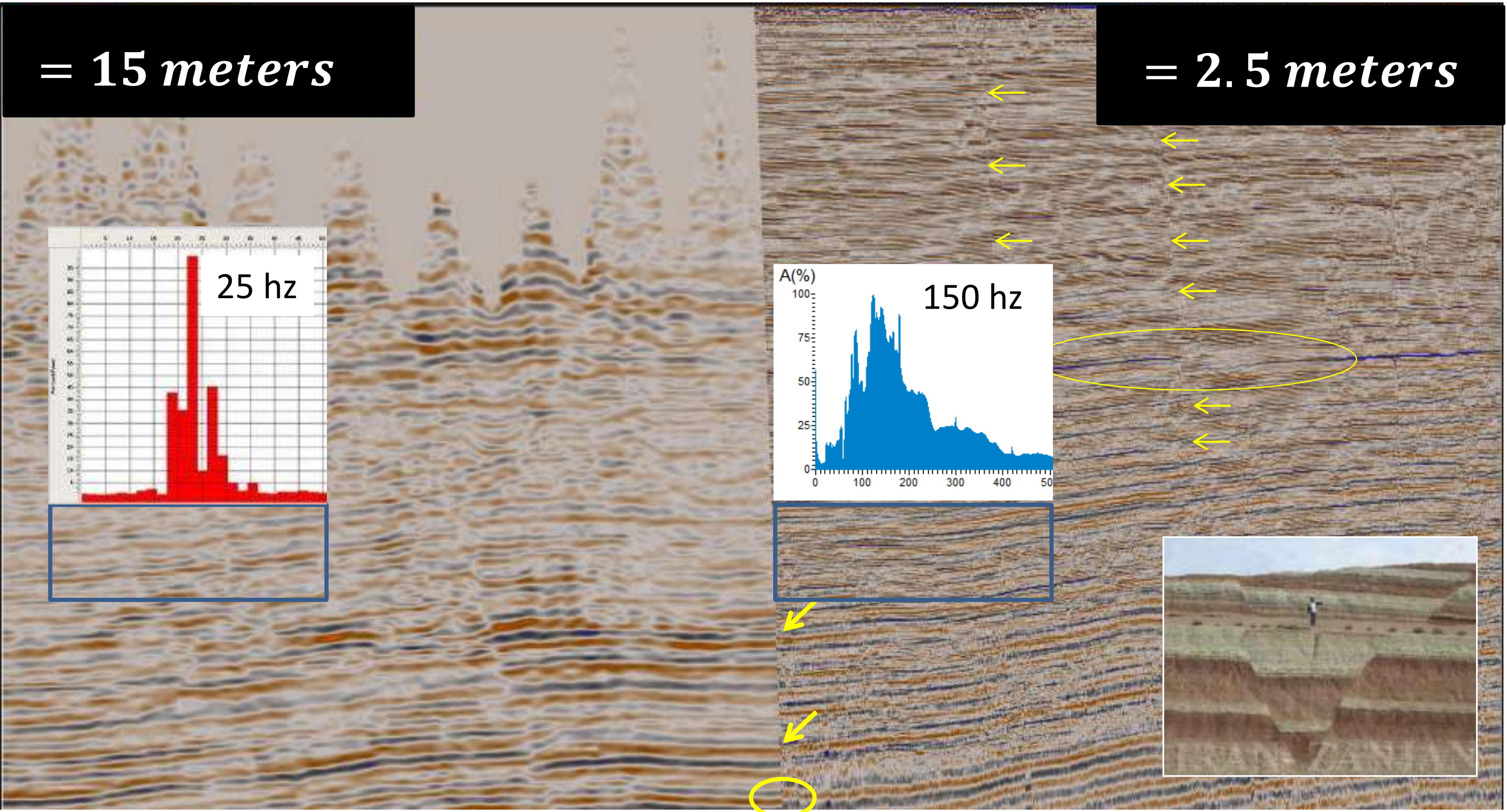
$$= \left(\frac{1}{25\ hz} * 1500\ m/s\right)/4$$

Vertical Resolution

$$= \left(\frac{1}{f} * V\right)/4$$

HR3D - PCable

$$= \left(\frac{1}{150\ hz} * 1500\ m/s\right)/4$$



Existing conventional 3D

1500 ms ~ 1125 meters depth

2012 UT Pcable HR3D

APPLICATIONS

- **Quaternary studies**

  RSL, processes, geology, etc.
- **Transition zone**
- **Geohazard**

  Fault, slump, etc. (seismicity and tsunami)
- **Geotechnical : Drilling & installations**

  Integrated JPC / CPT for 3D distribution of shallow properties.

  OBS options for velocity (shear strength).
- **Fluid Systems**

  Overburden characterization: Stratigraphy, faults, seals, secondary accumulations
- **Modern/Recent Reservoir Analog Studies**:

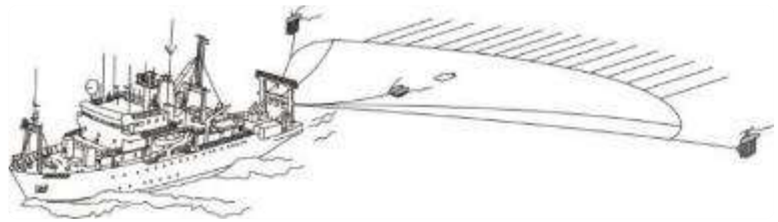
  Clastics, Carbonates
- **Monitoring**

  Acquisition (NRMS); 4D repeatability currently being explored.

  Fluid effects; Saturation changes.
- **Gas Hydrates**
- **IODP**

See also:
Near Surface Geophysics
V 15 #4
Applied Marine Geophysics

P-Cable Development History



2001: P-Cable concept testing

2004: P-Cable1 prototype; patent

2006: P-Cable2 system / 24 streamer digital system

2007: P-Cable2 Peon survey; better resolution than conventional 3D

2008: P-Cable 3D Seismic established

2009: Commercial P-Cable2 data on Peon , Statoil (188 km^2)

2010: P-Cable3 tested

2011: Commercial P-Cable3 sales

2011: P-Cable3 Snøhvit survey

2011: P-Cable3 San Luis Obispo survey

2012-14: Three UT GoM surveys 137 km^2

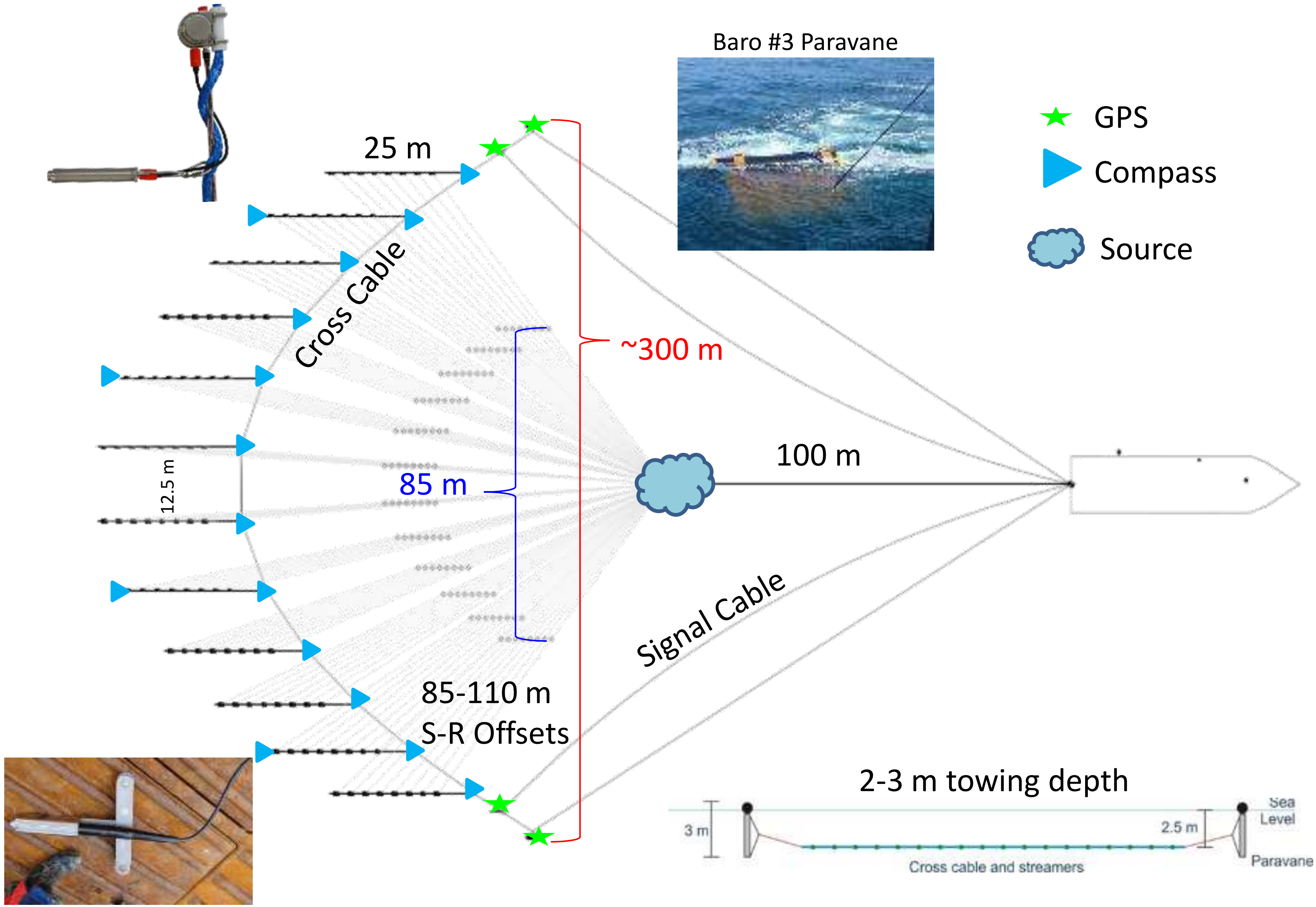
2014: NCS, WGP commercial system orders

2015: NCS GoM SAFEBAND

2016: NSF Langseth – New Jersey Shelf

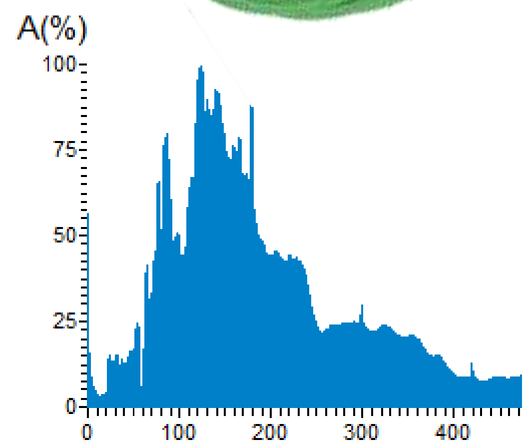
~6 active 'systems' globally; >70 surveys

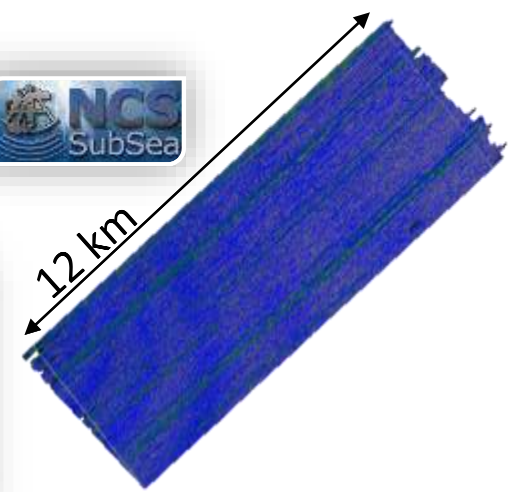
Geometry Detail: UT System



UT System/Survey Specifications

- Water Depth = 10-15 m (CA, NS, NCS-SB much deeper)
- ~3-4 knots through water
- 12 streamers: GeoEel Solid
- 25 m streamer length (short offset, low fold)
- 8 Channels per streamer (3.125 spacing; 96 total)
- Streamer separation: ~12.5m
- CC compasses for orientation, positioning.
- Source: 90-420 in^3 Sercel GI (compressed air)
- 12.5 m shot spacing (6.25 m^2 bins, 4 fold)
- Dominant frequency: 150 Hz (50-250 Hz typical)
- Coverage and positioning: 3rd party navigation hardware/software with proprietary processing



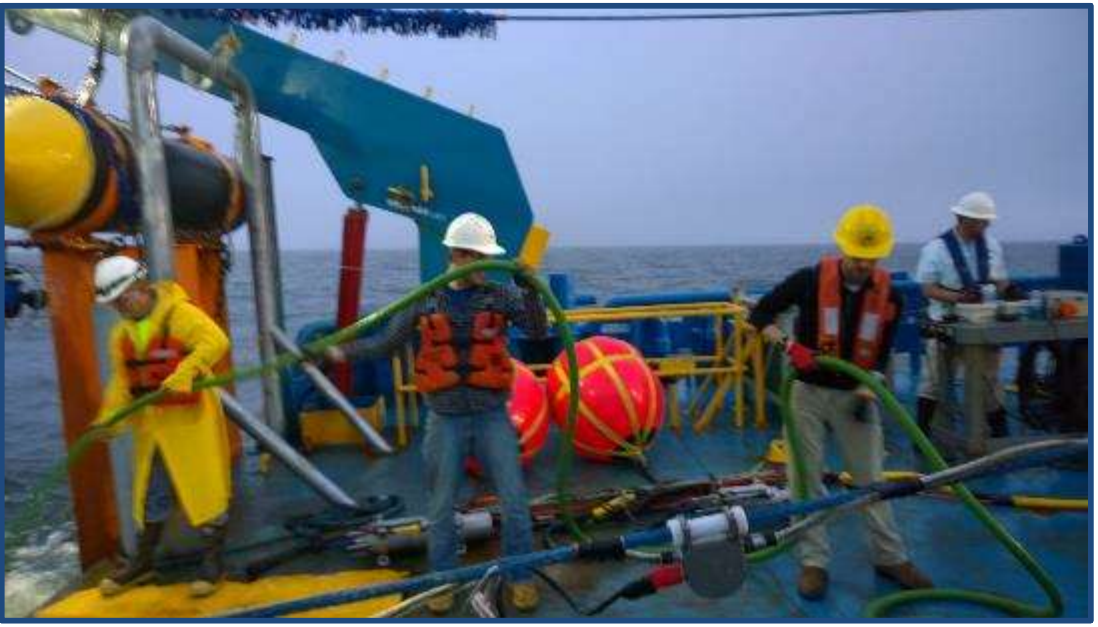


No ITAR restrictions

Yes MMOs

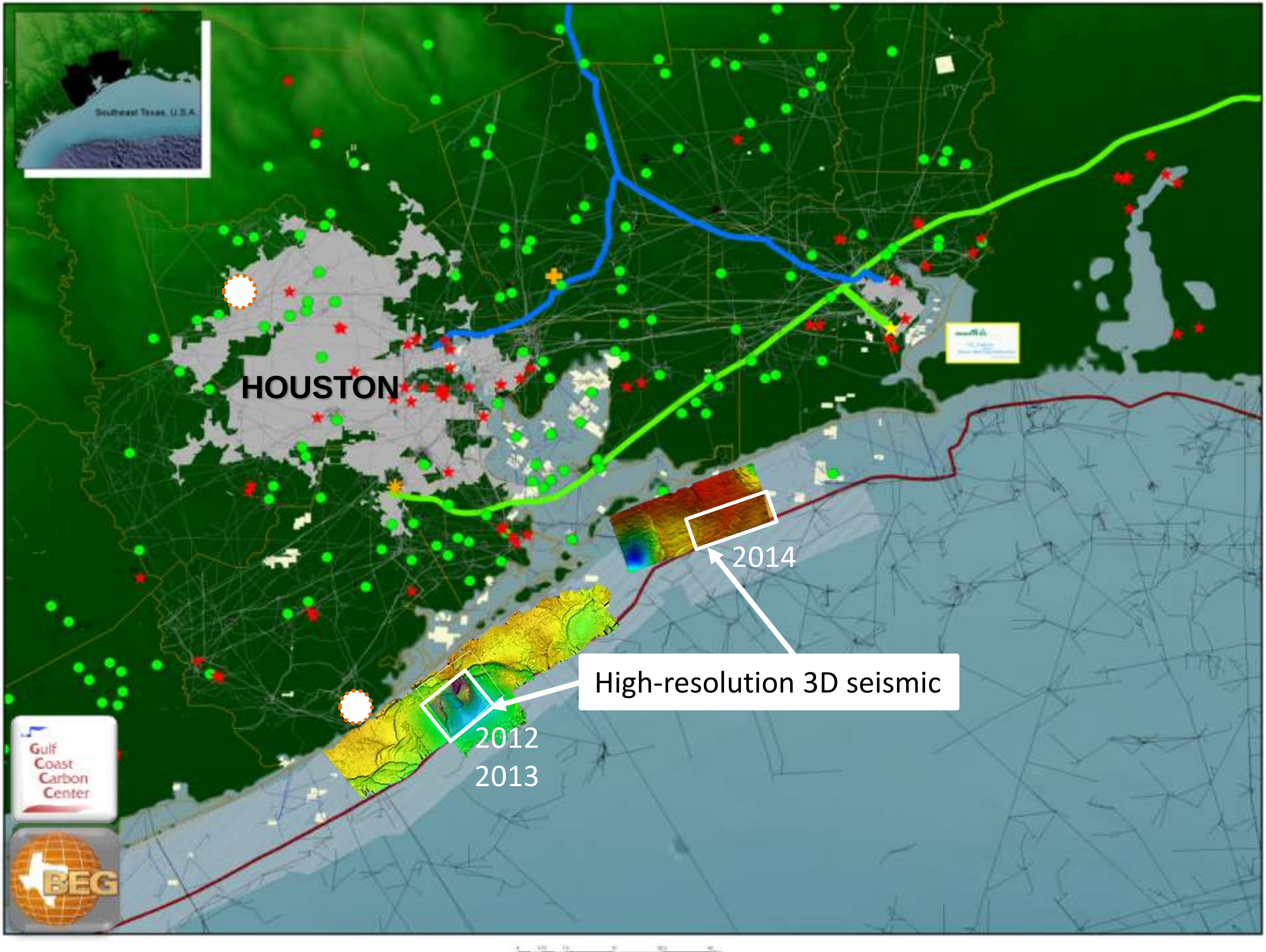
HSE Aspects

- No unique operational HSE considerations
- High tension, pressure, electricity, deck wash.
- Solid core streamers (no oil; permitting)



Streamer deployment involving graduate students

Leave some things to the professionals!



Southeast Texas, U.S.A.
HOUSTON
2014
High-resolution 3D seismic
2012
2013
Gulf Coast Carbon Center
BEG

OCTOBER 2013 and April 2014

R/V Brooks-McCall **based out of Freeport, TX**

50 m length, A-Frame

Primary operations: Sediment coring

Portable air compression
Four 100 scfm units

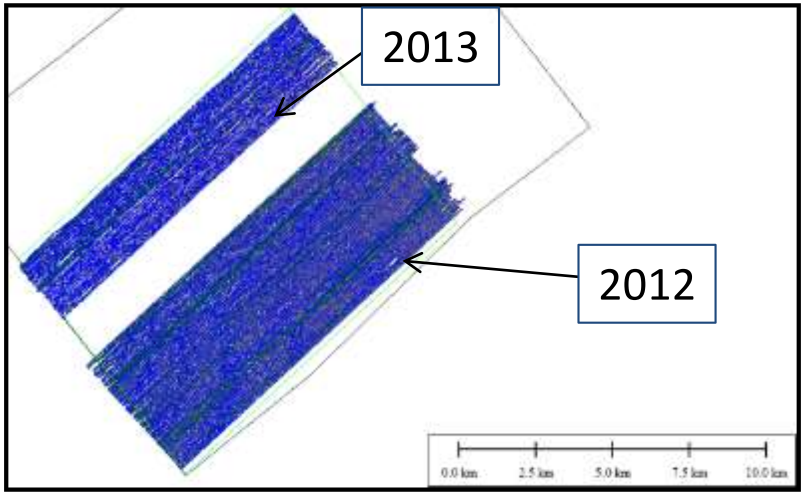

Sources
Starboard Paravane
Port Paravane
Cross Cable
Data Cable
Streamers
Tow Winch
Tow Winch

2013 Survey: San Luis Pass, TX

Photo by Eddie Tausch, courtesy of TDI-Brooks, Int.

Example Survey Statistics

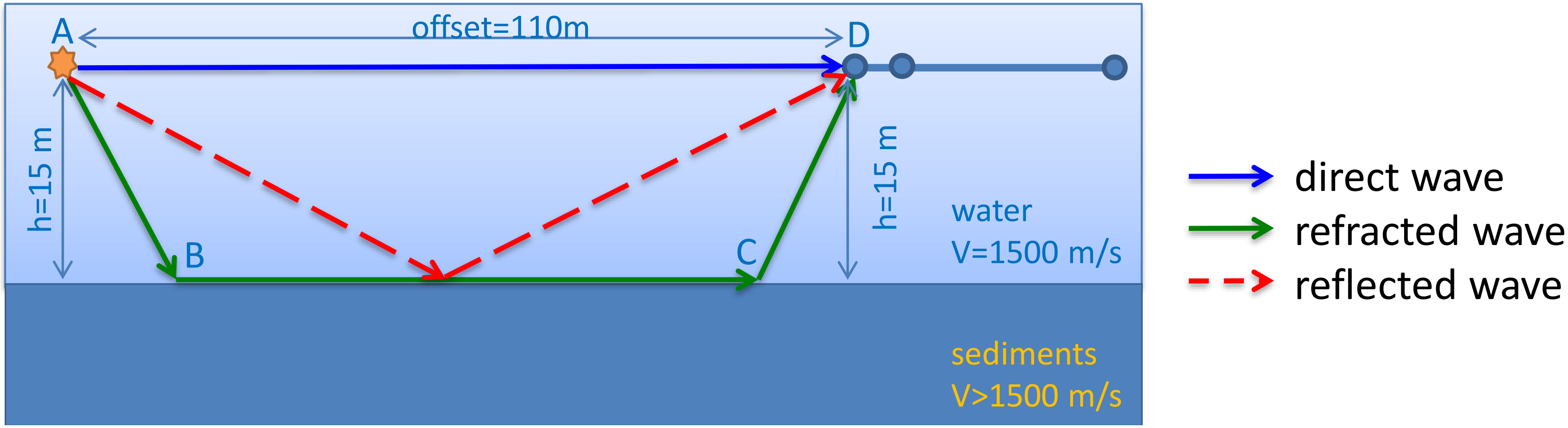
- GLO Permitting to date (weeks, MMO)
- 24 hour operations
- 27 crew aboard
  - 5 science (acquisiton / QC)
  - 6 support (Nav., guns, compr.)
  - 3 environmental monitors (MMO)
  - 13 ship crew
- 2-3 day mobilization (welding, etc.)
- Deployment/Recovery: 2-3 hours
- Data collection: 5-7 sq. km / day
- 2 days demobilization

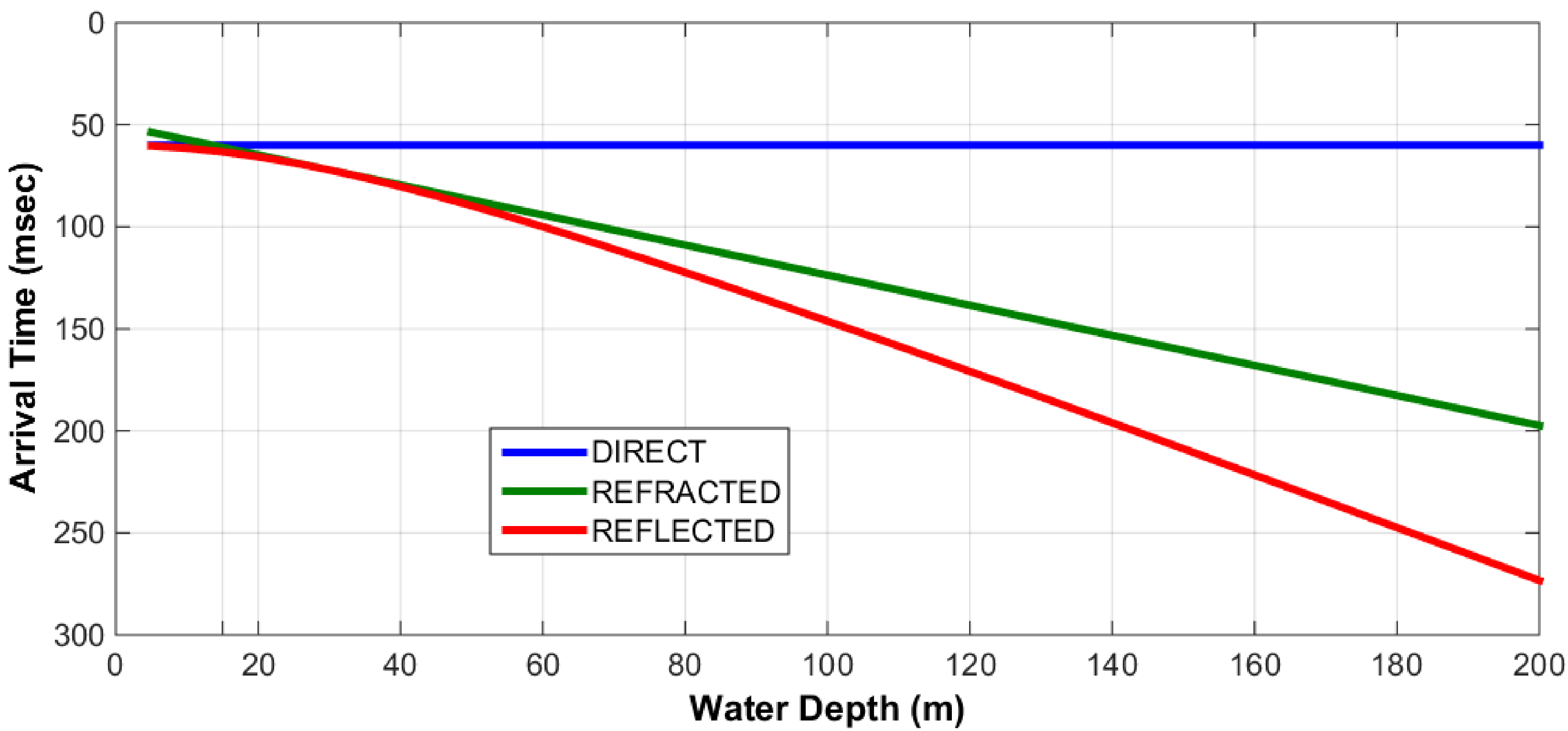


Weather issues:
Seas and GPS visibility
Deployment/recovery; streamers
3 ft seas cutoff; but NS up to 10 ft

DATE	TX LOCATION	AREA (sq. km.)	LINE KM	AIRGUN SOURCE
July, 2012	San Luis Pass	58	1,077	Two 210 cu. in. GI
October, 2013	San Luis Pass	31.5	420	One 90 cu. in. GI
April, 2014	High Island	47	627	Two 90 cu. in. GI

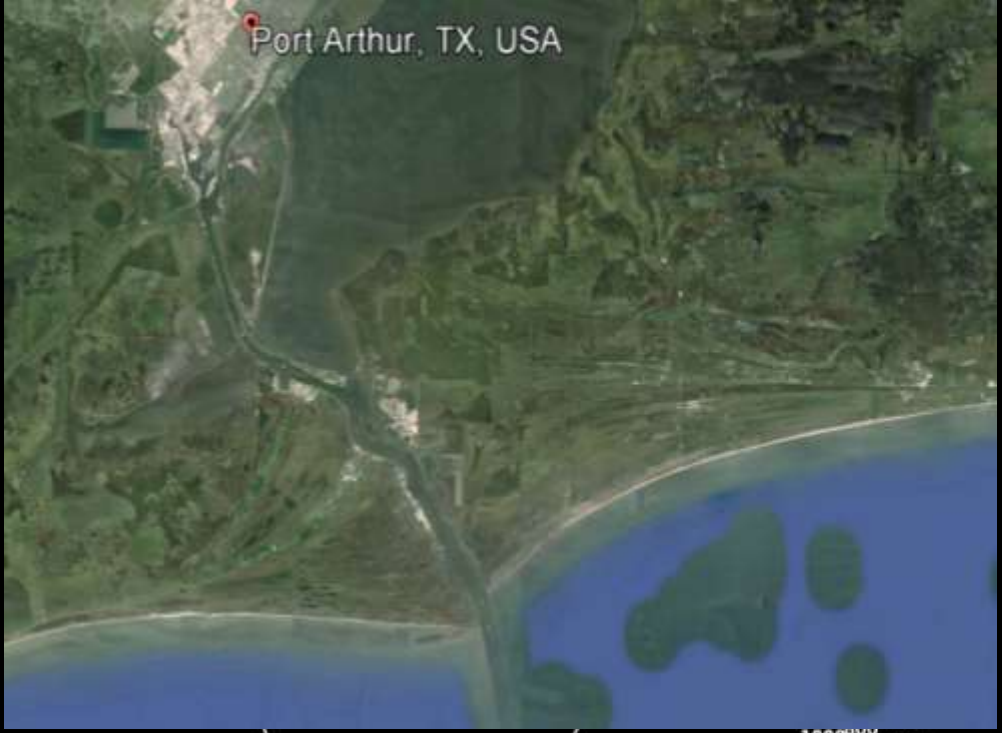
Shallow water can be challenging

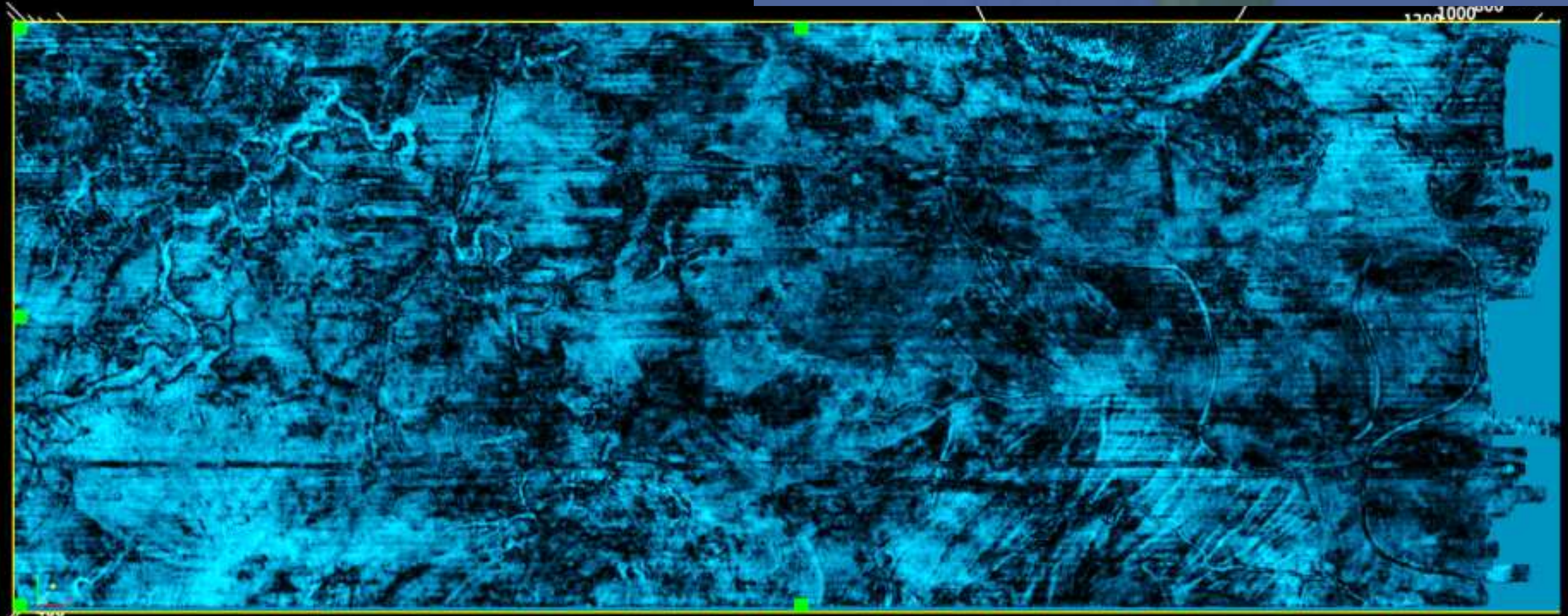




Spectral decomposition @ 500 ms 2012 dataset

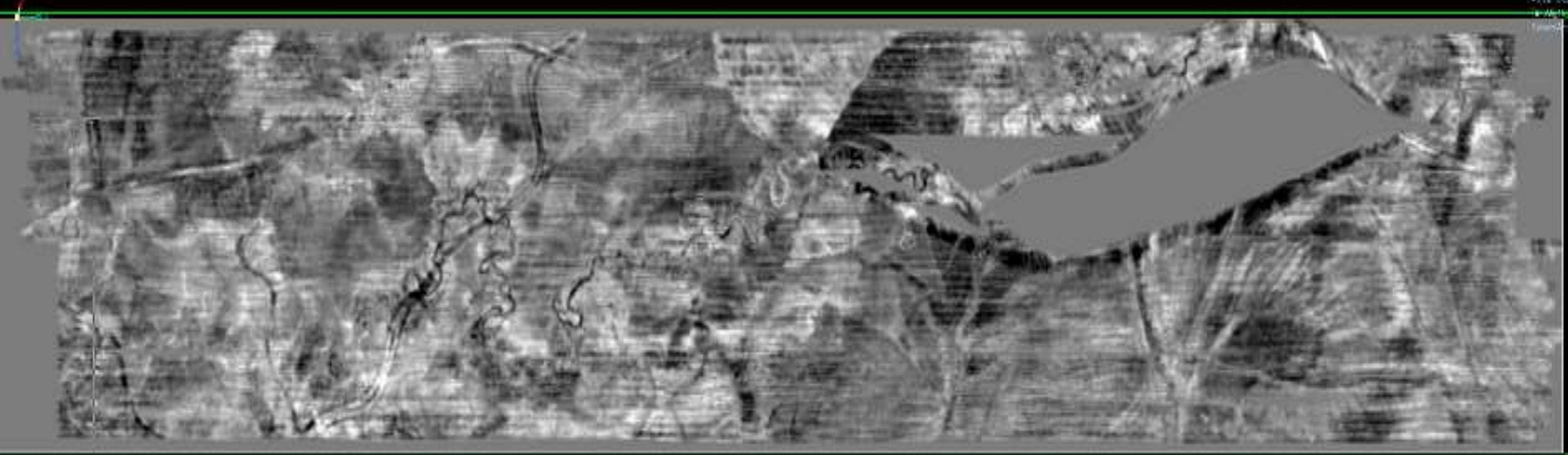
D. Dunlap, BEG



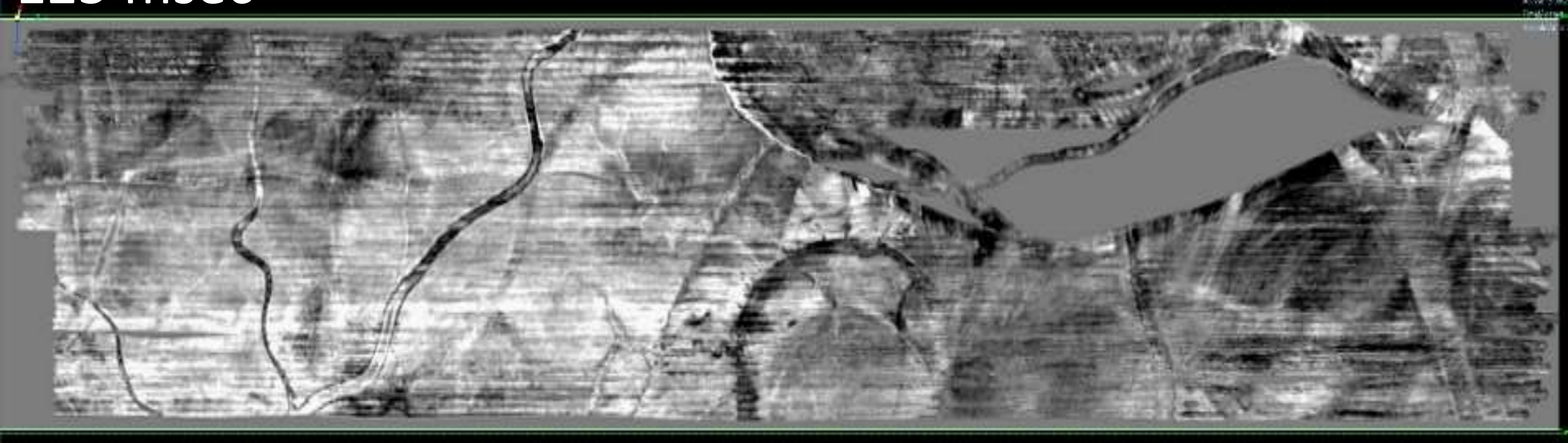


UT 2014 Pcable Survey – High Island

100 msec



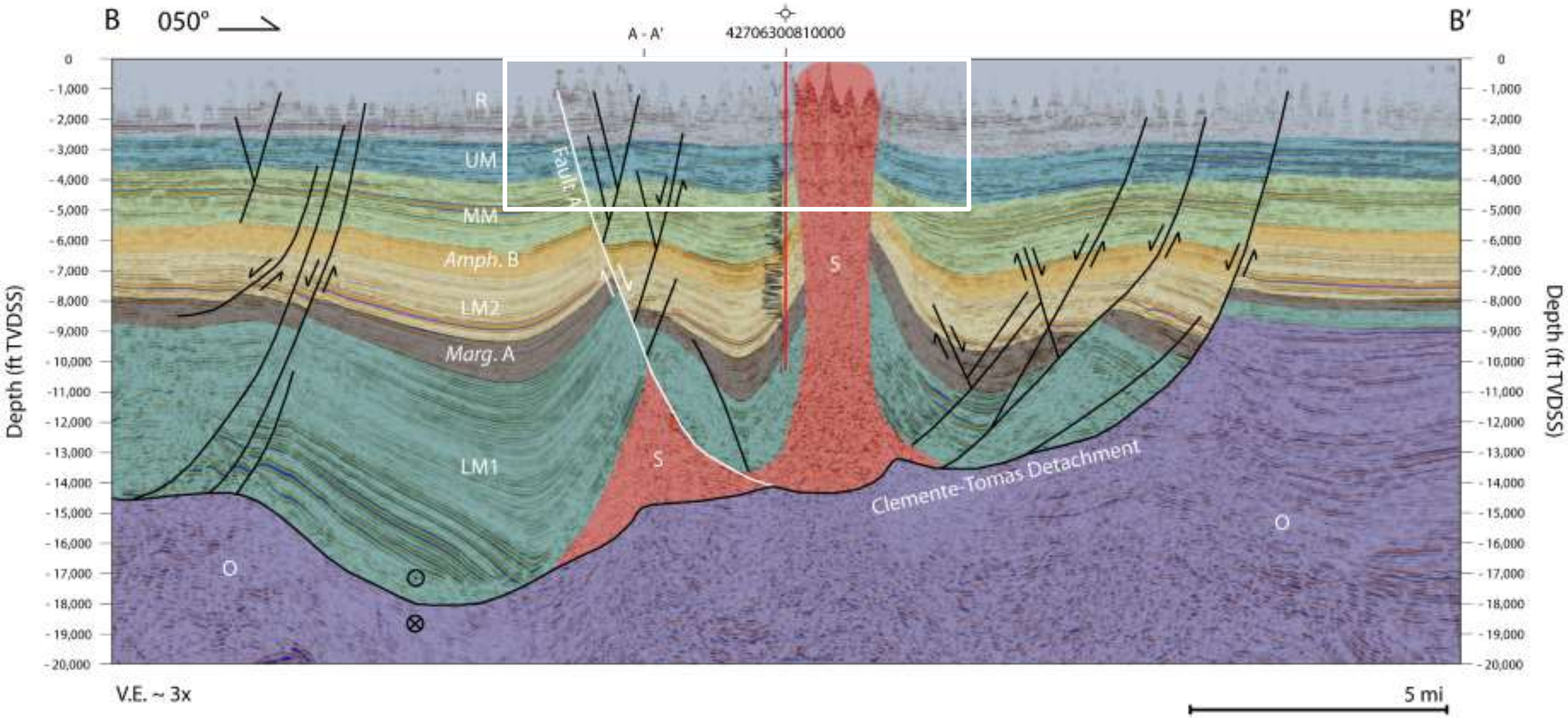
125 msec



Interpreted Seismic-Section B to B′ - San Luis Pass Area, Offshore

Figure 1.3B

B.)



Texas Offshore OBS 3-D

Key to Geologic Features and Symbols

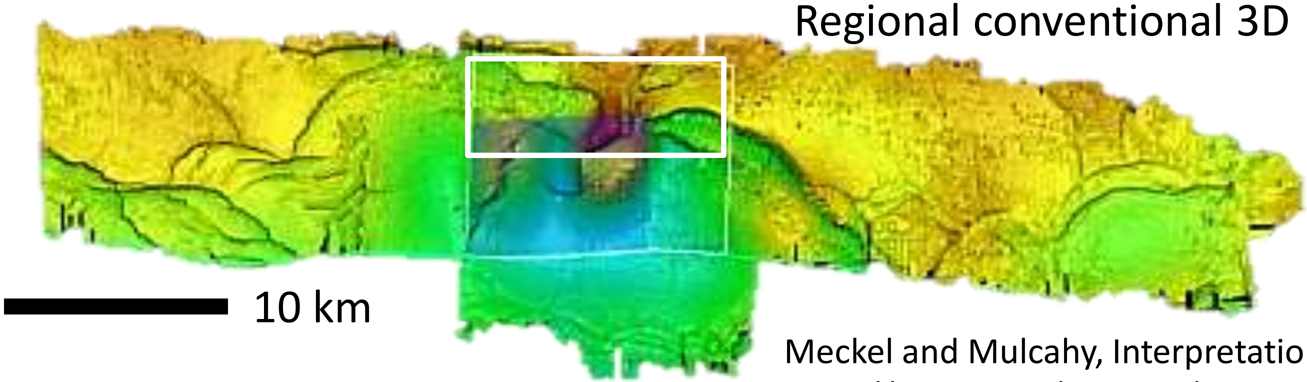
- R — Recent through Pliocene Siliciclastics
- UM — Upper Miocene Siliciclastics
- MM — Middle Miocene Siliciclastics
- *Amph. B* — *Amphestegina chipolensis* Shale
- LM2 — Lower Miocene 2 Siliciclastics
- *Marg. A* — *Marginulina ascensionesis* Shale
- LM1 — Lower Miocene 1 Siliciclastics
- O — Oligocene Anahuac Shale and Older
- S — Jurassic Allochthonous Louann Salt
- ⊙ ⊗ — Faults

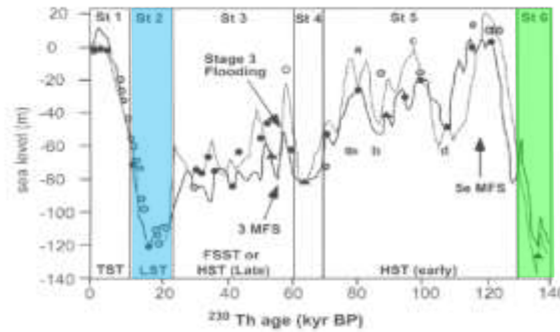
OBS Amplitude + −

SP Log - +

Osmond thesis, 2016

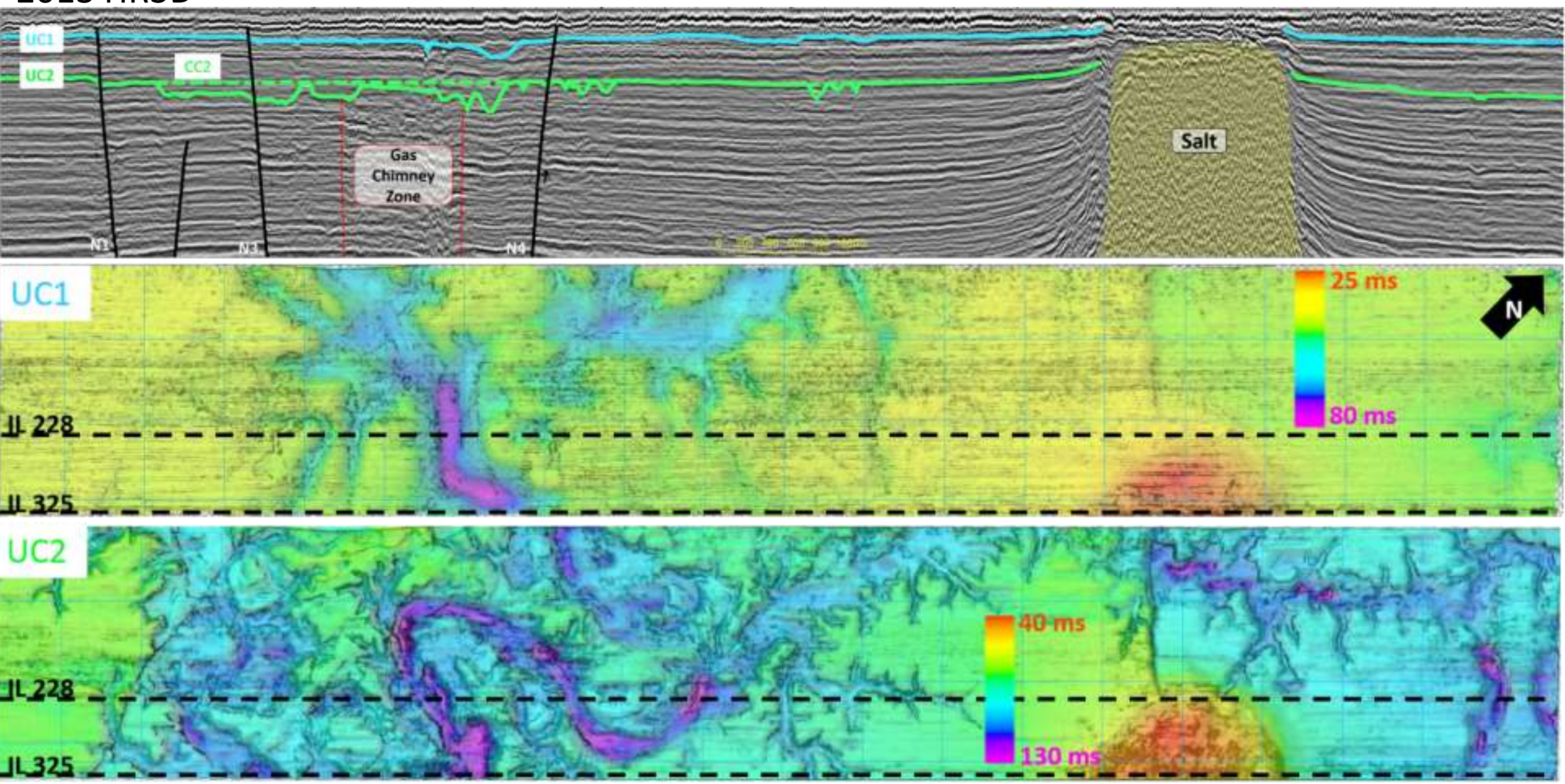
Regional conventional 3D



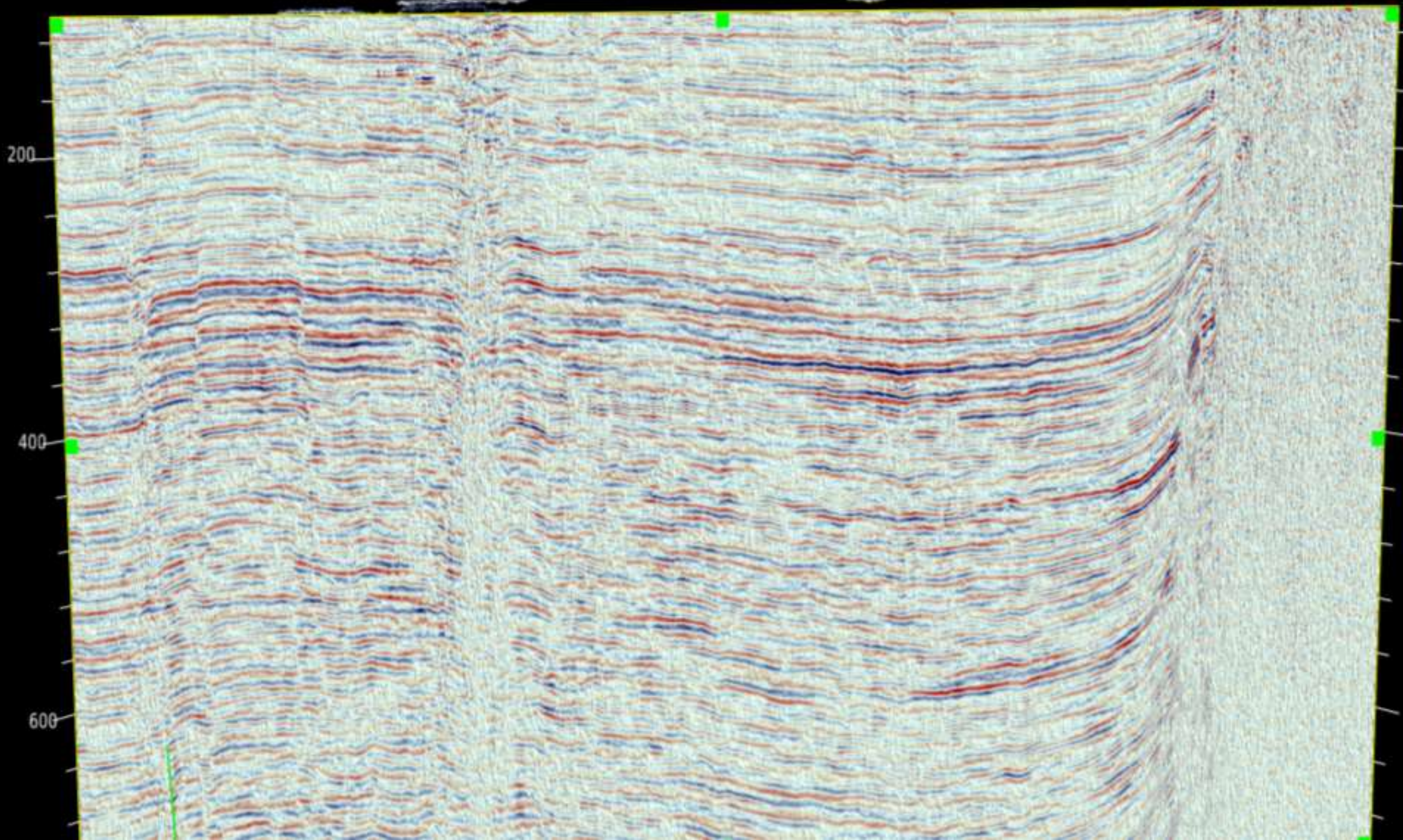


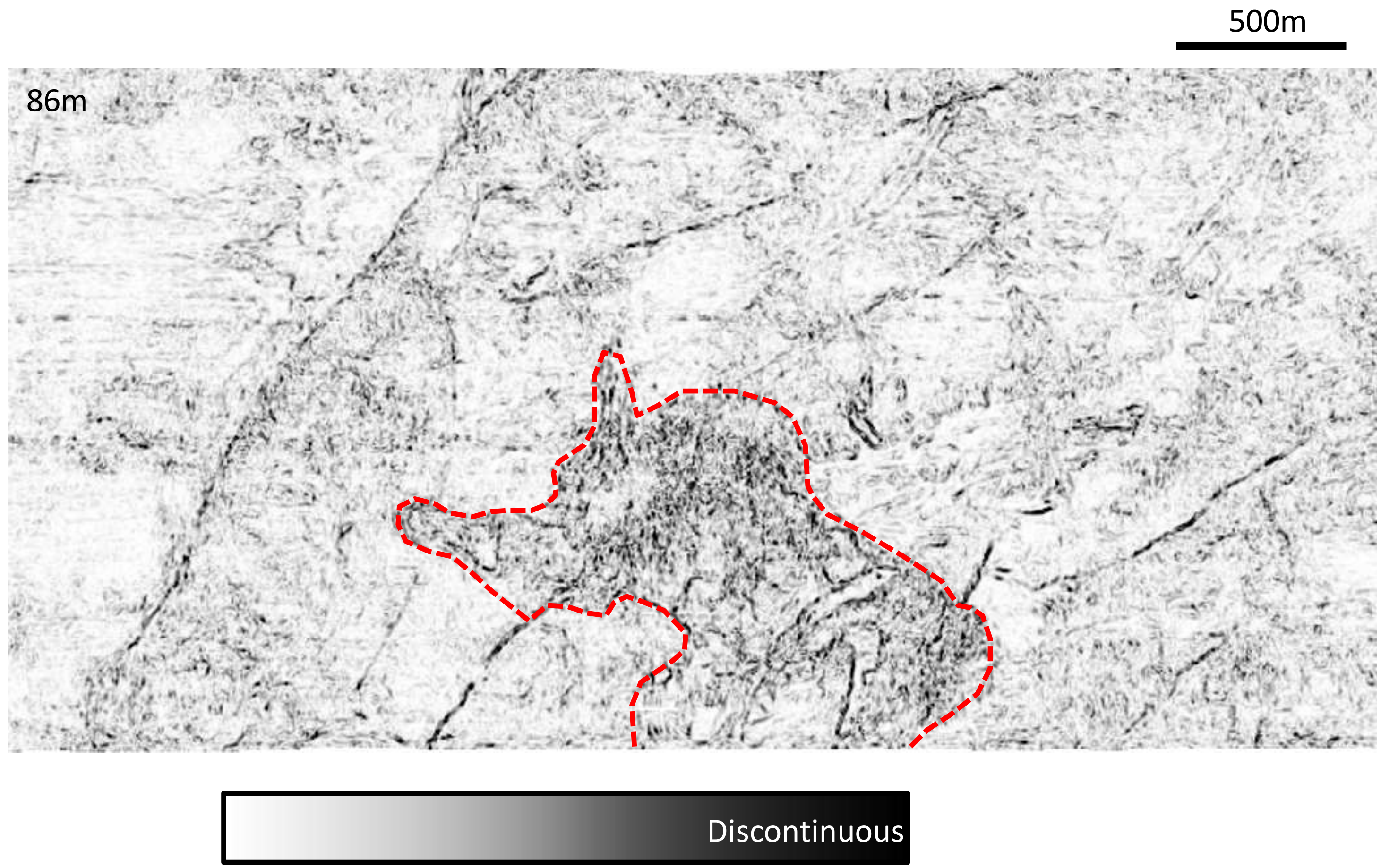
Meckel and Mulcahy, Interpretation
http://dx.doi.org/10.1190/INT-2015-0092.1

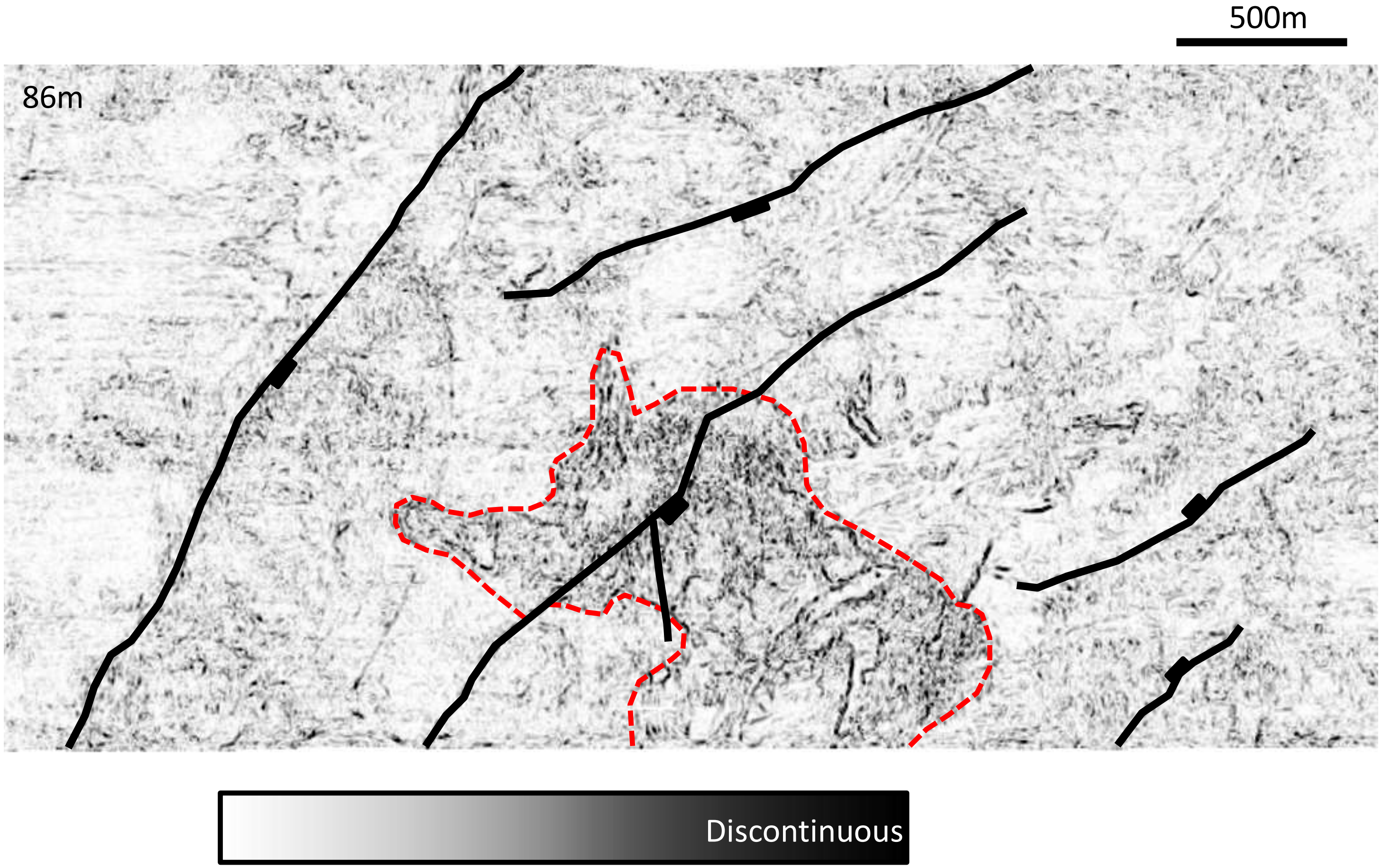
2013 HR3D



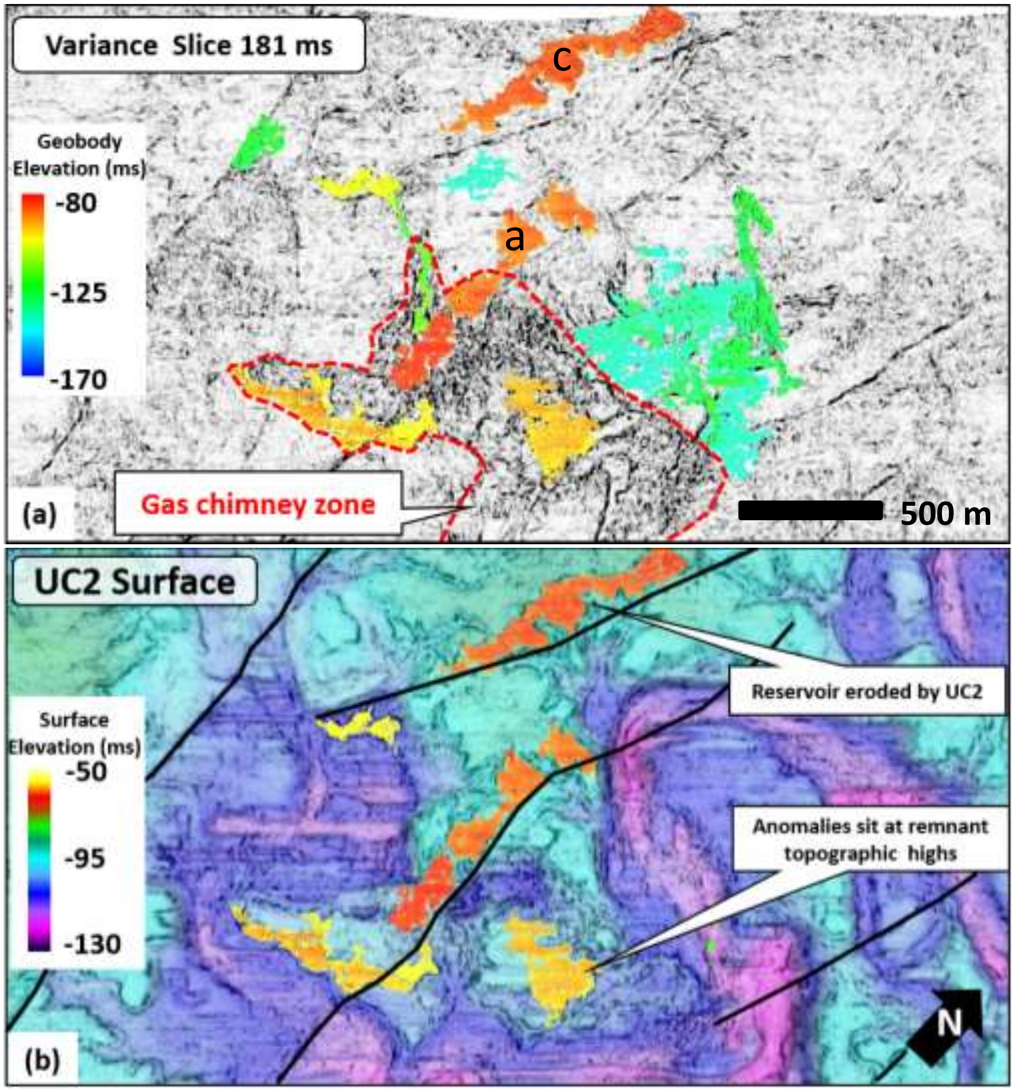
Largest anomaly is ~0.5 sq. km.

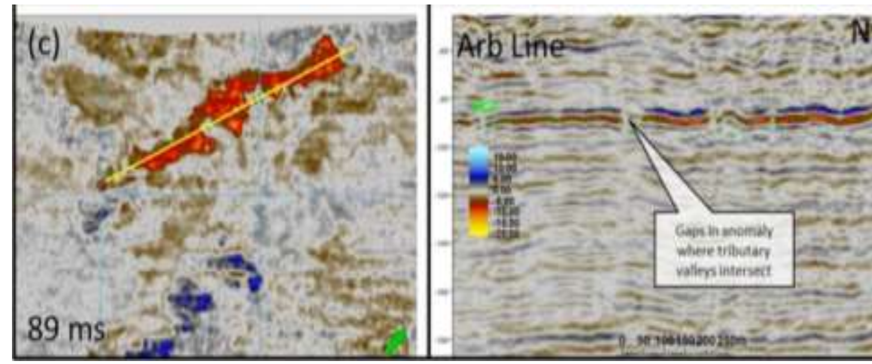


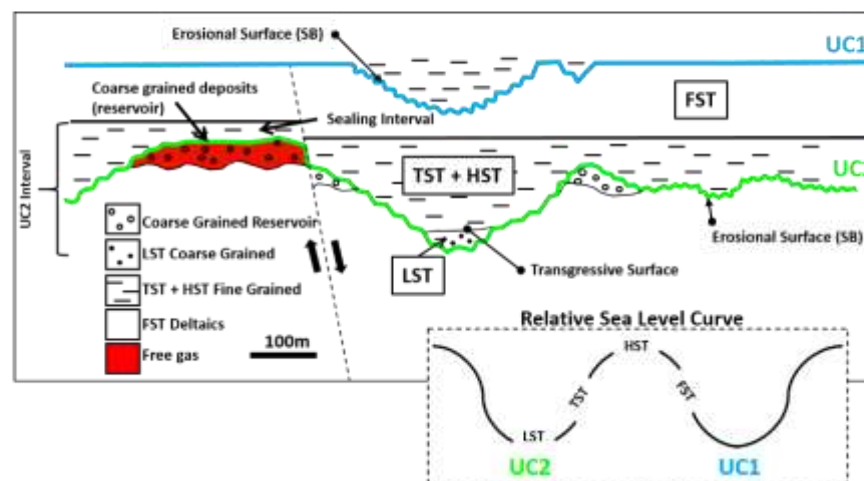

500m
86m
Discontinuous


500m
86m
Discontinuous

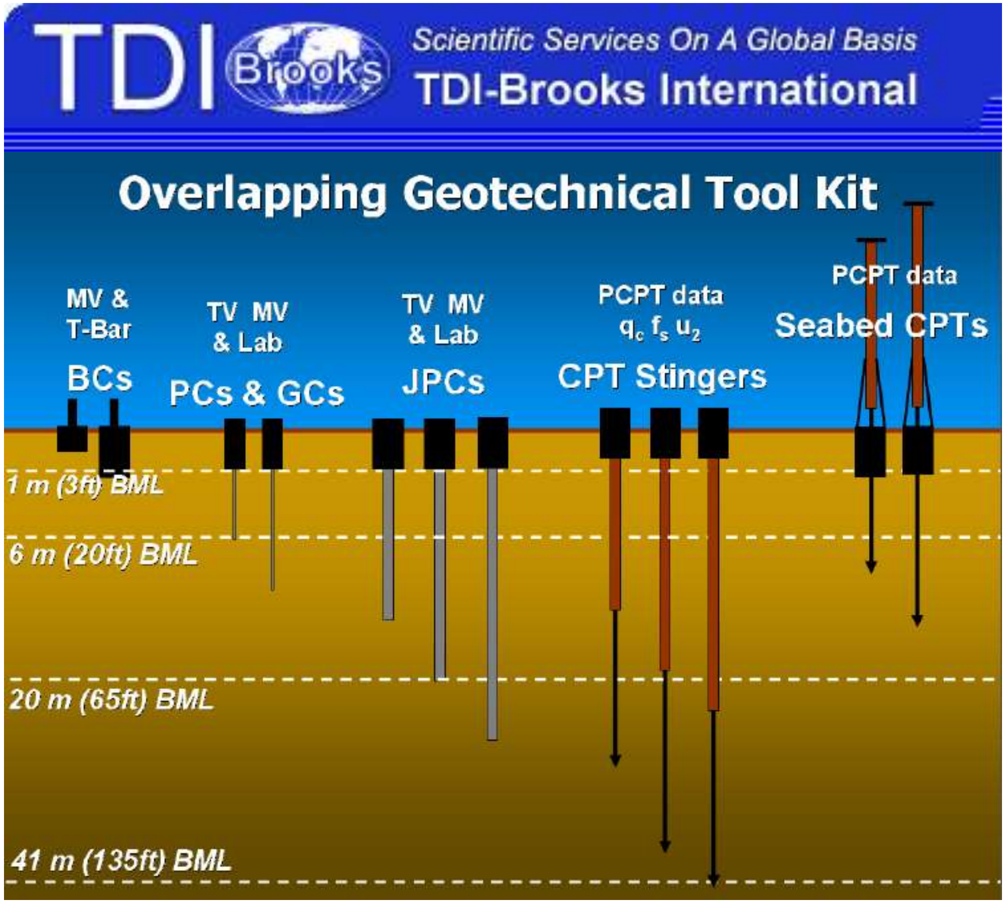
Meckel and Mulcahy, 2016, INTERPRETATION



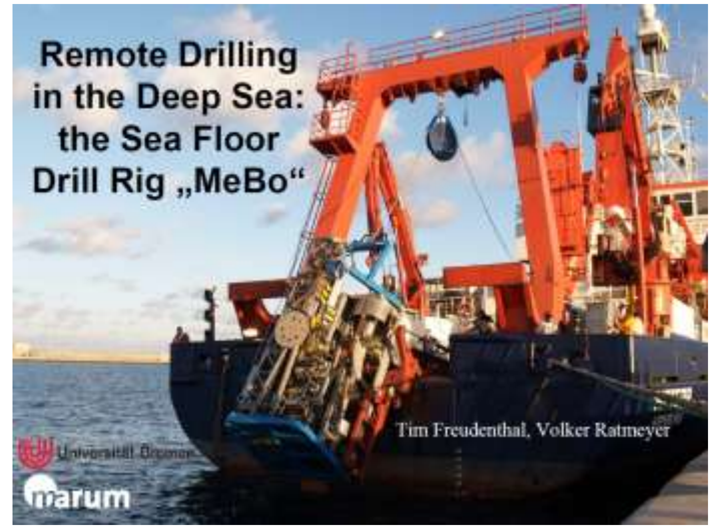




Integrated coring opportunities



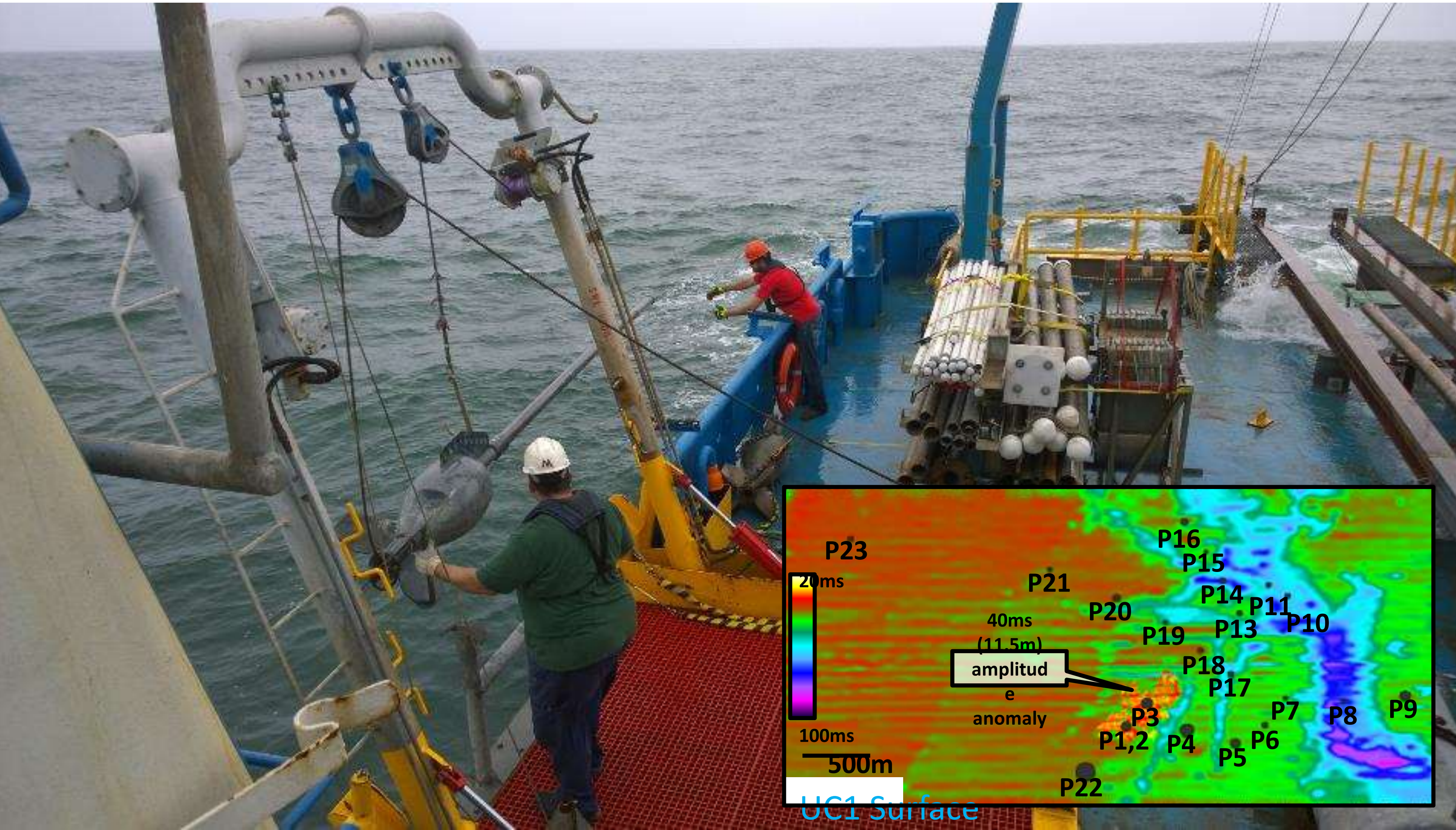
MeBo



>50 m possible; goal of deeper
Sediments & rocks
0-2000 m water depths
Transport in six 20’ containers

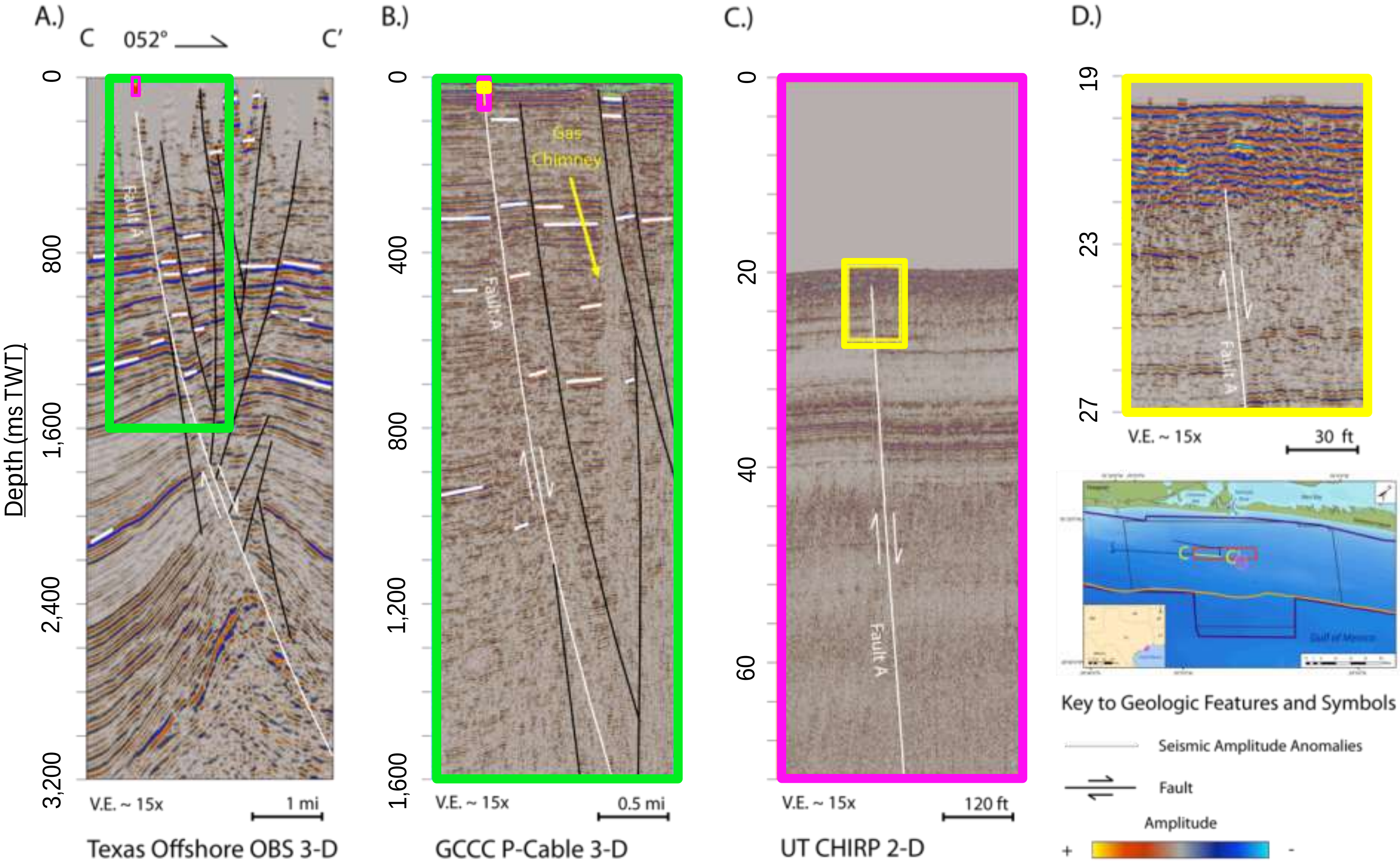
Shallow Sediment Piston Coring - San Luis Pass, TX
HR3D Gas Anomalies
February, 2015

Anderson et al., in review



Nested Geophysical Datasets

Osmond thesis, 2016



Texas Offshore OBS 3-D

Vertical Resolution: ~ 80 ft

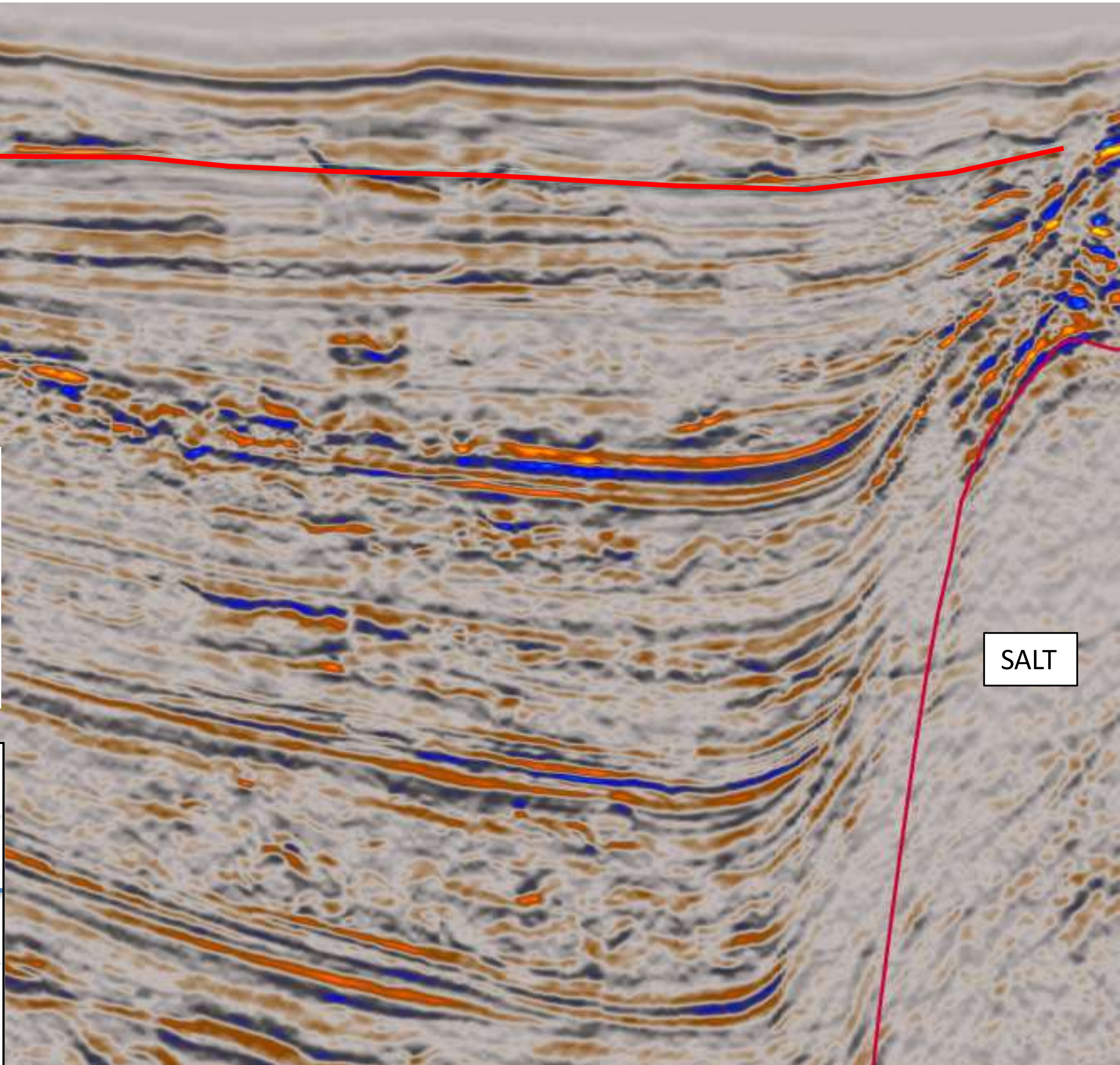
GCCC P-Cable 3-D

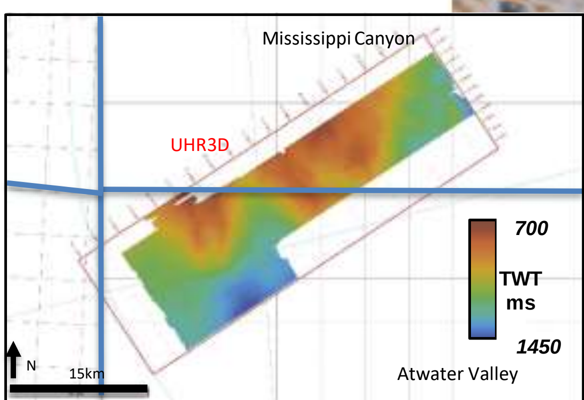
Vertical Resolution: ~ 10-40 ft

UT CHIRP 2-D

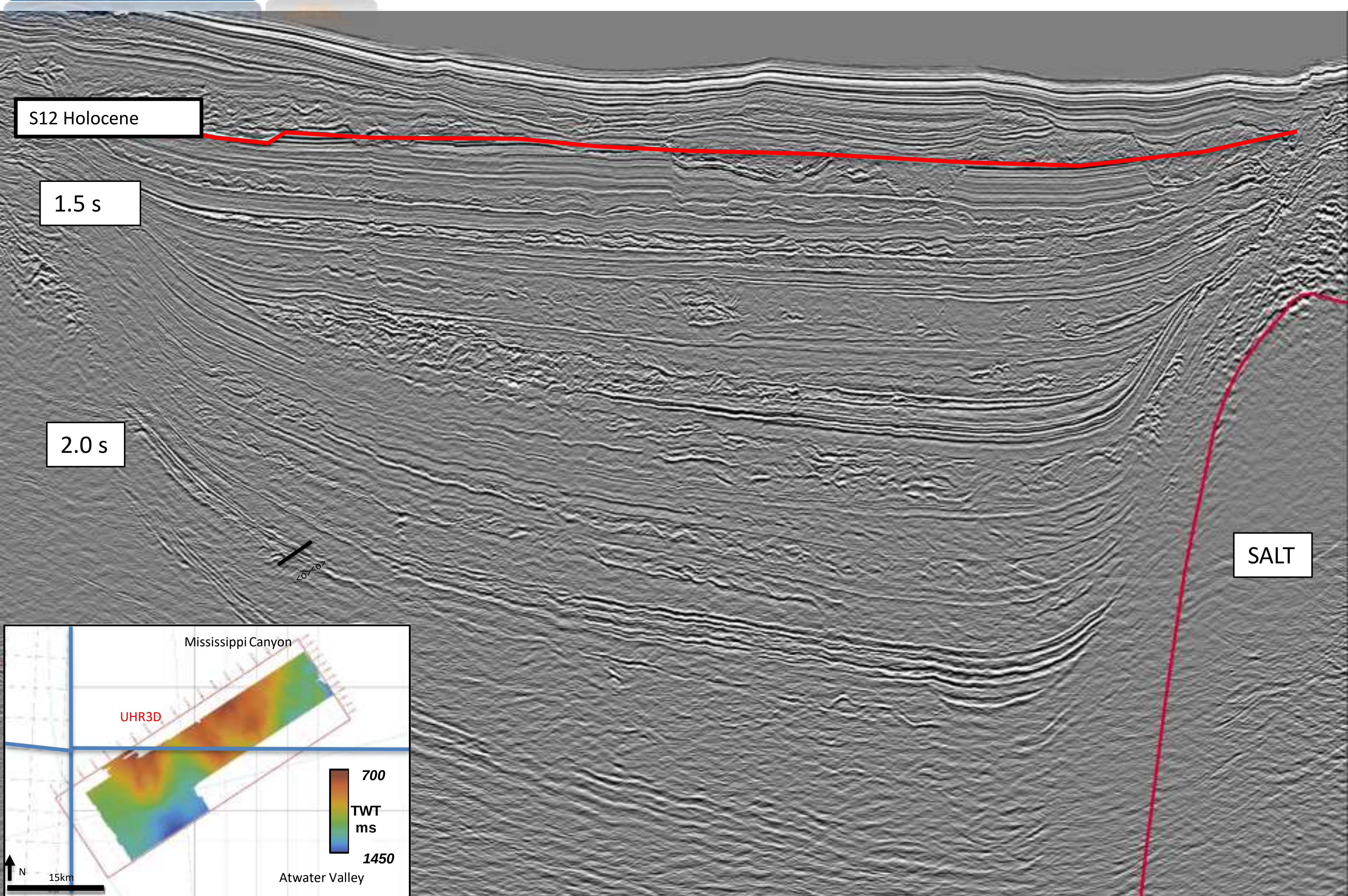
Vertical Resolution: ~ 2 in

Salt MTD Interactions

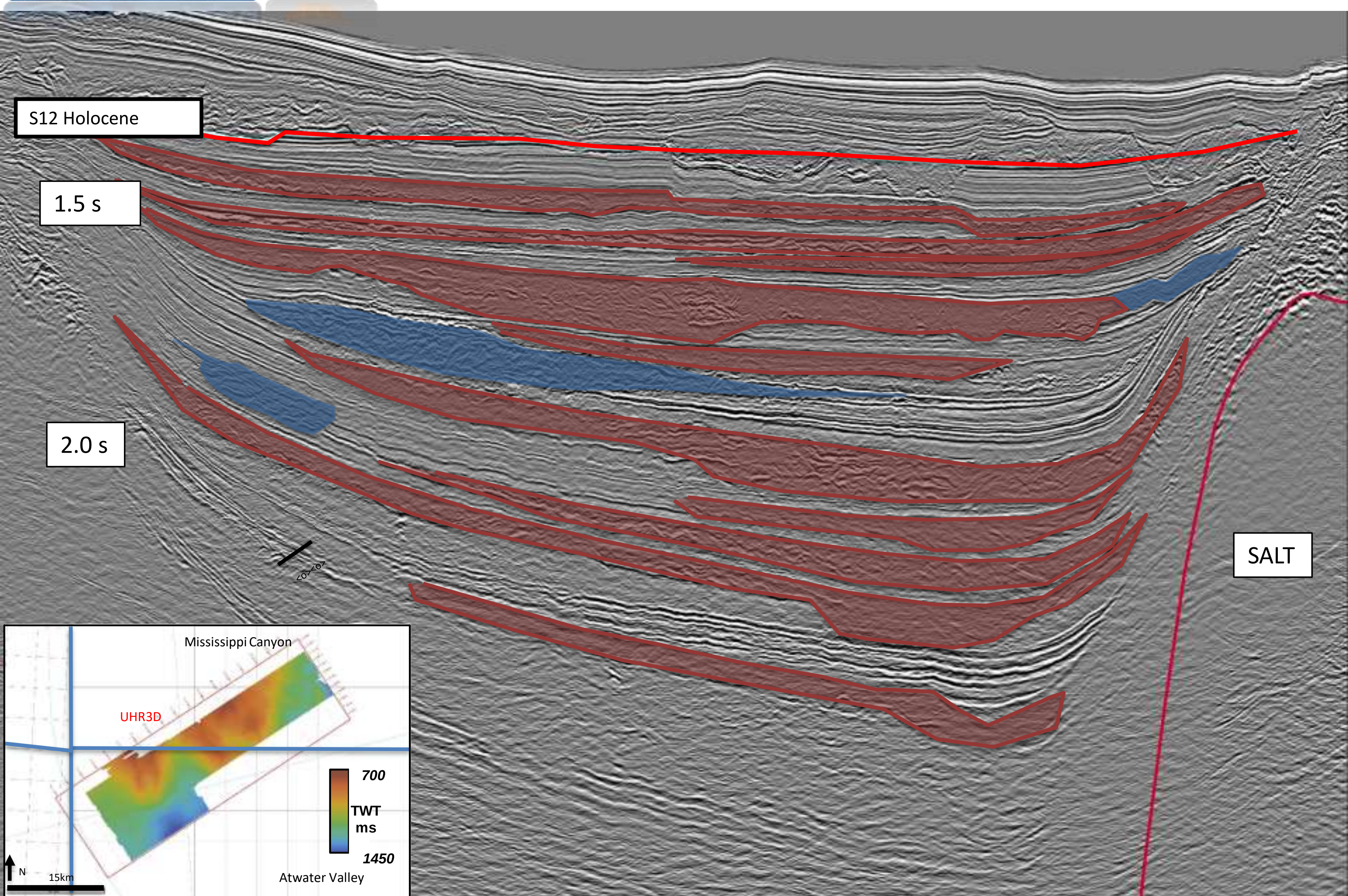




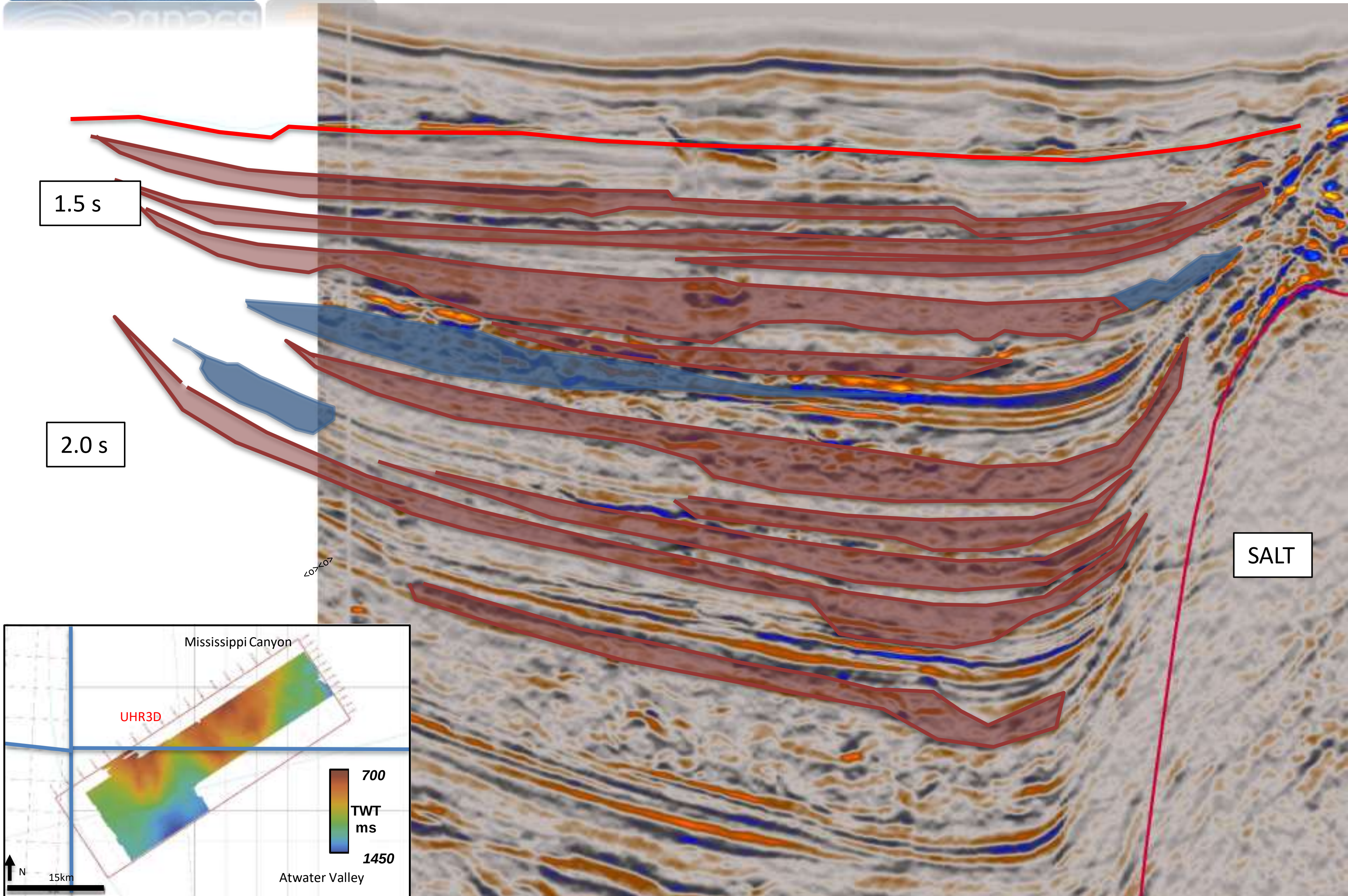
Salt MTD Interactions



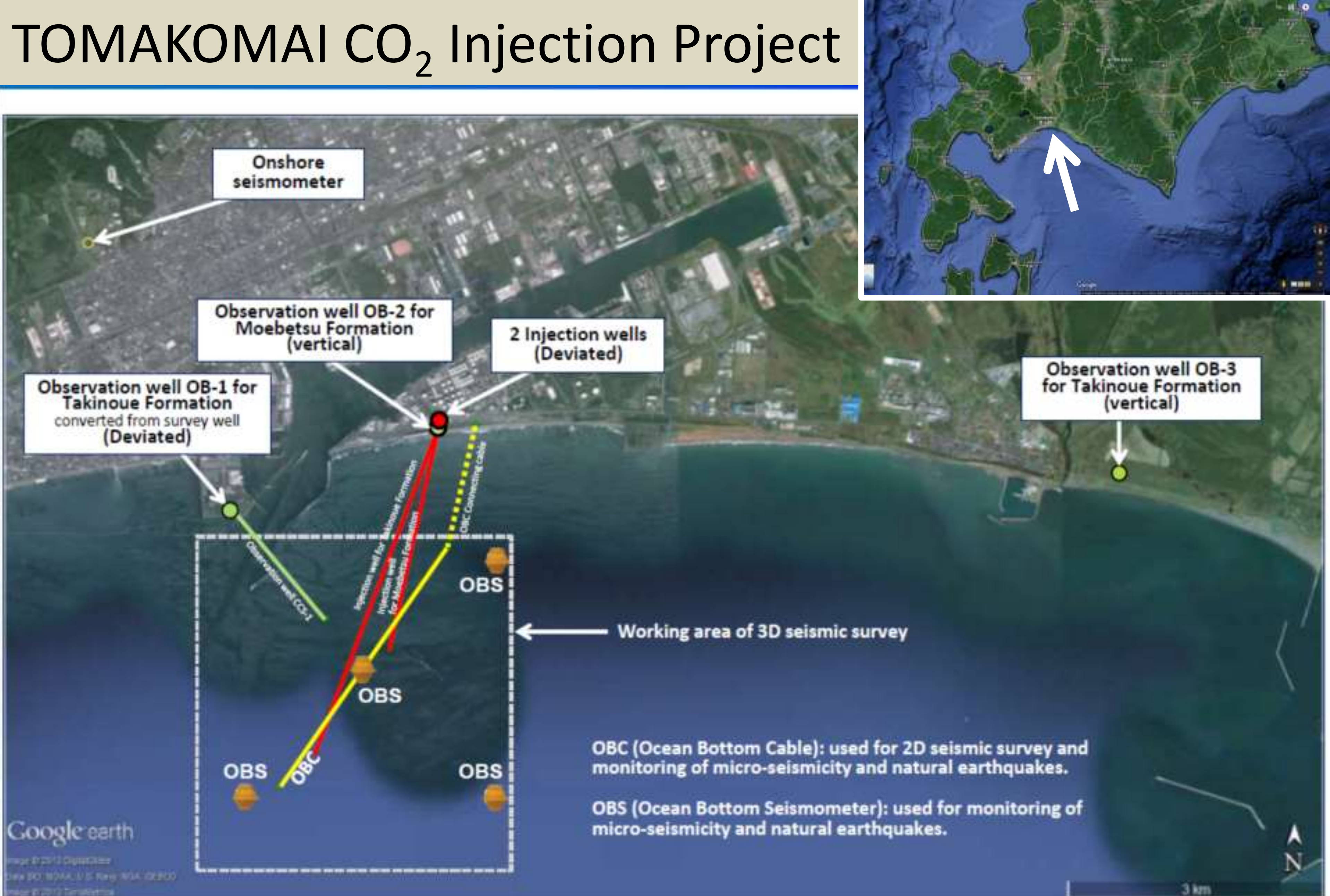
Salt MTD Interactions



Salt MTD Interactions

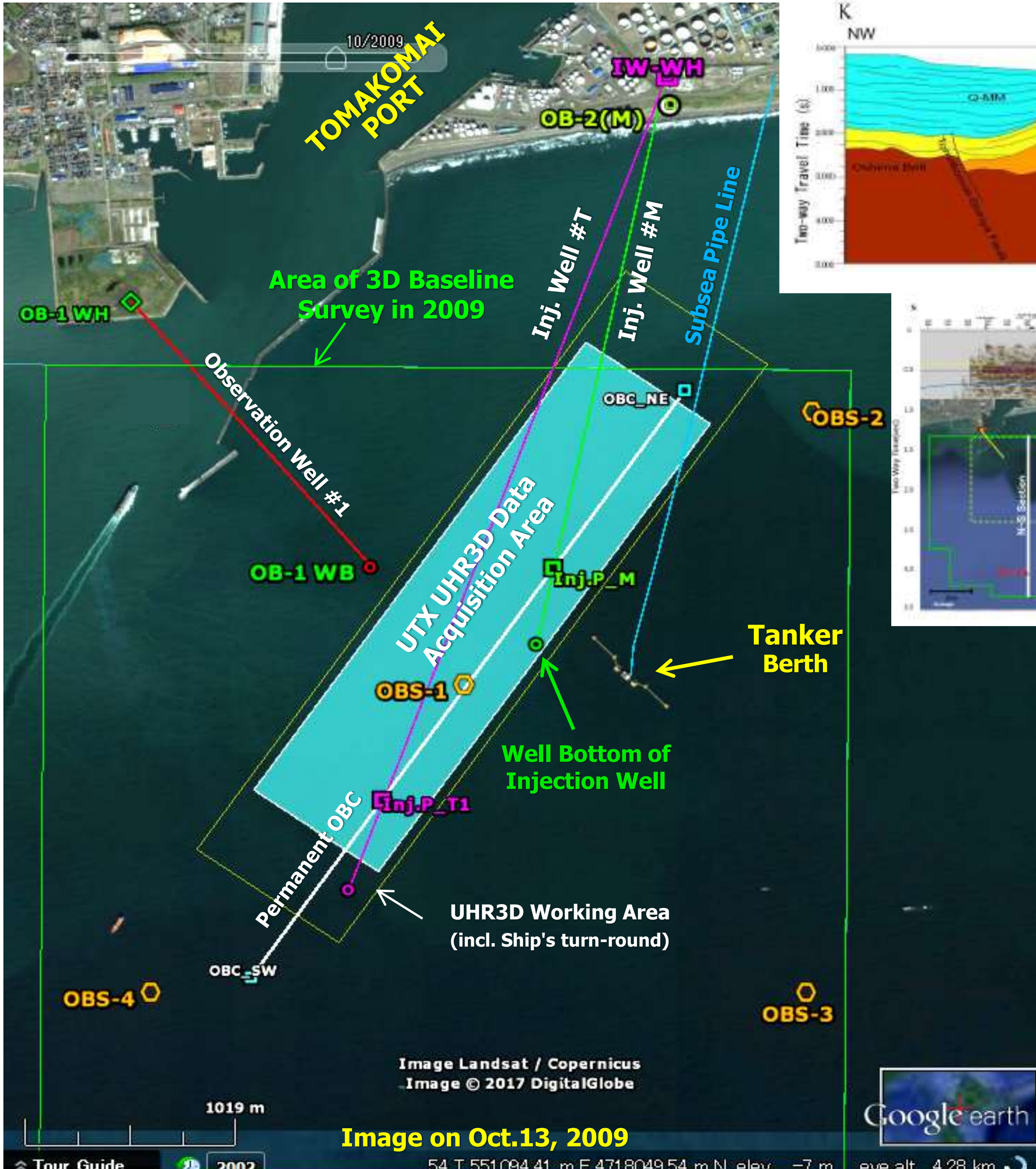


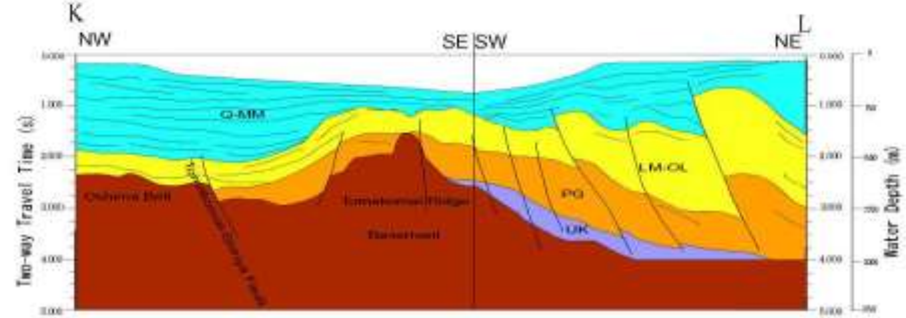
TOMAKOMAI CO_2 Injection Project

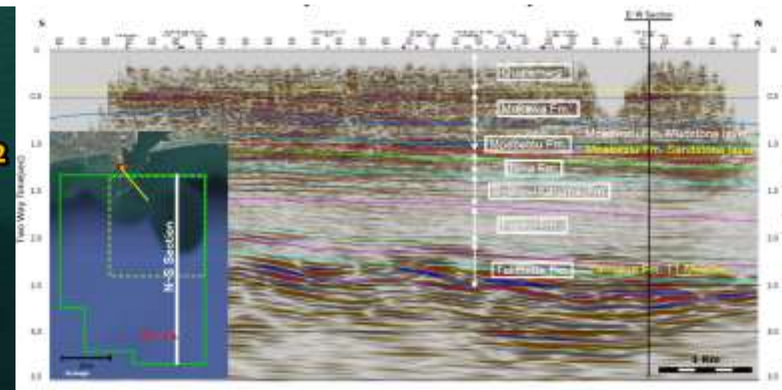


© Google Image © 2013 DigitalGlobe Data SIO, NOAA, U.S. Navy, NGA, GEBCO Image © 2013 TerraMetrics

JCCS





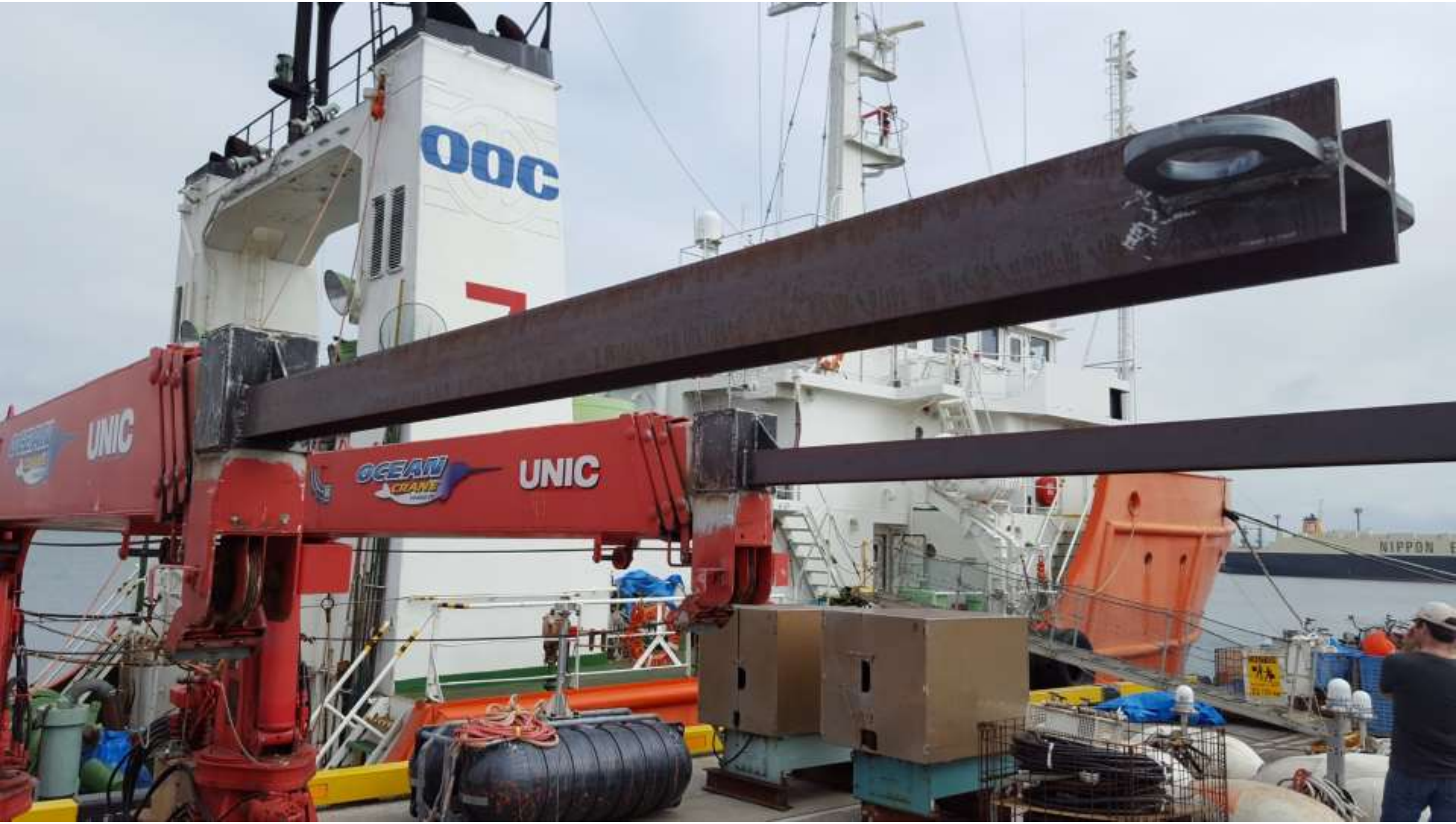


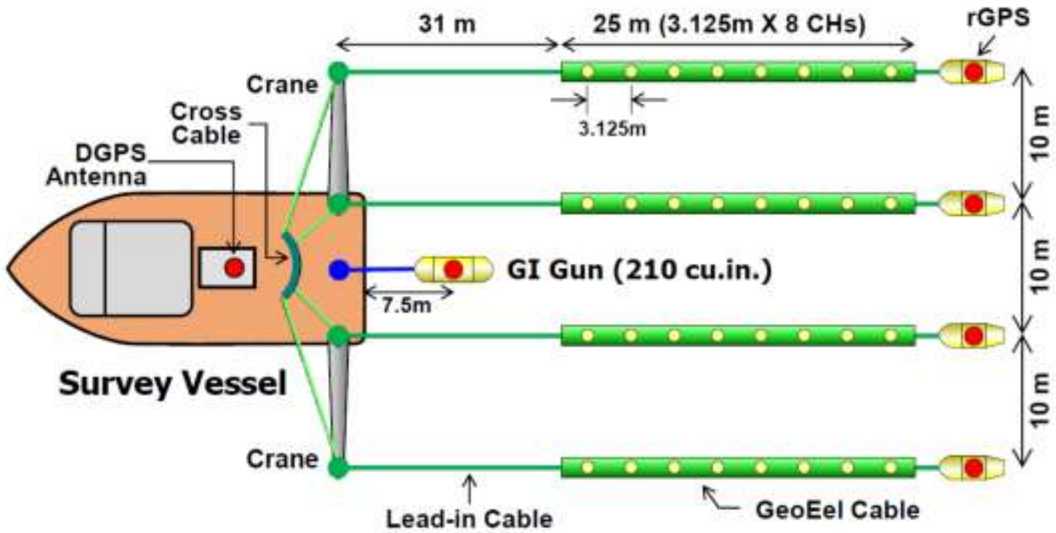
~$400,000 USD
6 days acquisition (daylight)
3 days mob, 1.5 demob
3 science; 6 navigation ship crew

4 x 25 m (8-channel; 3.125)
6.25 m shot spacing (4 sec)
0.25 msec sampling
GI source
2.75 km lines

August, 2017: Kaiku Maru

August, 2017: Kaiku Maru



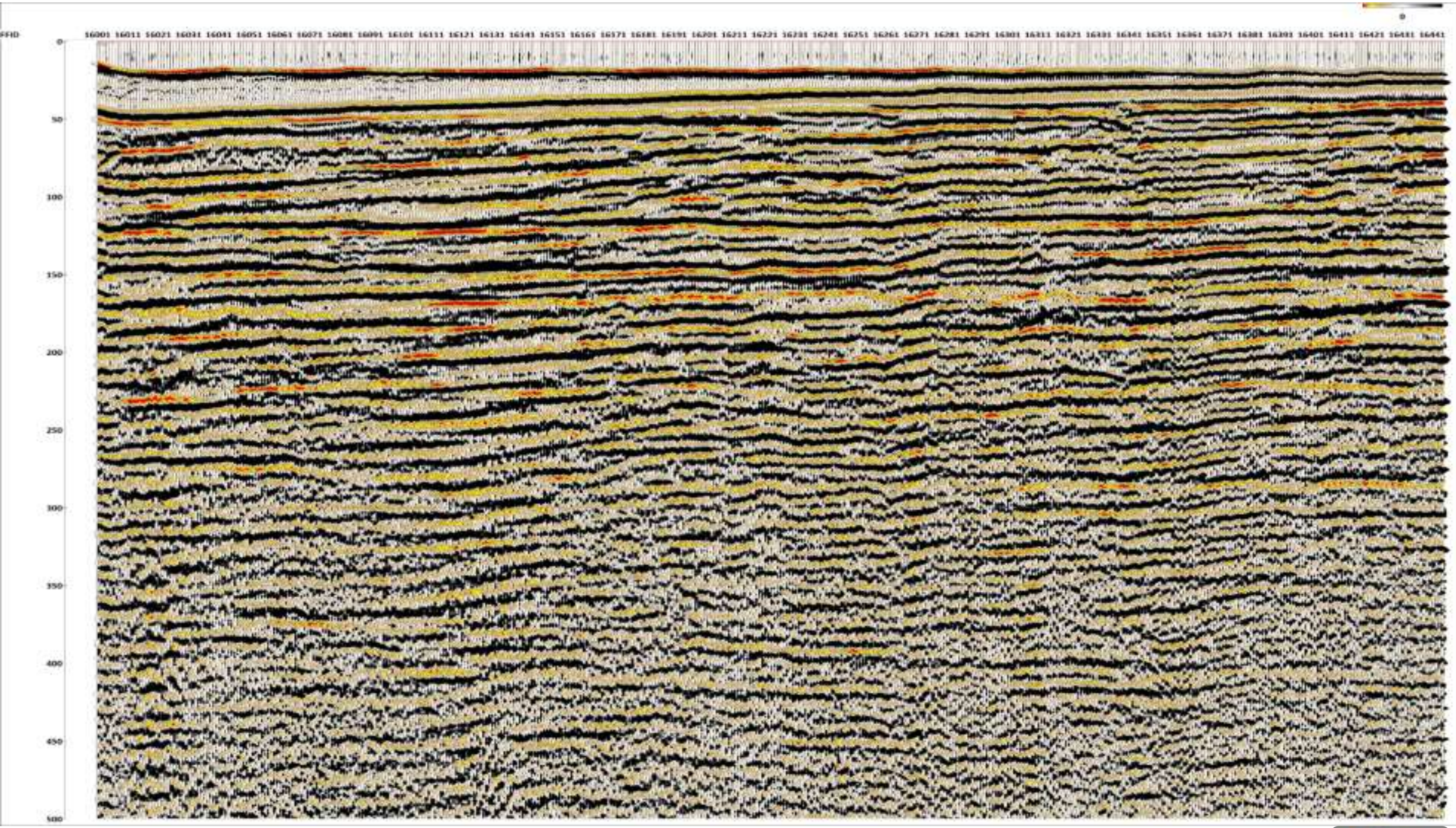


August 2017 Tomakomai Survey
BEG & JGI

New long streamer interconnects
Cross cable on deck

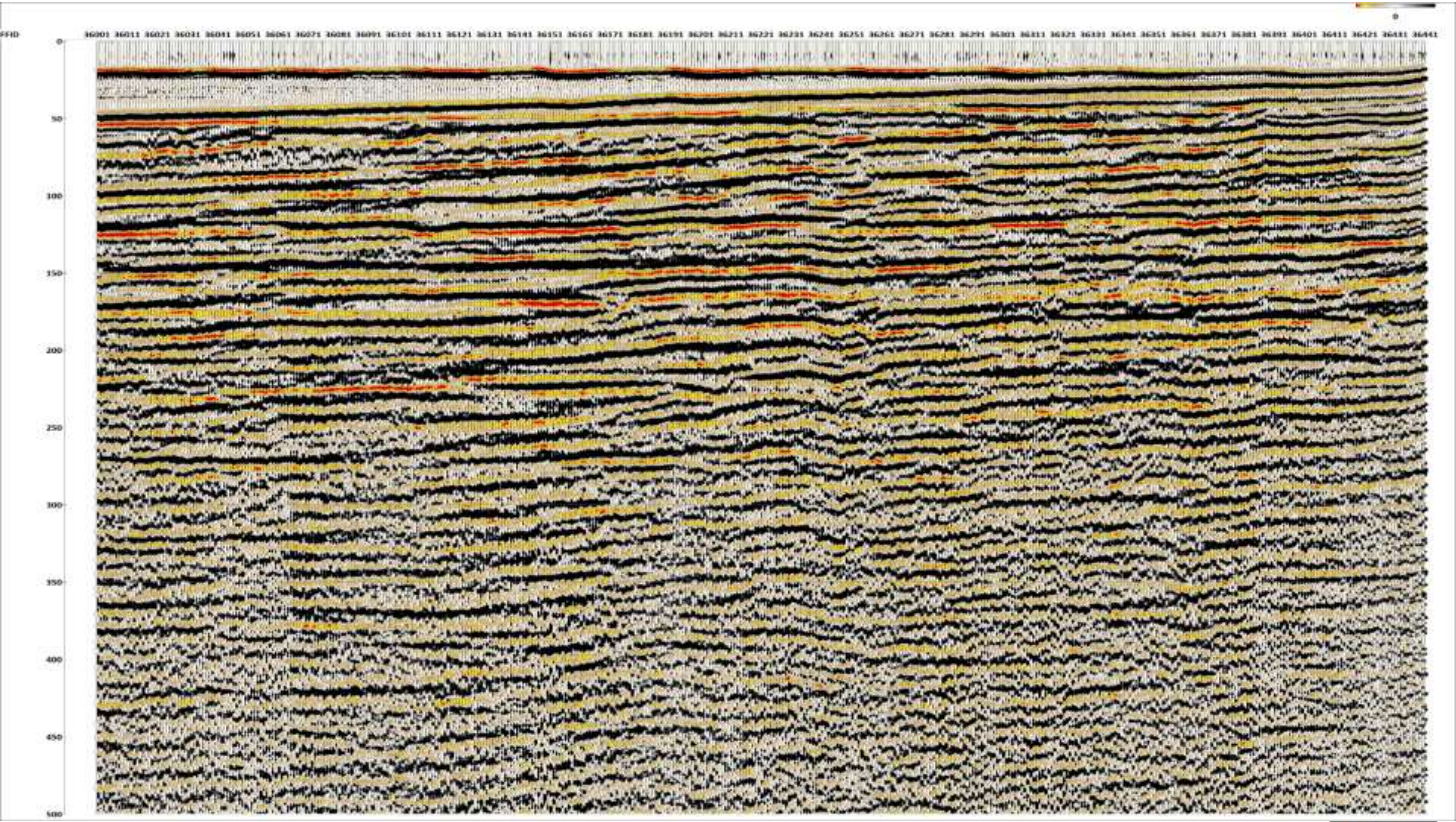
30 minute deployment / recovery

Single-channel field record – minimal processing



500 msec

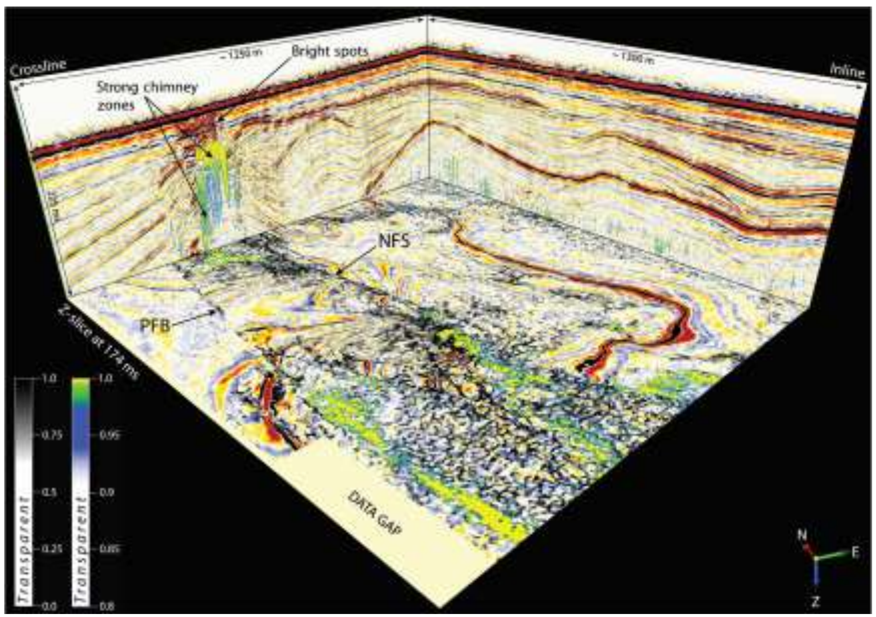
Single-channel field record – minimal processing

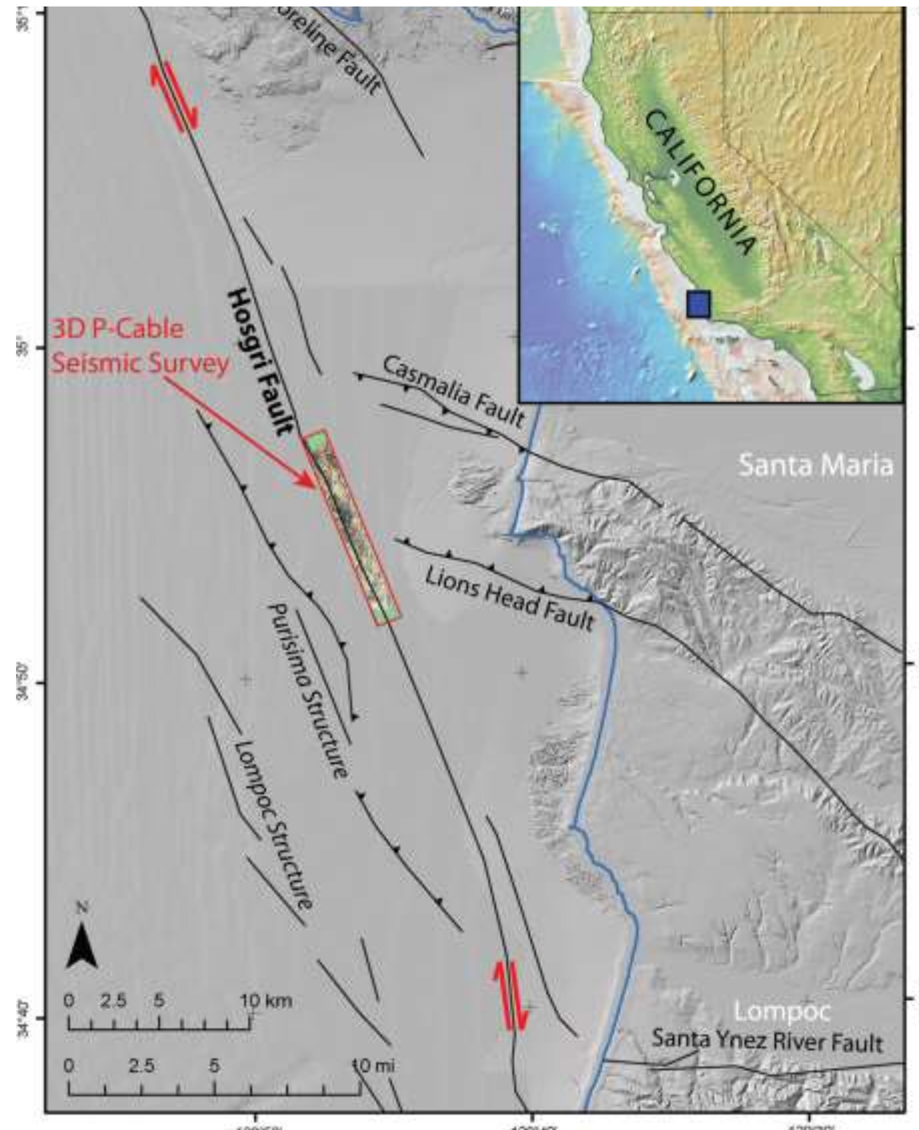


500 msec

Seismic attribute detection of faults and fluid pathways within an active strike-slip shear zone: New insights from high-resolution 3D P-Cable™ seismic data along the Hosgri Fault, offshore California

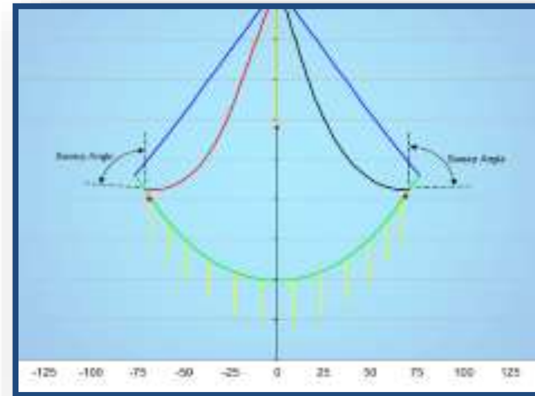
Jared W. Kluesner[1] and Daniel S. Brothers[1]





Acquisition Challenges, but surmountable

- **Receiver Positioning**
  - Accuracy; GPS method
- **Leakage**
  - Signal Cable / Tri-point connection
    - Custom sheave (3PS)
  - Junction boxes: connectors
  - Streamers
- **Optimize Geometry**
- Source tuning
- (Multiples)



Forward plans –

TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences

- **UT 2013 HR3D GoM dataset is publically available**
  - **UTIG ASP Data Portal: http://www-udc.ig.utexas.edu/sdc/**

- **Looking for research partners for a variety of HR3D +/- coring/EM/other applications.**
  - Some funds and partners in hand.
  - HR3D training cruise?

- **New equipment?**

- **Japan – second UT survey late 2018.**
  - **Repeatability; direct ranging?**

Forward plans –

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- <u>**UT Service Center established**</u> **ABS: All But Ship…**
  - Broader use of equipment: academic, government, industry.
  - ?? Hire new staff to support program development.
- >$2M equipment investment

  15 x 25 m solid Geoeel streamers
  2 Baro #3 paravanes
  4 winches: 2 tow, 1 data, 1 cross-cable
  Acquisition computer rack (2 SPSU + PC)
  3 Sercel GI airguns (210 cu.in. + inserts)

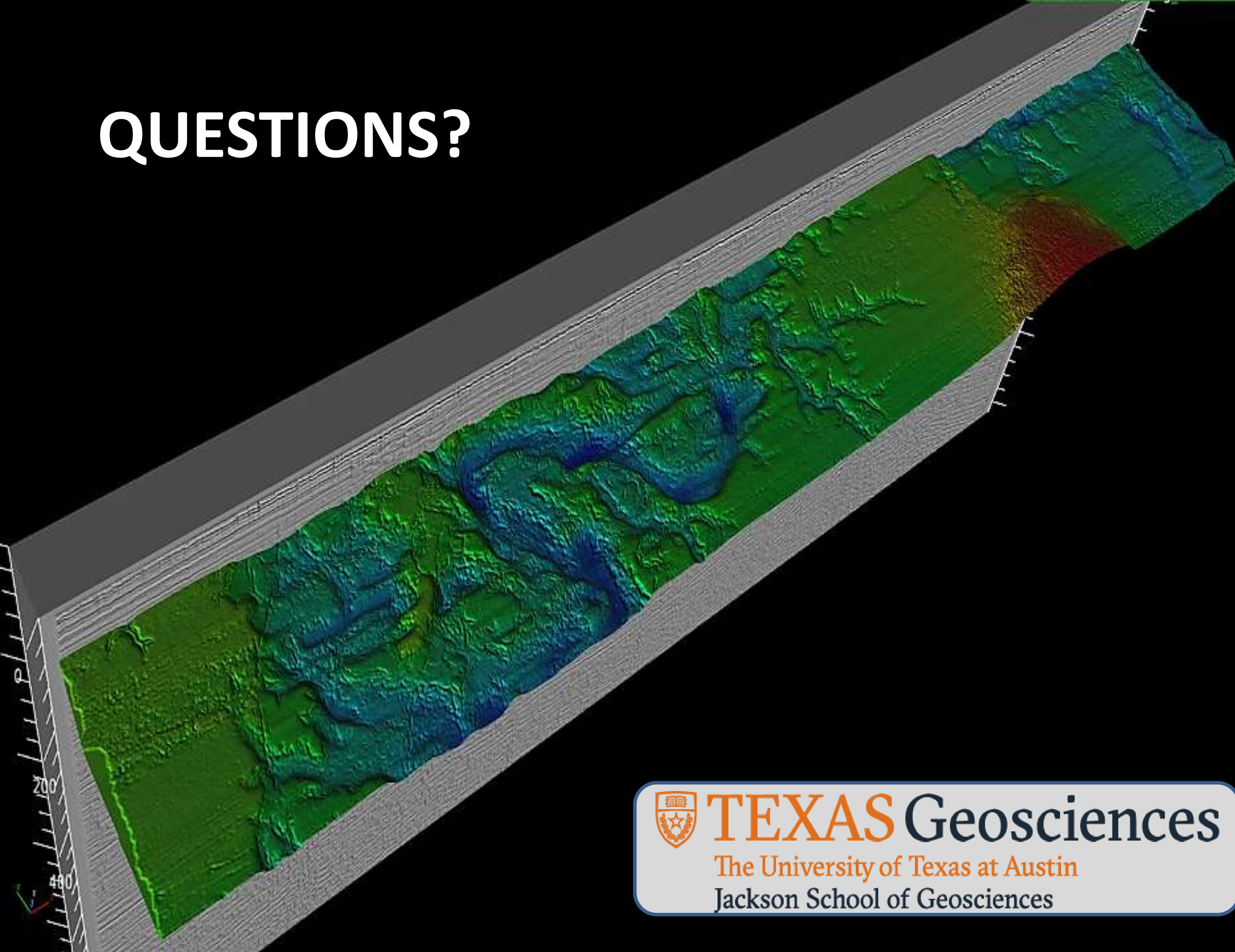
  (lack streamer/umbilical spool)

  No ITAR restrictions

  2 LMF Compressors

  From *R/V Thompson,* Univ. WA
  300 scfm, 2175 psi

QUESTIONS?



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PROGRAM DEVELOPMENT

- **<u>Technical</u>**
  - Navigation / Positioning
  - Equipment repair & replacement
  - Platform / vessel
- **<u>Personnel</u>**
  - Dedicated acquisition team
  - Training
- **<u>Equipment</u>** function of intended investigation
  - Streamer length: 25, 50, 200 m
  - Source: mini-GI, GI, sparker, etc.
- **<u>Other</u>**
  - Other

SELECT PUBLICATIONS

Petersen, 2010, MPG, *HR3D imaging of gas chimney structures in hydrated sediments of an **Arctic** sediment drift*.

Hustof, 2010, BR, *3D seismic analysis of the morphology and spatial distribution of chimneys beneath the Nyegga pockmark field, **Norway***.

Moss, 2010, BR, *3D seismic expression of km-scale fluid escape pipes from offshore **Namibia***.

Lippus, 2013, SAGEEP, *High-resolution offshore 3D seismic geophysical studies of infrastructure geohazards (PG&E Diablo Canyon, **California**).*

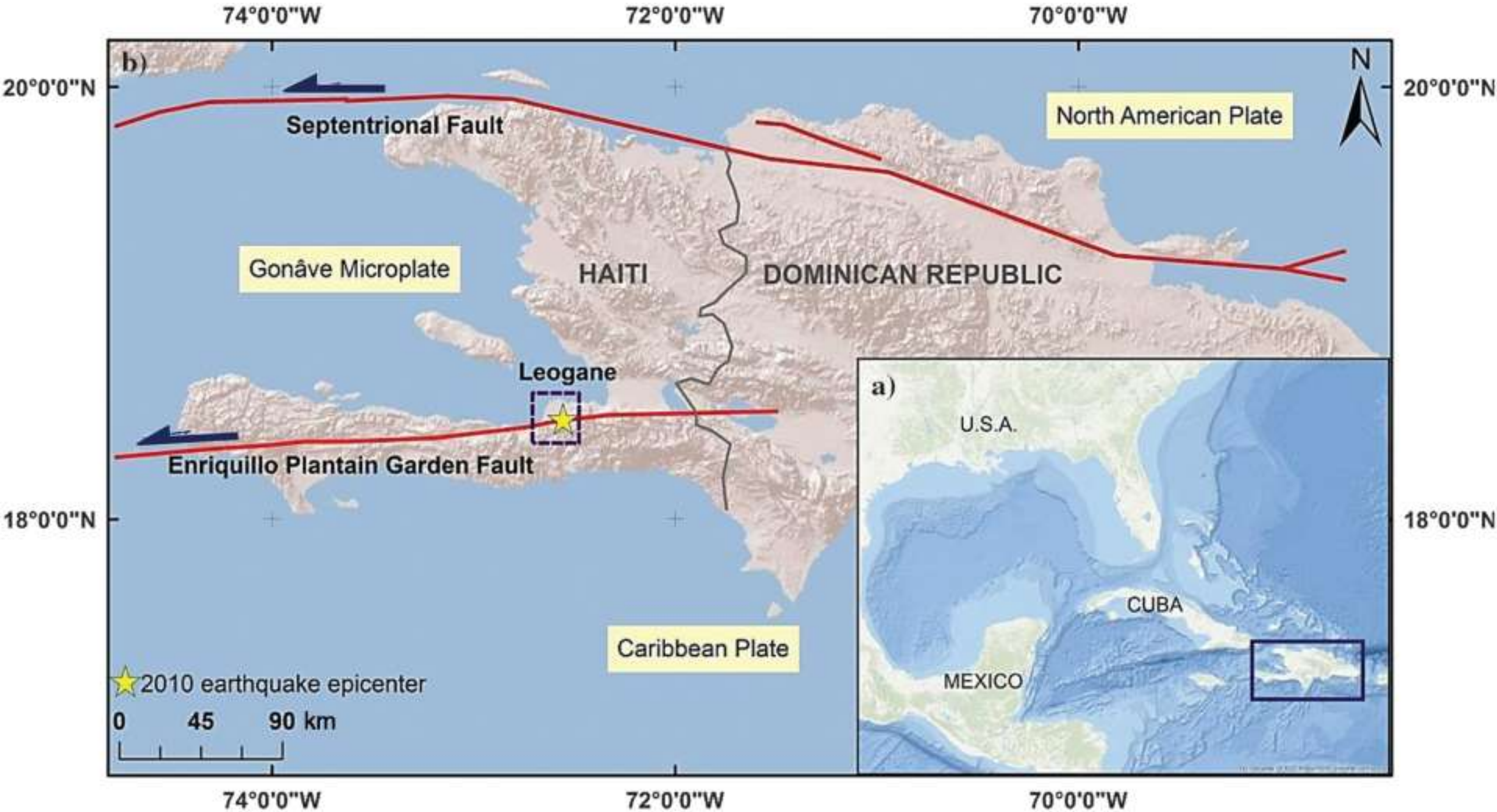
Kluesner, 2016, *Seismic attribute detection of faults and fluid pathways within an active strike-slip shear zone – New insights from HR3D P-Cable seismic data along the Hosgri Rault, offshore **California**.*

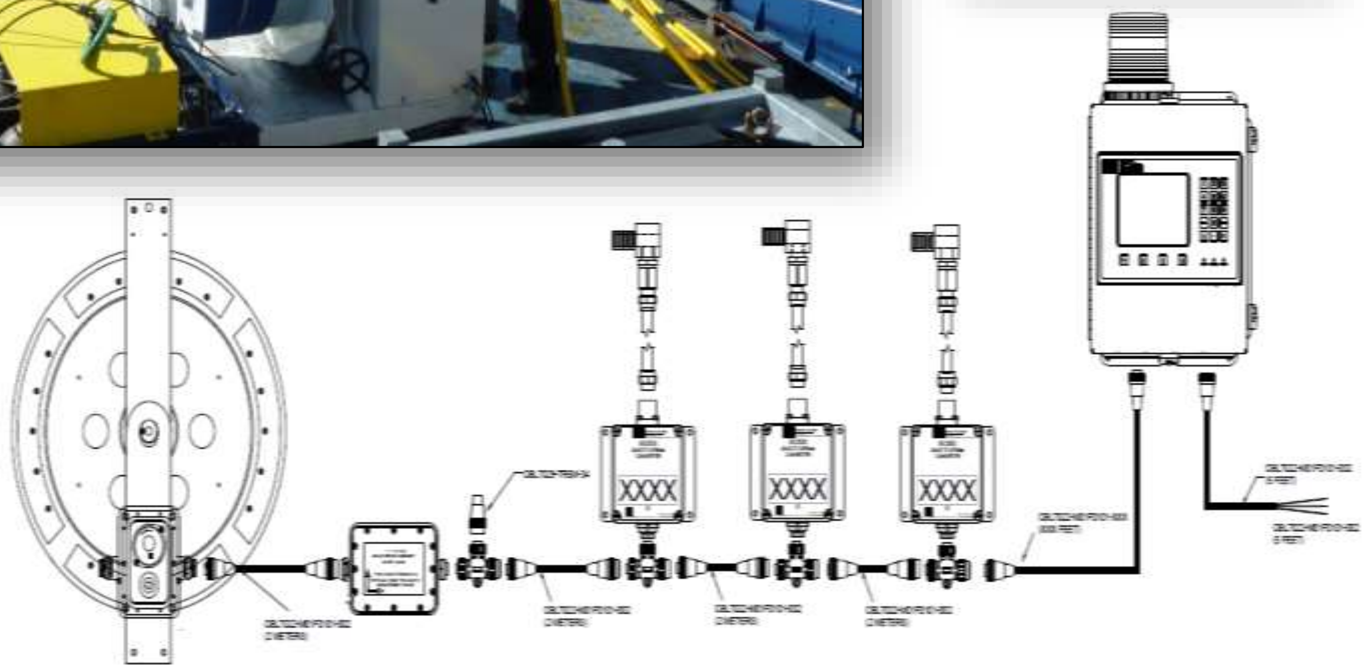
Brookshire, 2015, UT, *Applicability of ultra-high-resolution 3D seismic for hazard identification at mid-slope depths **GoM***.

Meckel, 2016, *Use if novel high-resolution 3D marine seismic data to evaluate Quaternary fluvial valley development and geologic controls on distribution of shallow gas anomalies, inner shelf, **GoM***.

APPLICATIONS

- **Quaternary Studies**
  - Sea level change
- **Geohazard**
  - **Natural systems:** Fault, slump, etc.
  - **Drilling: NTL 2008-G05** (update soon via BOEM)
  - Integrated JPC and CPT for 3D distribution of shallow physical properties.
  - OBS/long 2D streamer options for velocity (fluids, shear data).
- **Fluid Systems**:
  - Overburden characterization: Stratigraphy, faults, seals, secondary accumulations.
- **Monitoring**: 4D repeatability currently being explored (positioning critical)
  - Acquisition (NRMS), Signal-to-distortion-ratio (SDR), time shifts
  - Fluid effects; Saturation changes.
- **Modern/Recent Reservoir Analog Studies**: outcrop resolution
  - Rio Grande Delta/Fan = Analog for Paleogene Wilcox
  - Other GoM clastic settings; inner-shelf, slope, to deep water. Carbonates: RCRL, Caicos
- **Gas Hydrates** – IODP Indian Ocean (NGHP-02); Flemings GoM
  - DOE FOA.798 (2013) – Alaminos Canyon, unfunded - but ideas transfer.
- **CO_2 Storage (CCS) –** Faults…Shallow Gas…Quaternary Stratigraphy...Coring


74°0'0"W
72°0'0"W
70°0'0"W
20°0'0"N
18°0'0"N
b)
N
Septentrional Fault
North American Plate
Gonâve Microplate
HAITI
DOMINICAN REPUBLIC
Leogane
Enriquillo Plantain Garden Fault
Caribbean Plate
2010 earthquake epicenter
0 45 90 km
a)
U.S.A.
CUBA
MEXICO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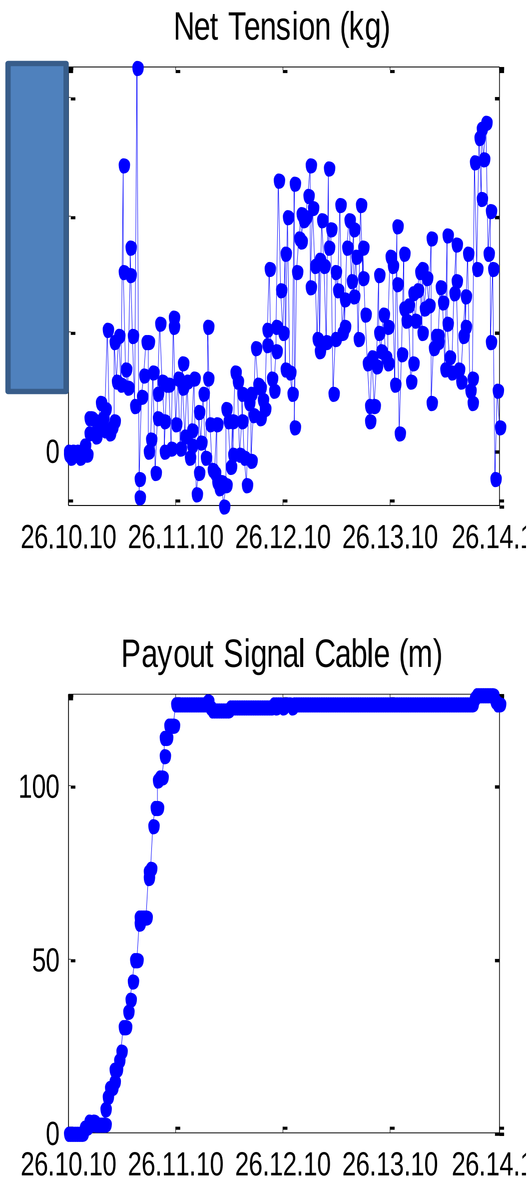
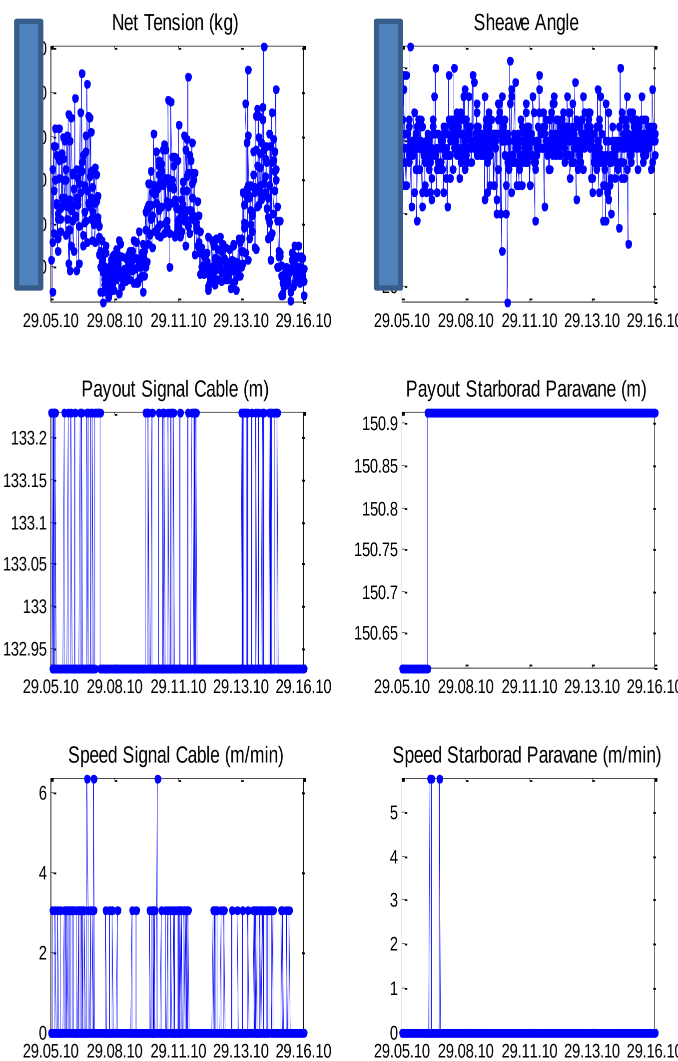
Deployment

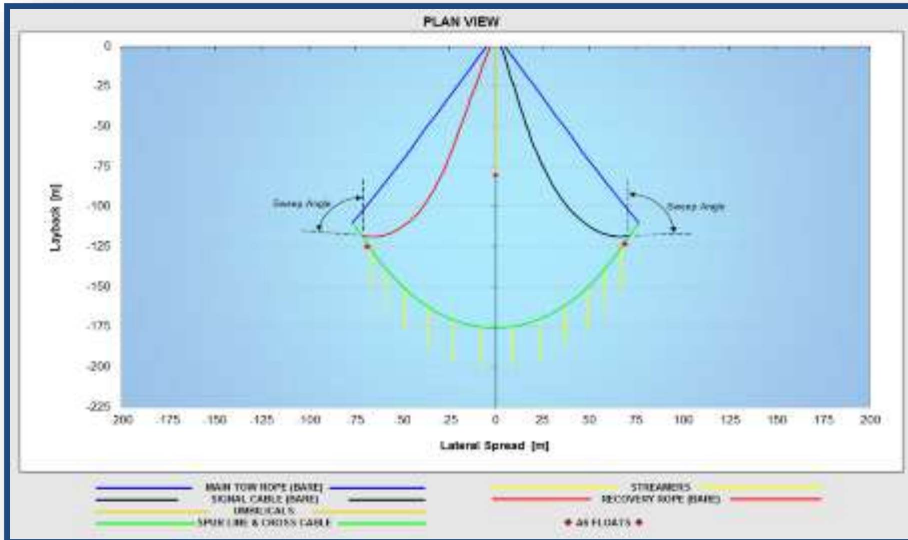


Acquisition

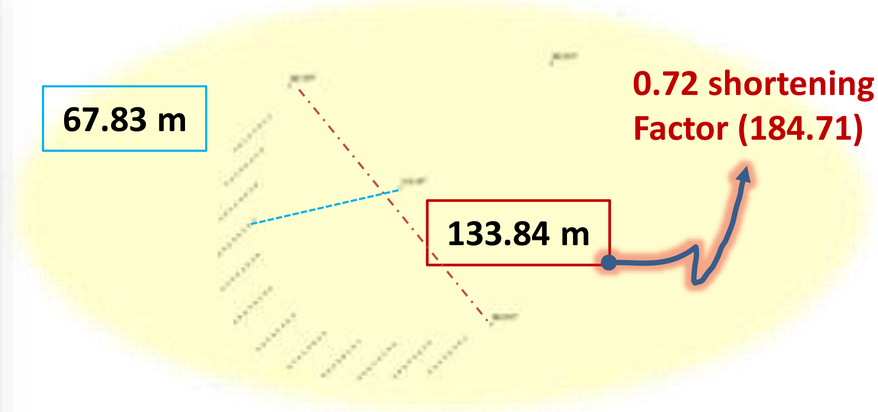


Array Geometry

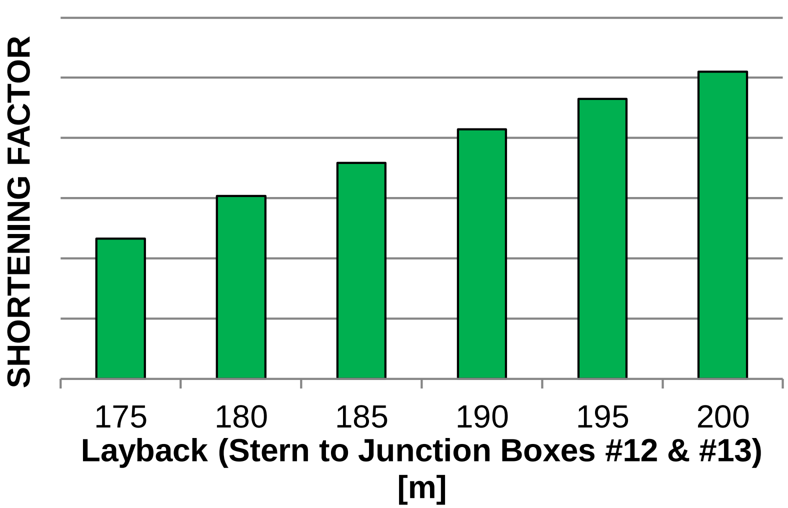
Modeling



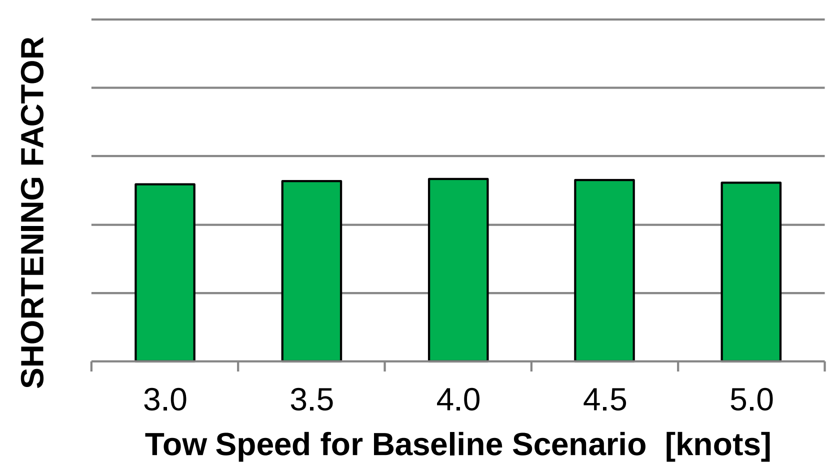
Field data



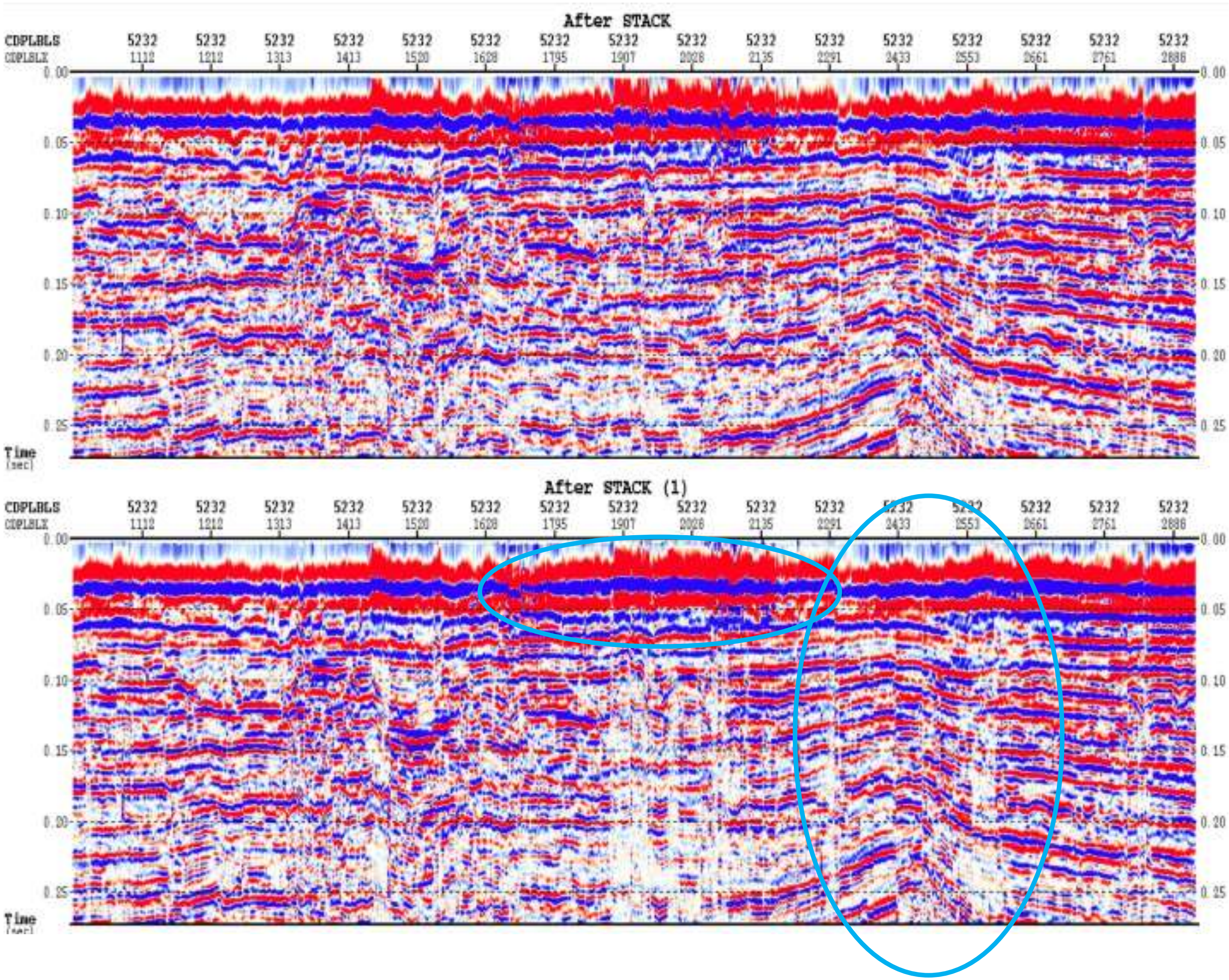
SHORTENING FACTOR VERSUS LAYBACK



SHORTENING FACTOR VERSUS TOW SPEED



Statics Corrections – GPS + acoustics



Recent news from North America

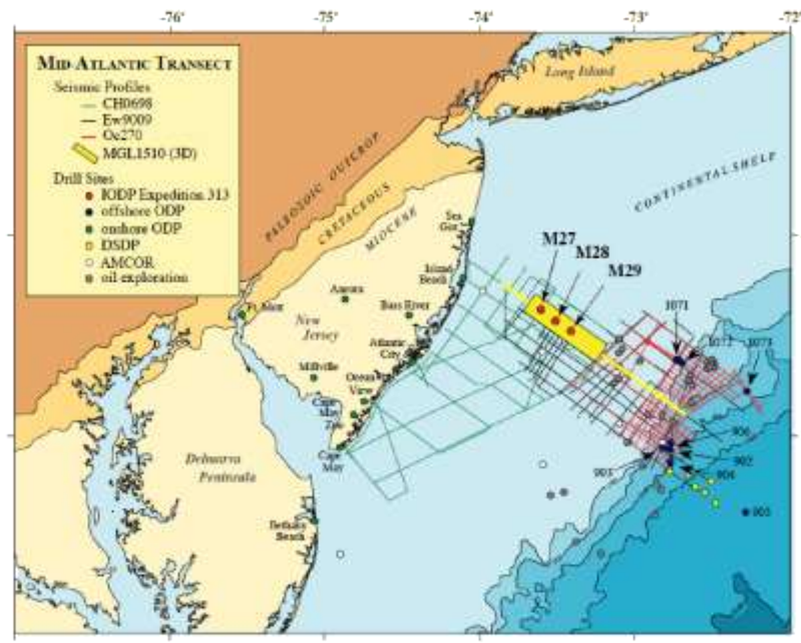
2014

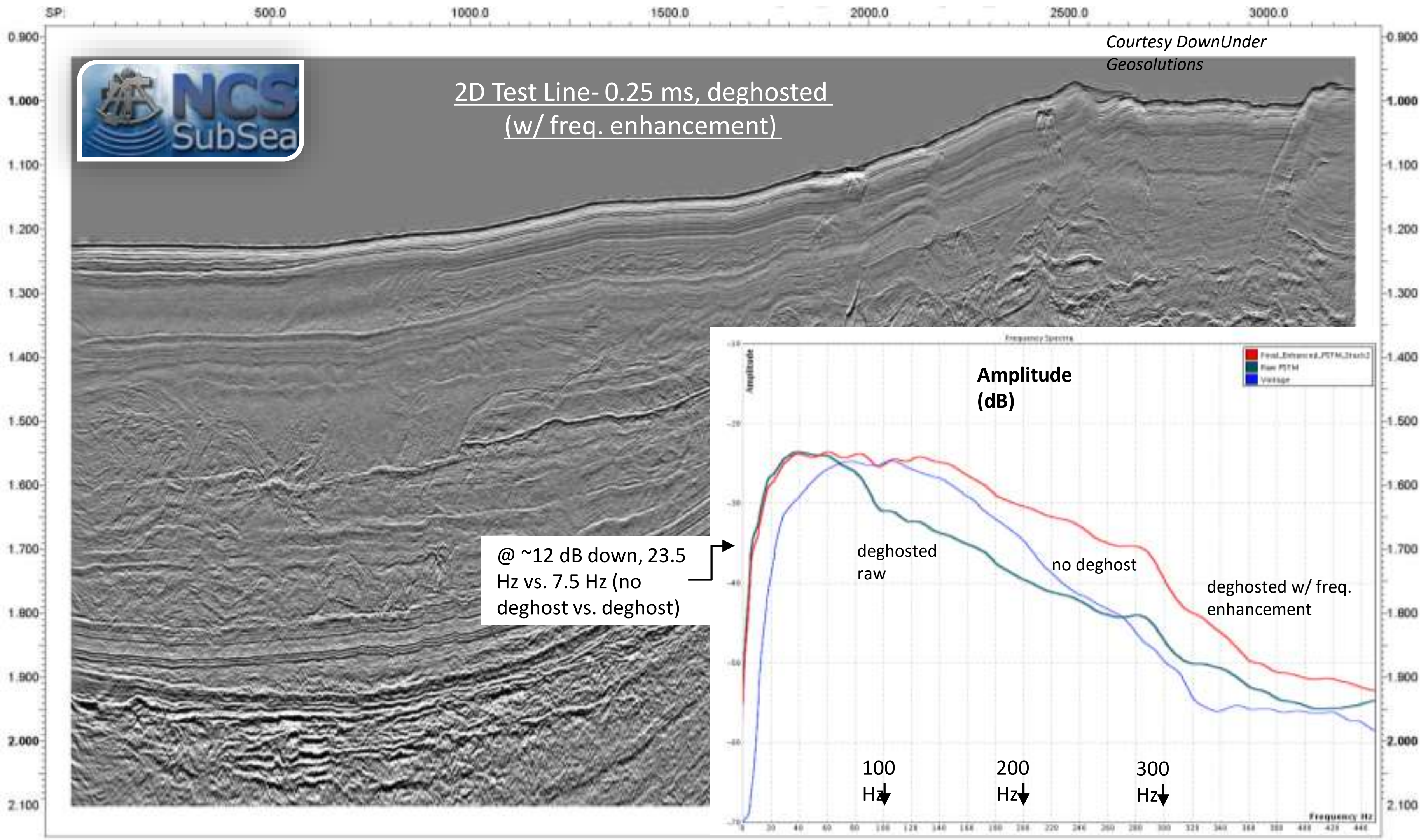
- SAFE-BAND, Phase 1 survey by NCS Subsea.
  - Mid-shelf GoM (~1,000 m)
  - Salt dynamics

Brookshire et al., 2015, Underwater Technology

June 1 – July 6, 2015

- New Jersey Shelf – Rutgers University (Greg Mountain) and UT-Austin (Austin & Fulthorpe).





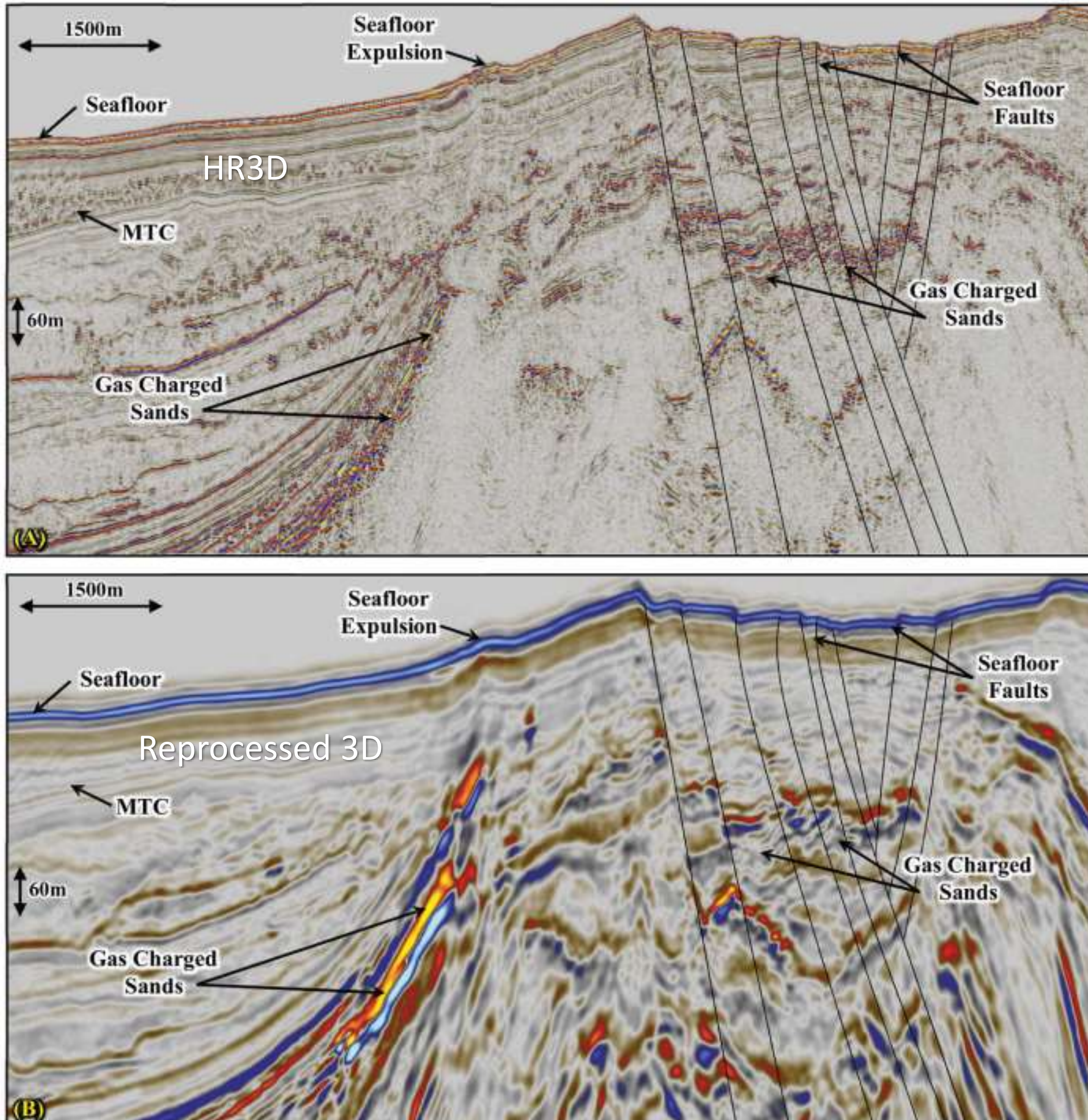
Courtesy DownUnder Geosolutions
2D Test Line- 0.25 ms, deghosted
(w/ freq. enhancement)
@ ~12 dB down, 23.5 Hz vs. 7.5 Hz (no deghost vs. deghost)
Amplitude (dB)
deghosted raw
no deghost
deghosted w/ freq. enhancement
100 Hz
200 Hz
300 Hz

Near Surface Geophysics, 2017, 15, 415-426
doi:10.3997/1873-0604.2017026

Identifying and mitigating against potential seafloor and shallow drilling hazards at a complex Gulf of Mexico Deepwater site using HR3D seismic and AUV data

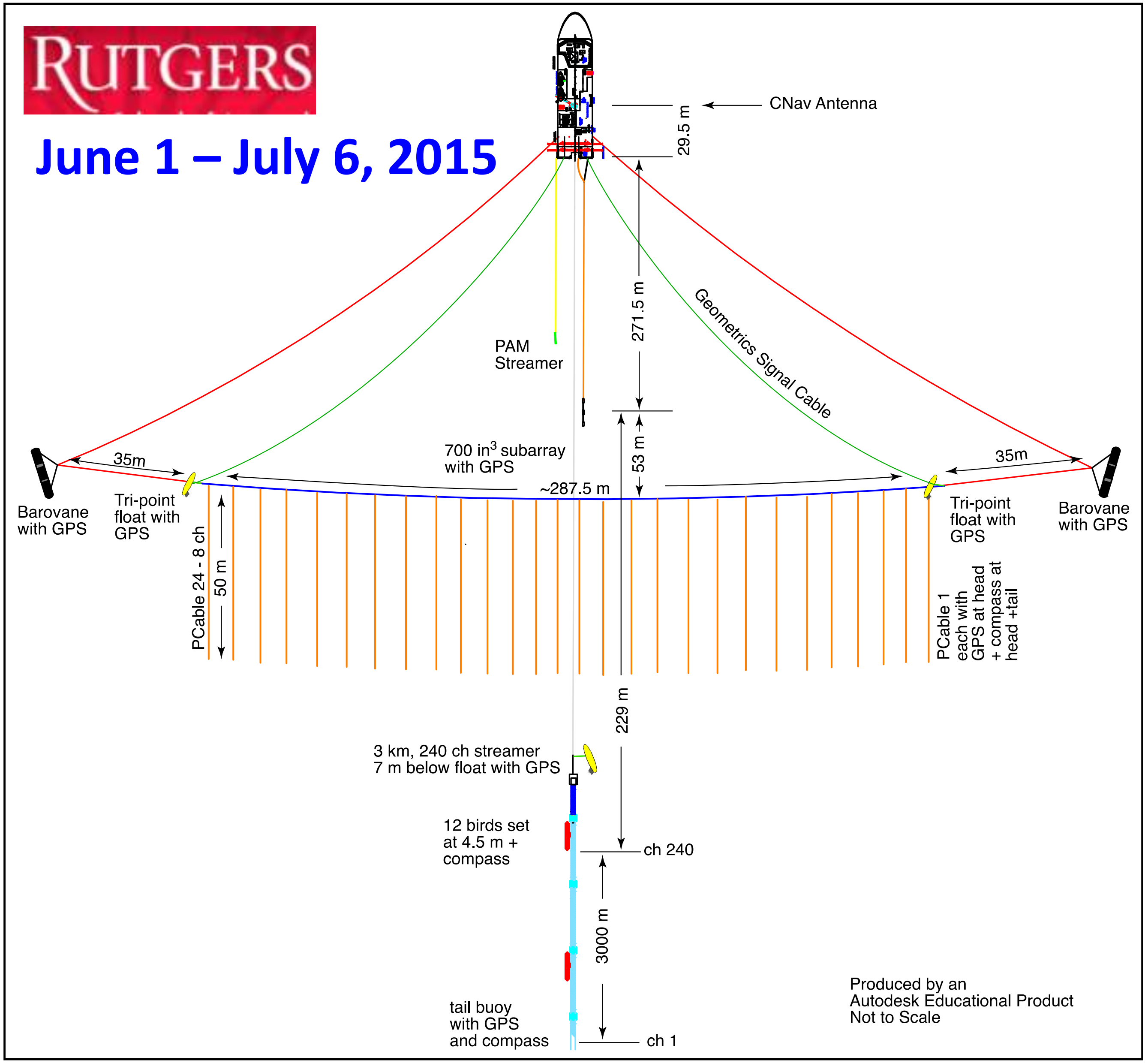
Kem Kassarie[1]*, Stephen Mitchell[1], Martin Albertin[1], Andrew Hill[1] and Robert Carney[2]

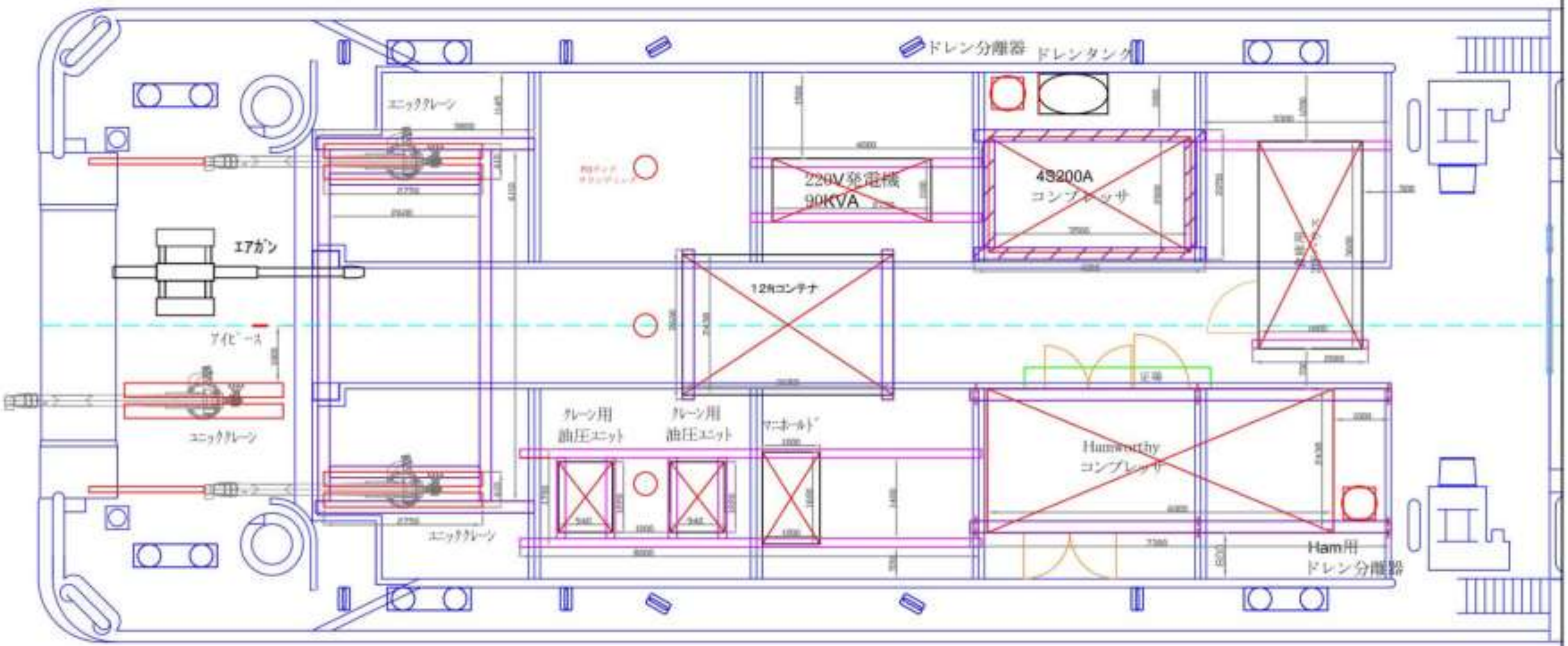
[1] BP America Inc., 501 Westlake Park Blvd, Houston, TX 77079, USA
[2] Louisiana State University, Baton Rouge, LA 70803, USA



MGL1510 Geometry

June 1 – July 6, 2015





H100 — H100 L2000 ×2本

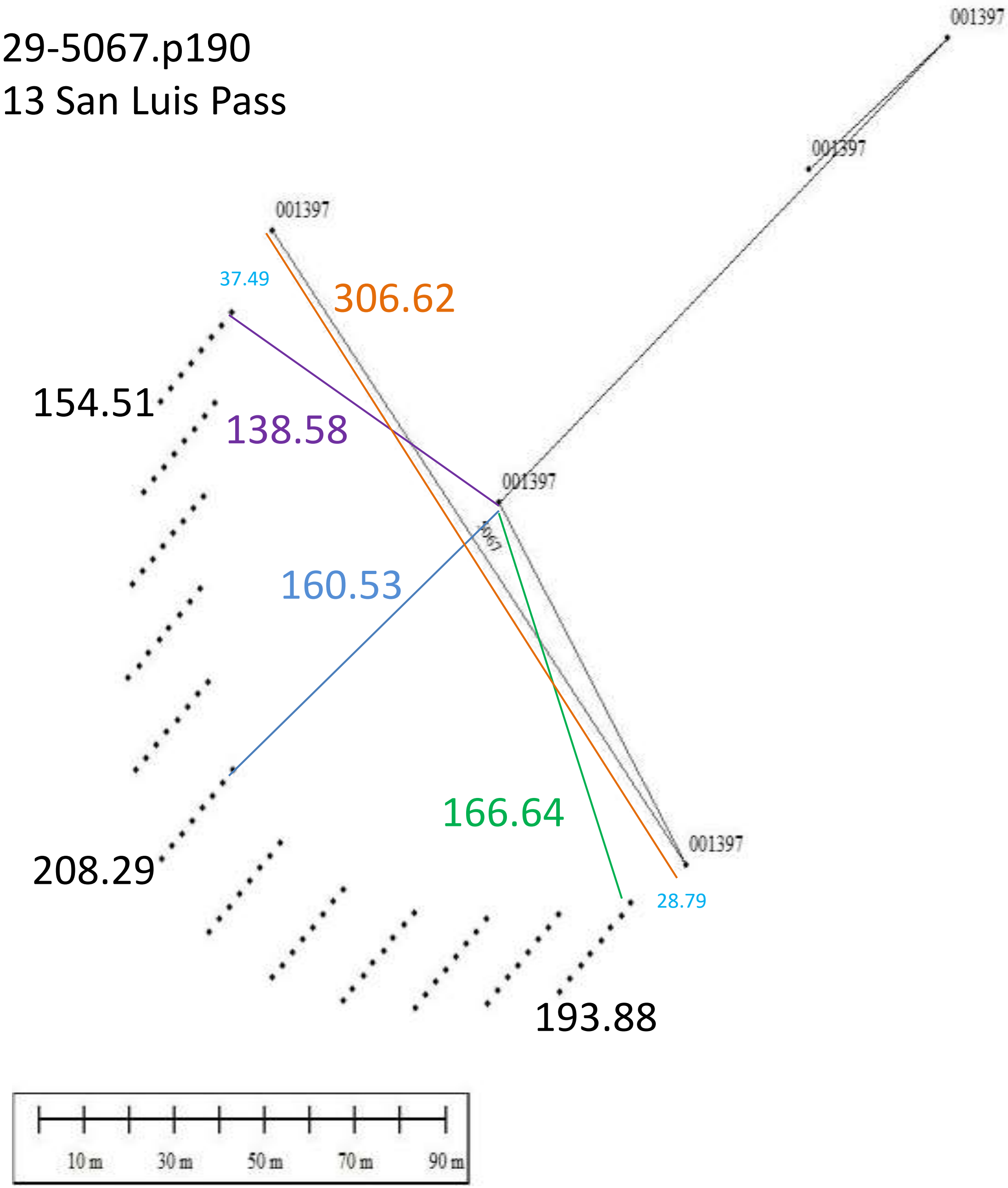
H200
- H200 L7300 ×2本
- H200 L4000 ×2本
- H200 L6110 ×2本
- H200 L3800 ×2本
- H200 L2600 ×2本

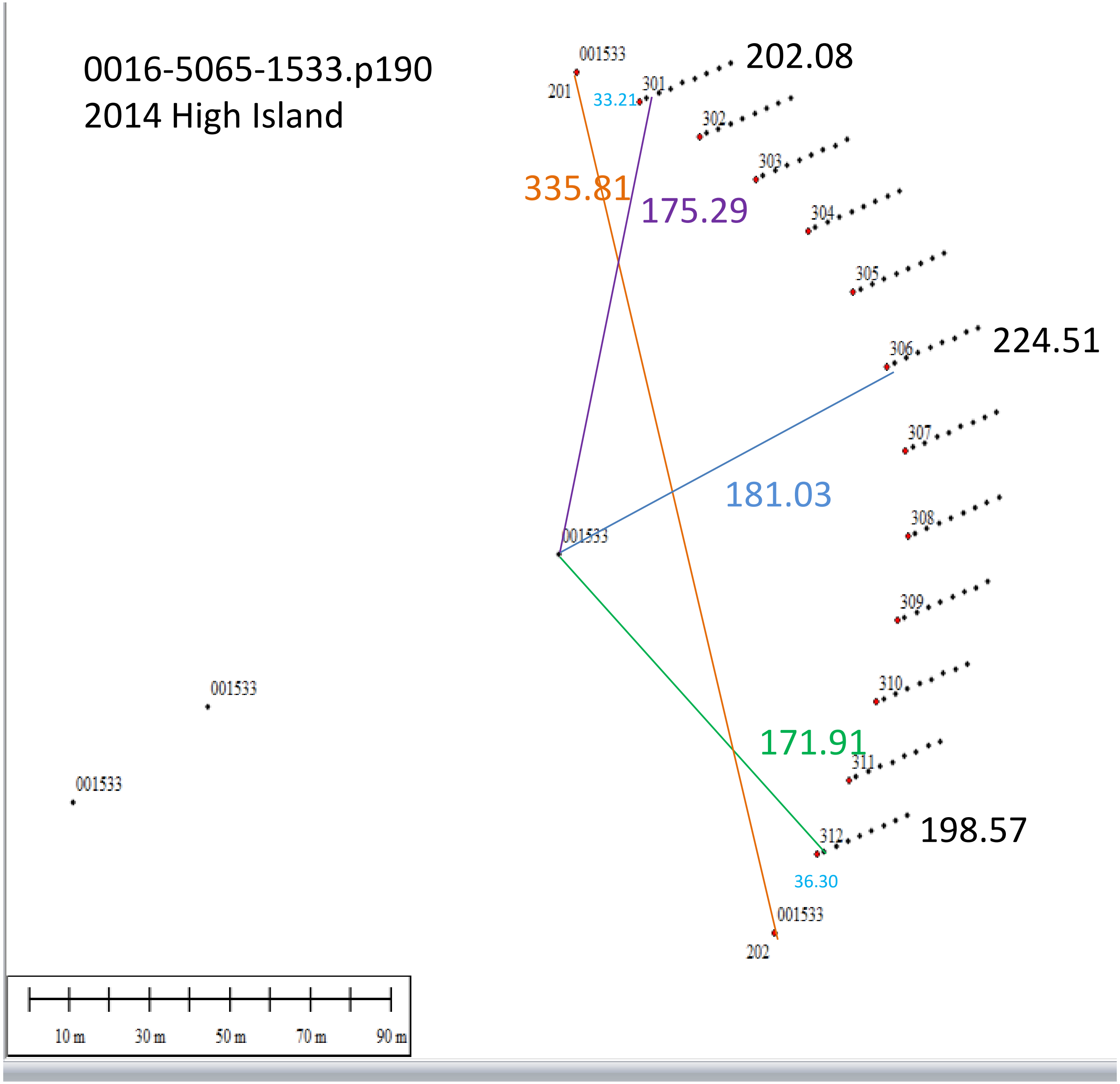
H150
- H150 L8000 ×2本
- H150 L4000 ×2本
- H150 L3300 ×1本
- H150 L2000 ×1本
- H150 L1400 ×2本

TITLE	日米協力実験 第7海工丸艤装図
SCALE	1/100
	OOC 株式会社 オフショア・オペレーション
FORM SIZE	A3

0029-5067.p190

2013 San Luis Pass

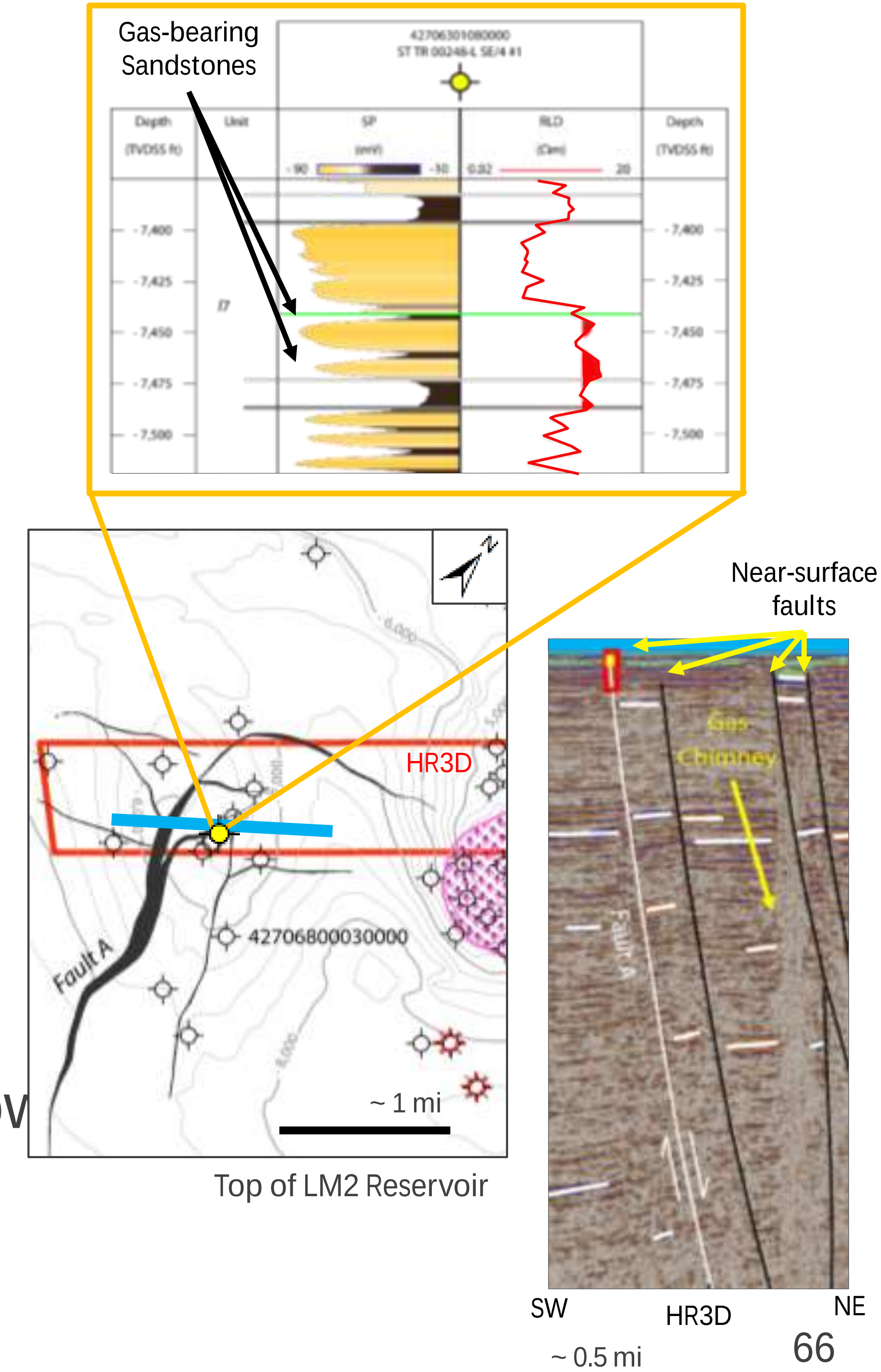



0016-5065-1533.p190
2014 High Island
001533
201
301
33.21
202.08
302
303
335.81
175.29
304
305
306
224.51
307
181.03
308
001533
309
001533
310
171.91
311
001533
312
198.57
36.30
001533
202
10 m
30 m
50 m
70 m
90 m

Primary Observations

- Structurally complex area.
- Evidence of charge.
- Non-economic well history locally.
- ***Is this a good place to inject CO_2?***

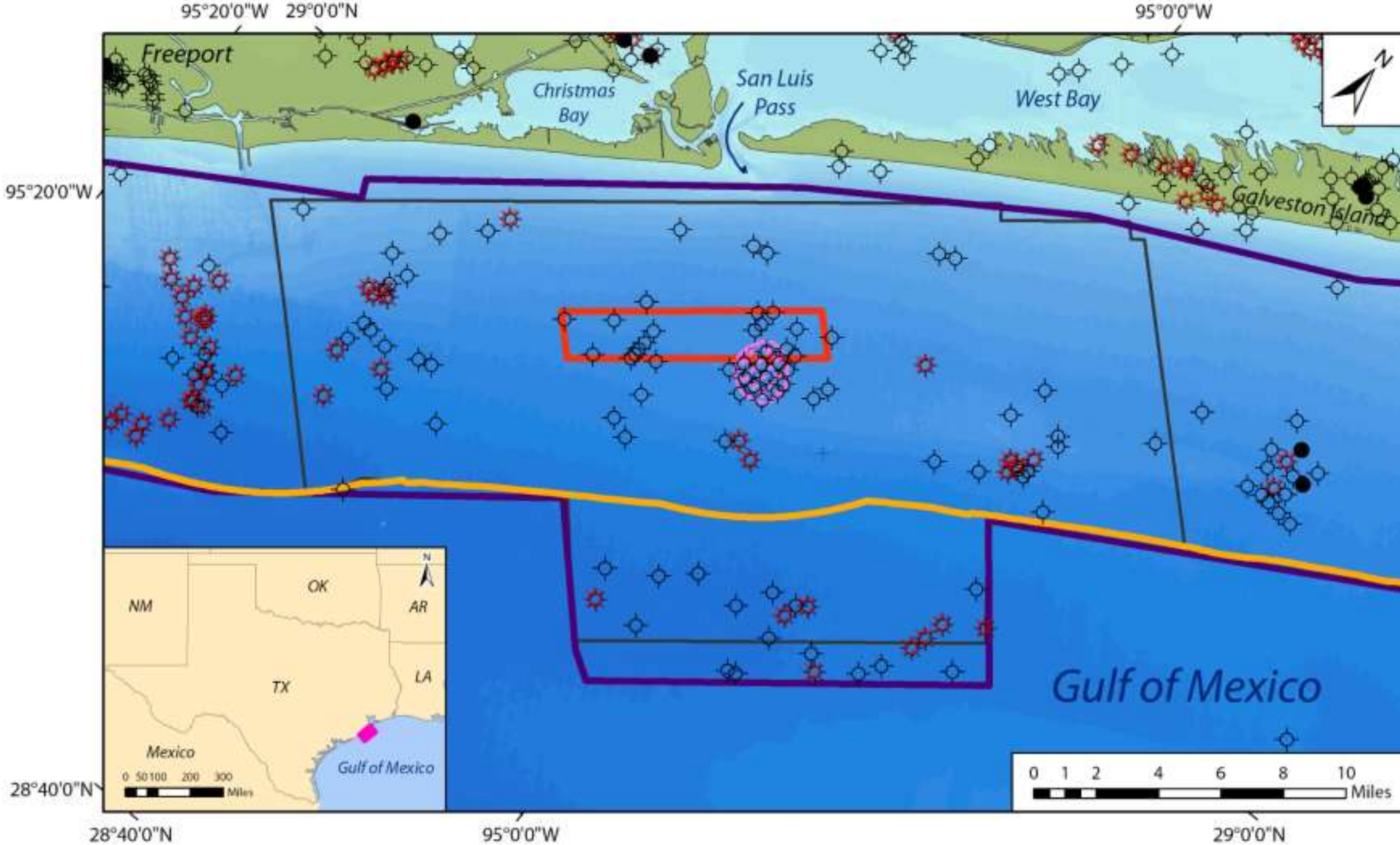
- HR3-D seismic
  - Near-surface faults
  - Anomalies: chimney and shallov
  - Quaternary stratigraphy



Top of LM2 Reservoir

Petroleum Wells - San Luis Pass Area, Offshore TX:

Figure 1.6



Key to Features and Symbols

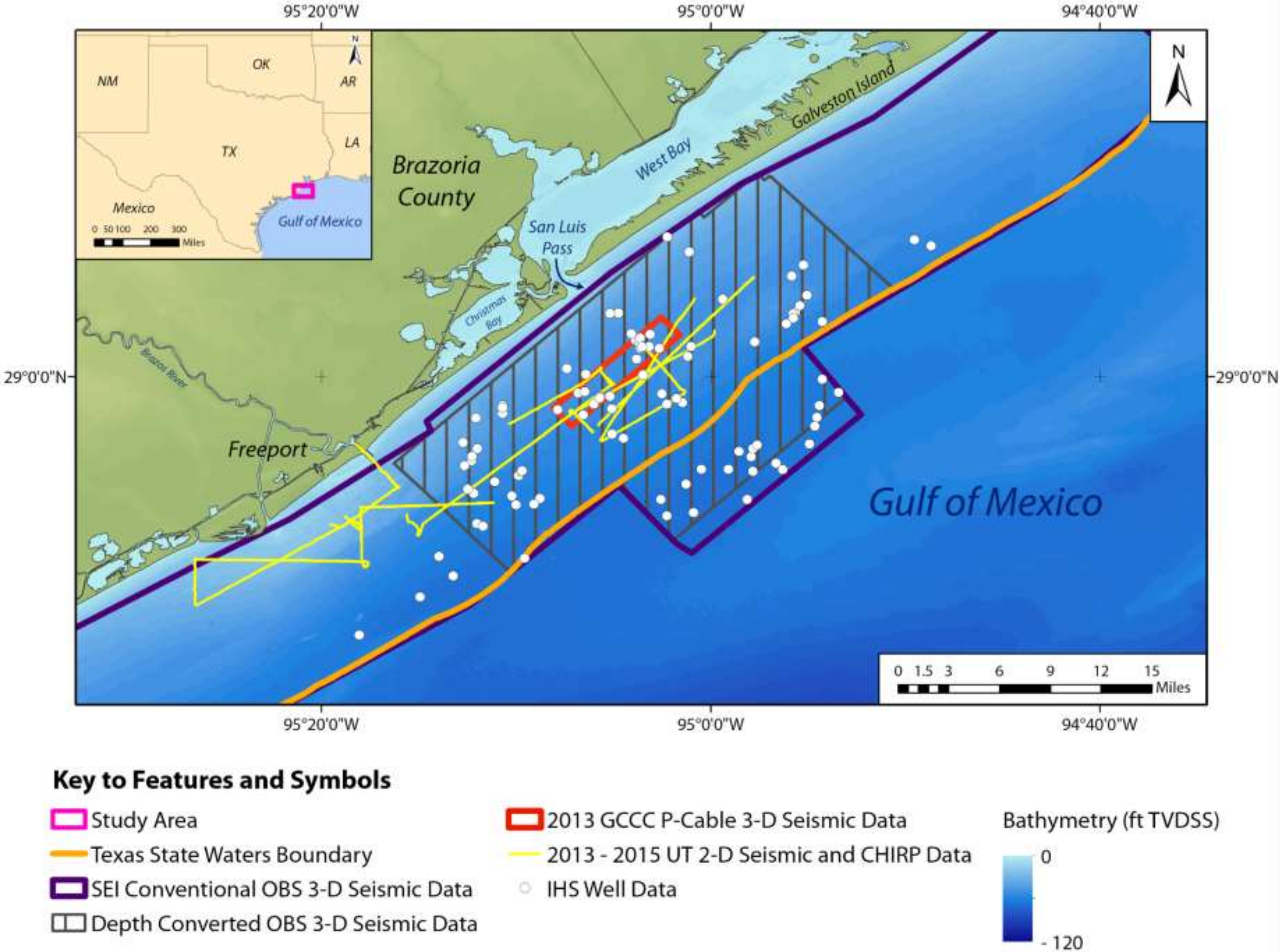
- Map Location
- Texas State Waters Boundary
- SEI Conventional OBS 3-D Seismic Data
- Depth Converted OBS 3-D Seismic Data
- 2013 GCCC P-Cable 3-D Seismic Data
- San Luis Pass Salt Dome
- Oil Well
- Gas Well
- Dry Well

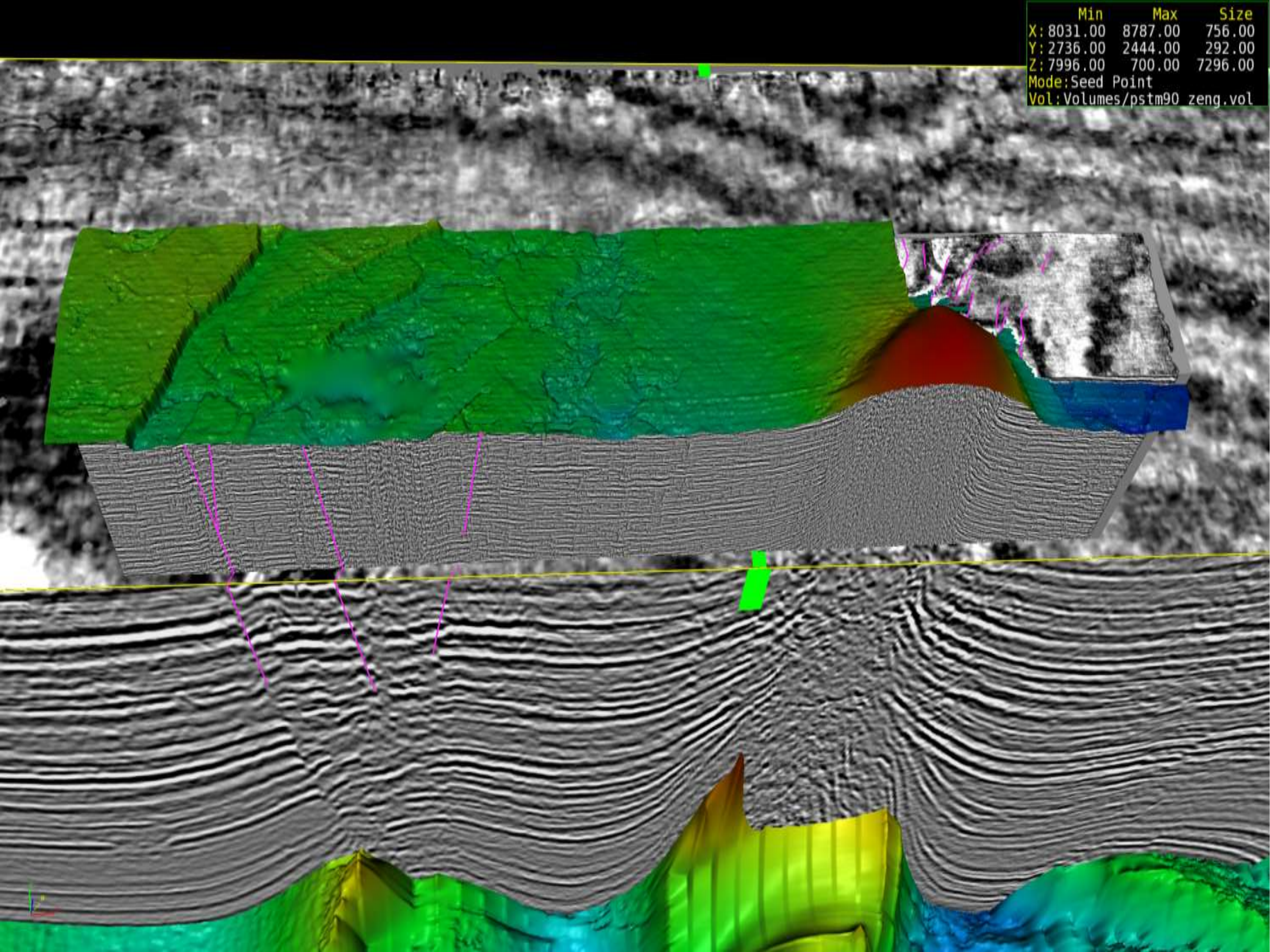
Bathymetry (ft TVDSS)

0

- 120

Study Area and Dataset - San Luis Pass Area, Offshore TX: Figure 1.1

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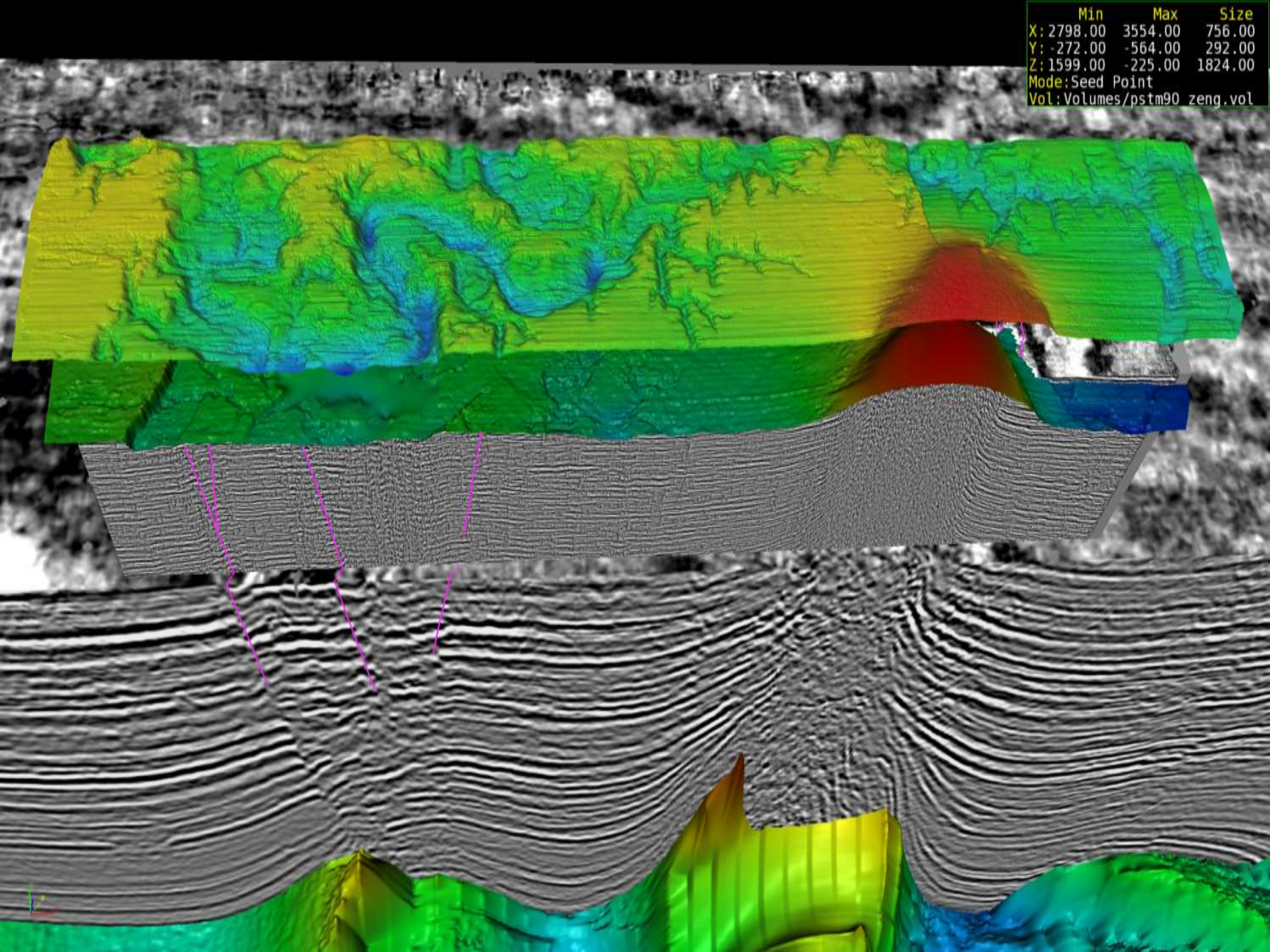
Z: 7996.00 700.00 7296.00
Mode: Seed Point
Vol: Volumes/pstm90 zeng.vol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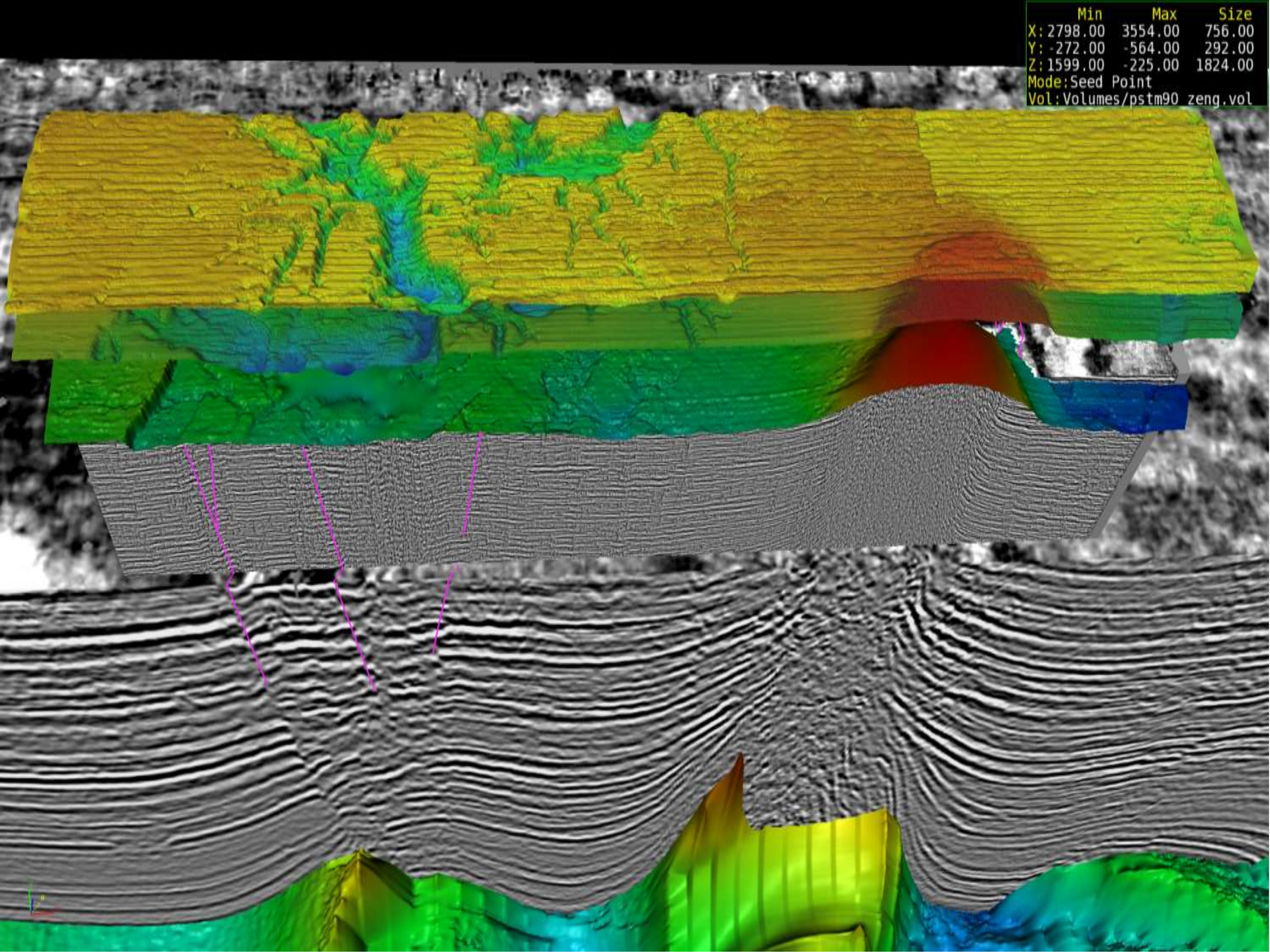
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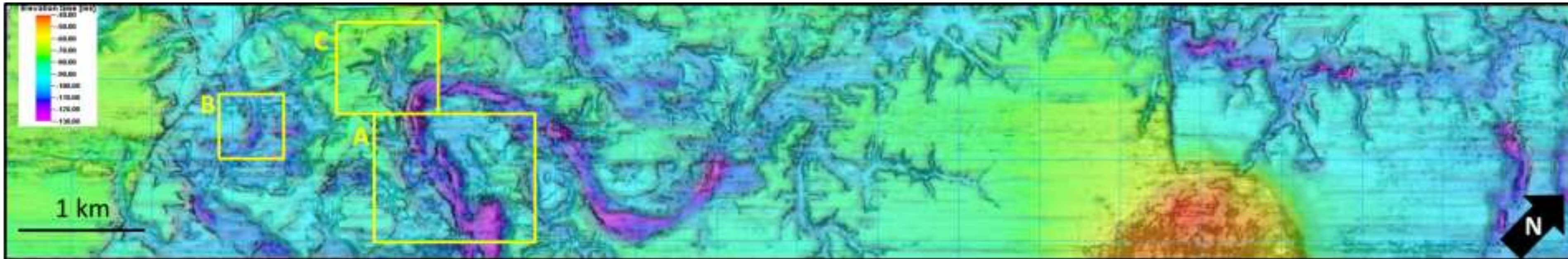
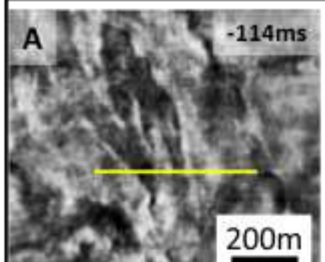
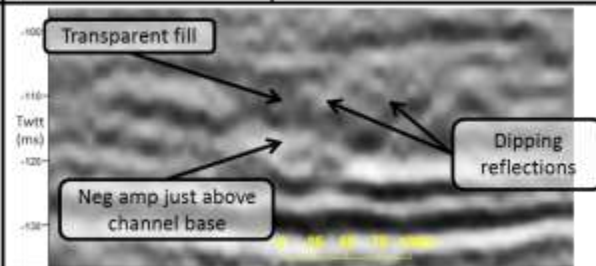
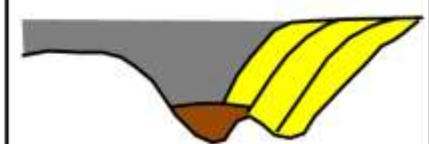
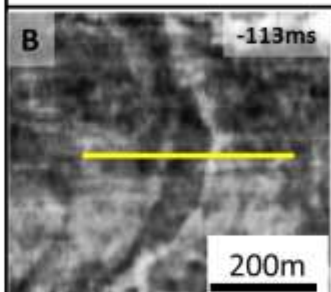
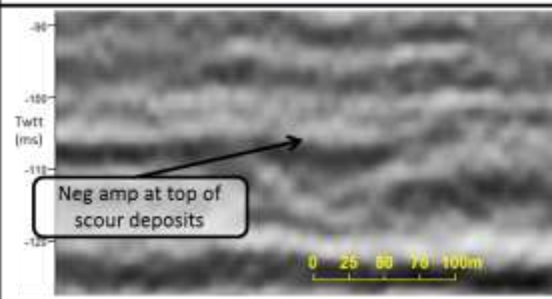
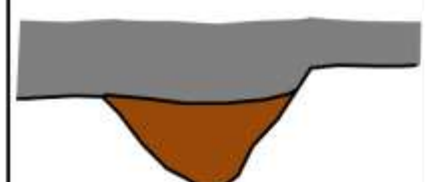
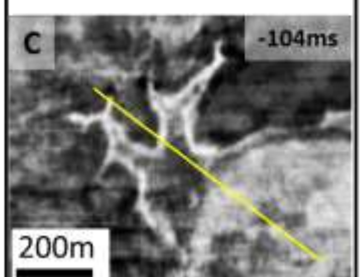
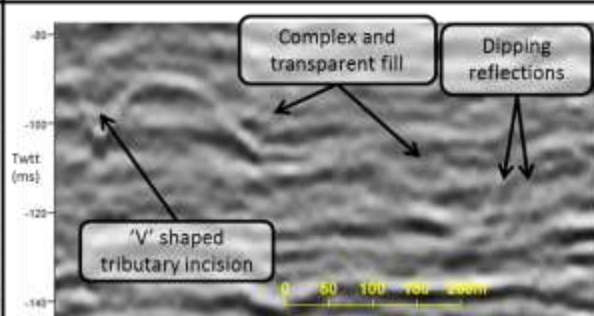
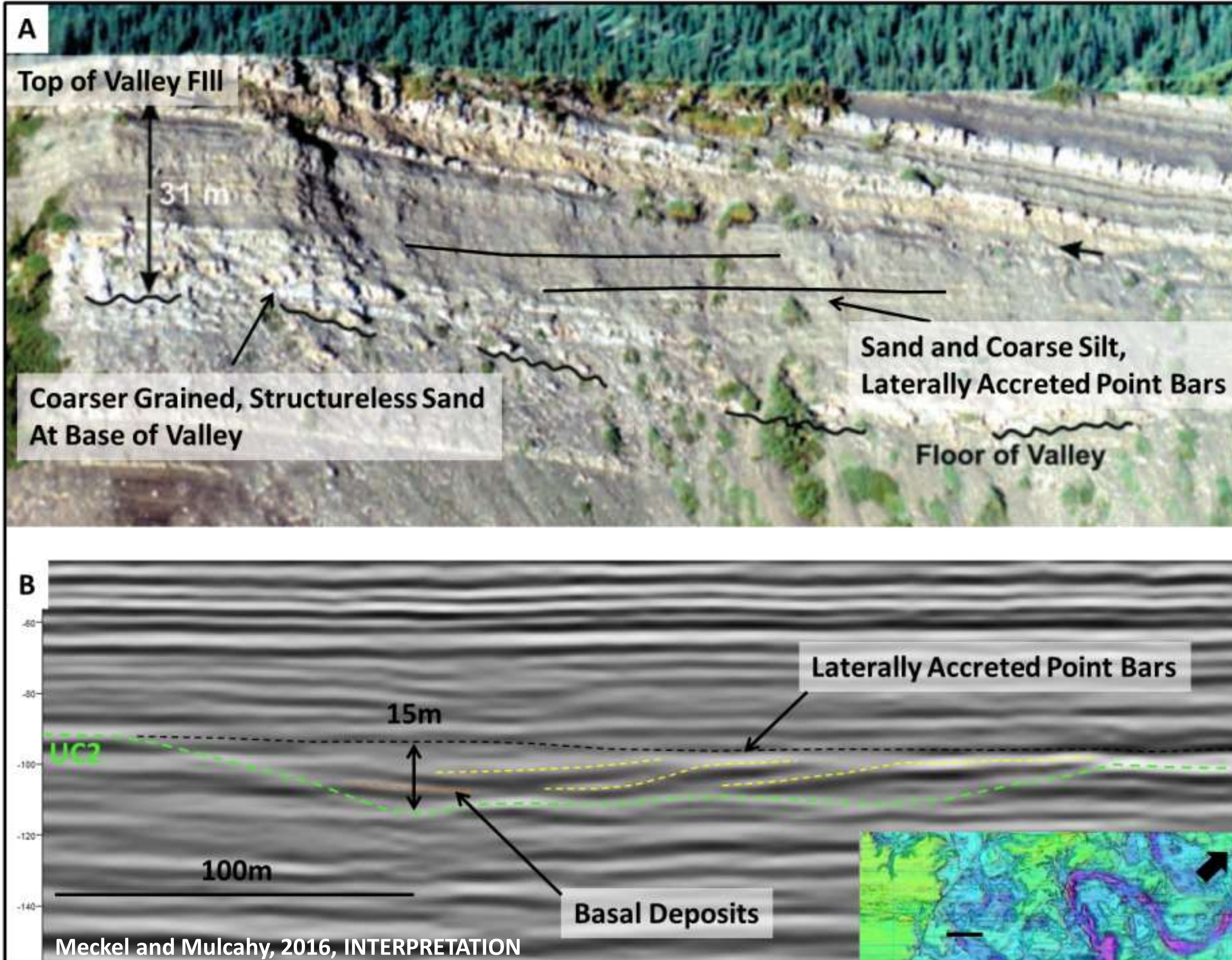
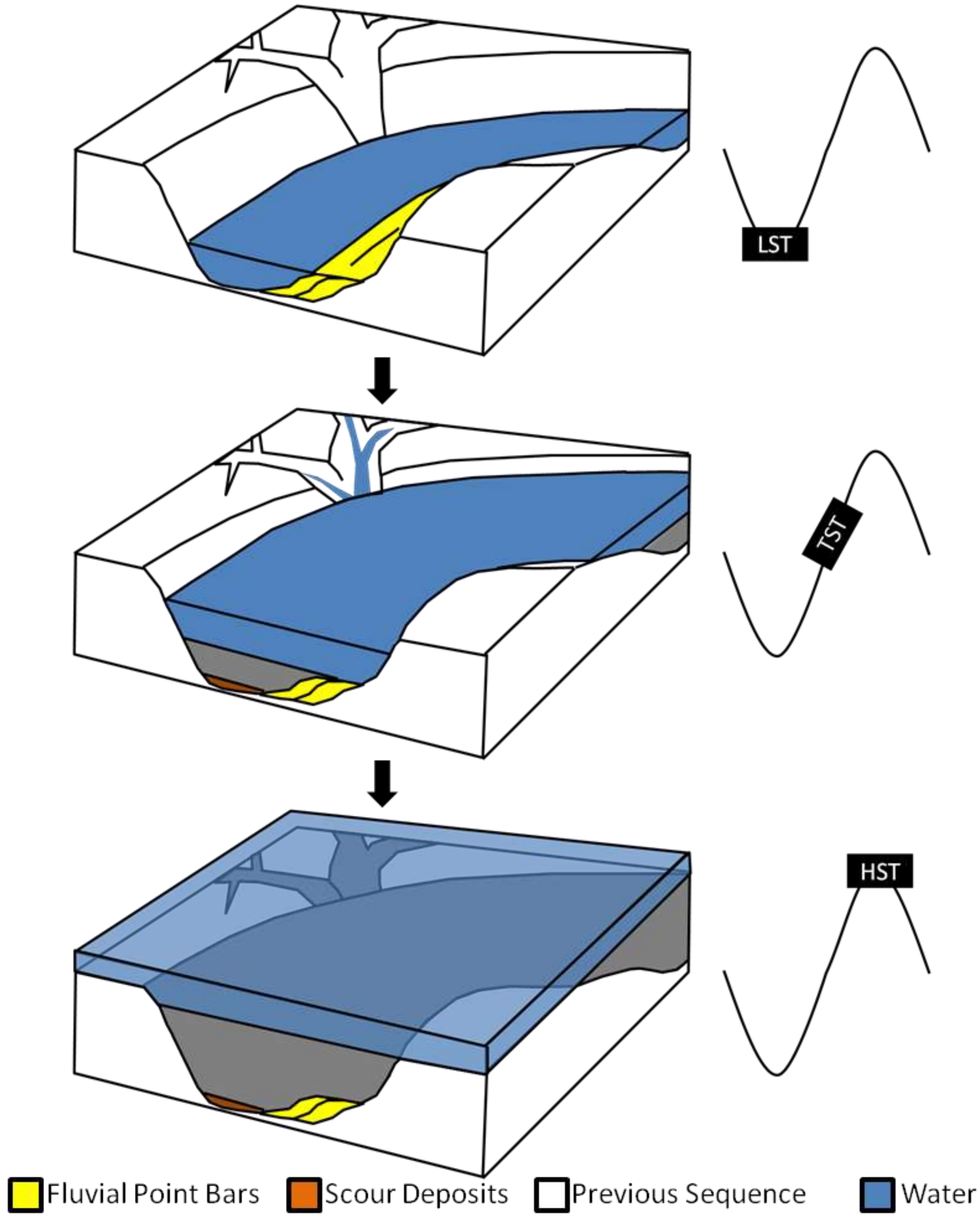
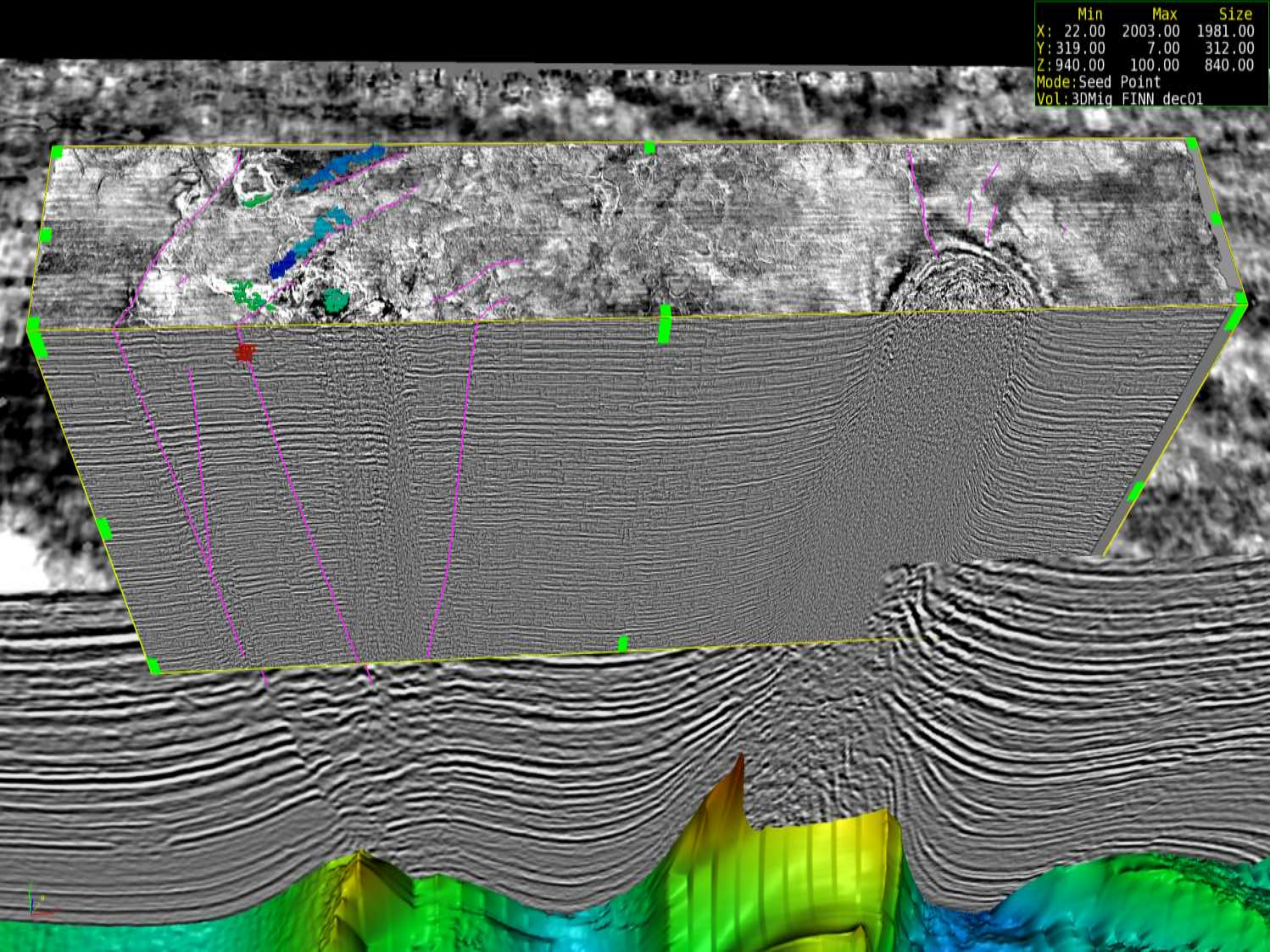


RelAcImp Timeslice	Seismic Amplitude Section	Description	Interpretation
		- Dipping reflections on inside of channel bend → Interpreted as coarser grained point bar deposits - Negative amplitude near base of channel form → Top of coarse grained scour deposits - Transparent channel fill → uniform muddy fill	
		- Channel scour in a meander bend - Negative amplitude response at top of scour → top of coarse grained scour deposits	
		- 'V' shaped tributary incision as it connects to the main meandering channel - Thin point bar deposits indicated by parallel dipping reflections - Complex and mostly transparent valley fill interpreted as fine grained muds	

Meckel and Mulcahy, 2016, INTERPRETATION


A
Top of Valley Fill
31 m
Coarser Grained, Structureless Sand At Base of Valley
Sand and Coarse Silt, Laterally Accreted Point Bars
Floor of Valley
B
-60
-80
-100
-120
-140
Laterally Accreted Point Bars
15m
UC?
100m
Basal Deposits
Meckel and Mulcahy, 2016, INTERPRETATION


LST
TST
HST
Fluvial Point Bars
Scour Deposits
Previous Sequence
Water



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Z: 940.00 100.00 840.00
Mode: Seed Point
Vol: 3DMig FINN dec01

SELECT RESOURCES

Petersen, 2010, Marine and Petroleum Geology, *HR3D imaging of gas chimney structures in hydrated sediments of an* ***Arctic*** *sediment drift*.

Hustof, 2010, Basin Research, *3D seismic analysis of the morphology and spatial distribution of chimneys beneath the Nyegga pockmark field,* ***Norway***.

Lippus, 2013, SAGEEP, *High-resolution offshore 3D seismic geophysical studies of infrastructure geohazards (PG&E Diablo Canyon,* ***California****).*

Brookshire, 2015, Underwater Technology, *Applicability of ultra-high-resolution 3D seismic for hazard identification at mid-slope depths* ***GoM***.

Kluesner, 2016, Interpretation, *Seismic attribute detection of faults and fluid pathways within an active strike-slip shear zone – New insights from HR3D P-Cable seismic data along the Hosgri Rault, offshore* ***California****. USGS PC&MSC*

Meckel, 2016, Interpretation, *Use if novel high-resolution 3D marine seismic data to evaluate Quaternary fluvial valley development and geologic controls on distribution of shallow gas anomalies, inner shelf,* ***GoM***.

Relative Methane Concentrations

(Ongoing work of PhD Jacob Anderson)