TEMPORAL AND SPATIAL RESPONSE TO NATURAL PERTURBATIONS OF A COLD SEEP HYDRATE SYSTEM: WOOLSEY MOUND, GULF OF MEXICO

SECARB Offshore Partnership

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Task 4.0

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SOUTHERN STATES ENERGY BOARD

NATIONAL ENERGY TECHNOLOGY LABORATORY

Task 4.0

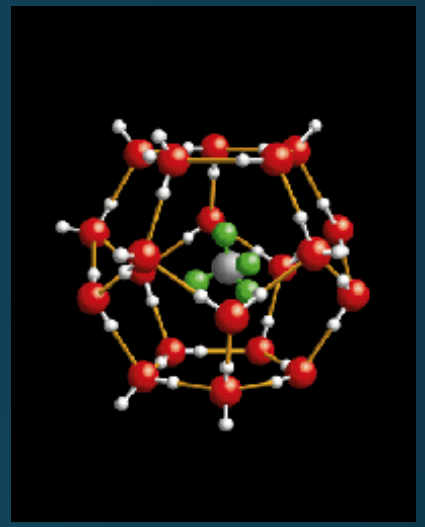
- Risk Assessment, Simulation, and Modeling. Going beyond the traditional NRAP process, this Task encompasses activities related to the refinement and adaption of existing data mining, analysis, and machine learning tools (SAS Viya decision system; Subtask 3.2), simulation tools, geologic models, and risk assessment and mitigation strategies for site-specific assessments of storage prospects in the offshore environment. To aid in a formalized process for characterizing prospects with high potential for commercial CO2 storage development, supported, to the extent possible and practical, by the SAS Viya platform, the project team will perform a robust characterization of risk, geologic/technical risk, operational risk, and commercial risk related to the full, integrated system (source, transport, and storage/utilization). Results will be used to highlight possible physical regulatory and/or commercial barriers, and mechanisms to overcome those barriers. This activity is directly dependent on the outcome of Task 3.0, namely the defined characteristics of representative storage opportunities.
- Subtask 4.3.2: Seismic Hazard Assessment and Earthquake Risk Analysis. Perform seismic hazard assessment and earthquake risk analysis in the study area, assess the evolution of gas hydrate-bearing systems and their temporal and spatial response to natural perturbations, based on lessons learned from the active Woolsey Mound cold seep at Mississippi Canyon 118.

Acknowledgements

- Southern States Energy Board (SSEB)
- U.S. Department of Energy (NETL)
- Gulf of Mexico Gas Hydrate Research Consortium
- Geophysical Exploration/ Tectonics and Geophysics Labs
- TGS-Nopec; WesternGeco
- Bureau of Ocean Energy Management (BOEM)
- Seismic Micro-Technology, Landmark Graphics, Veritas Hampson-Russell, Schlumberger- Petrel

Gas Hydrates and Methane

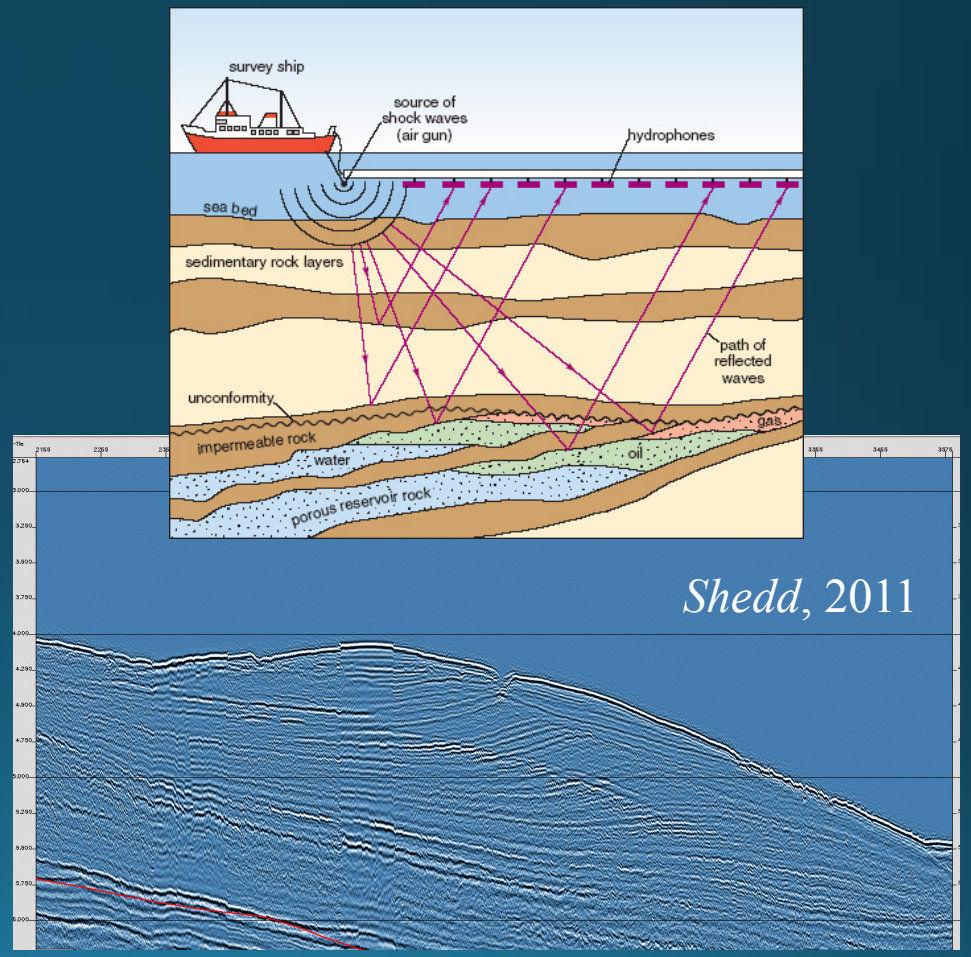
- Solid, ice-like structures
- Store CH_4 and other greenhouse gases
- Stable at high P and low T
- Each volume of hydrate contains up to 160 volumes of methane
- CH_4 is 20x more effective at trapping heat in the atmosphere compared to CO_2
- Role in climate, geohazards, and energy



Oak Ridge National Laboratories, USGS

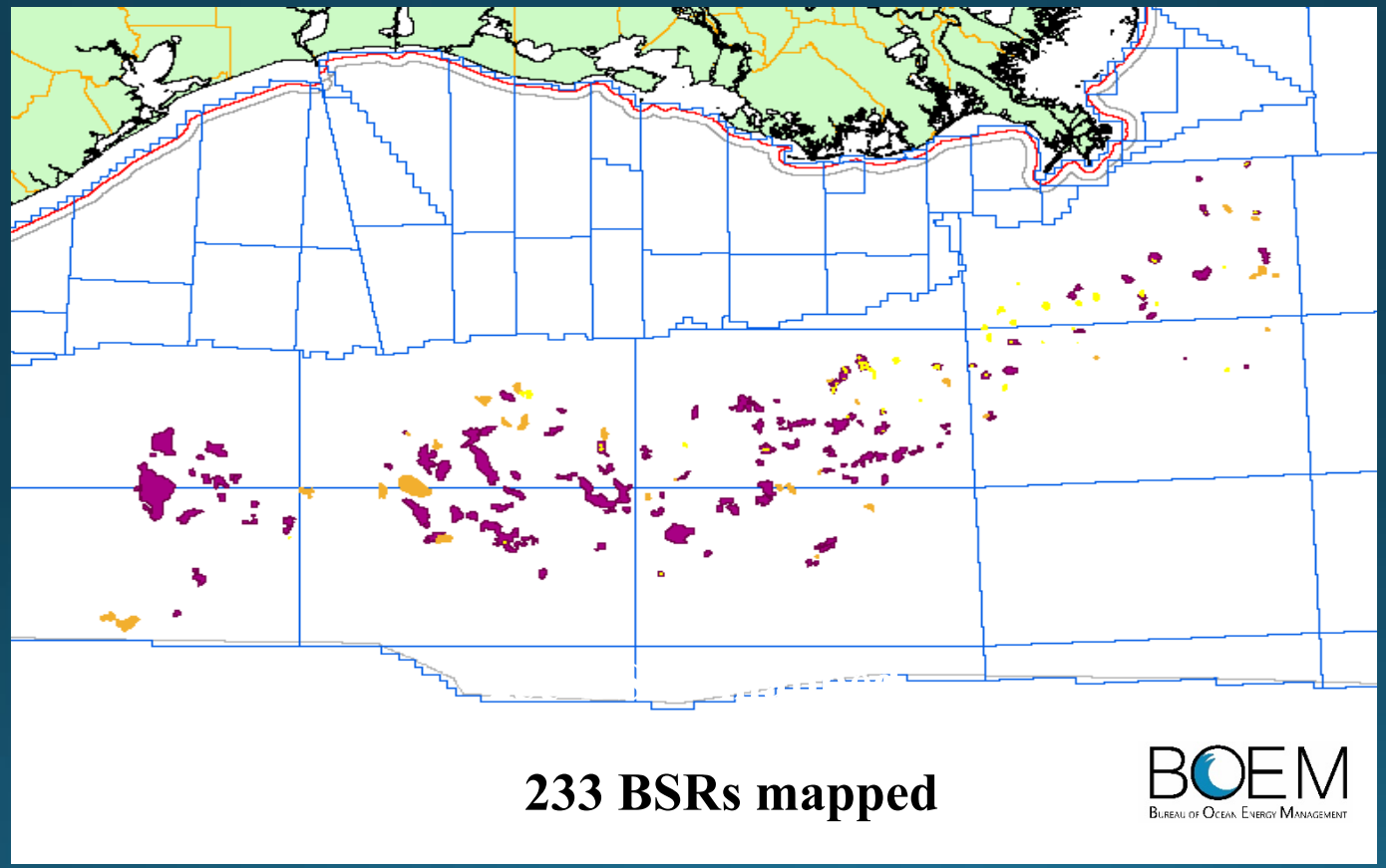
Remote Assessment of Gas Hydrates

- High amplitude (BSR)
- Crosscutting geometry
- Reversed polarity
- High seismic velocities
- “Blanking” effect
- AVO effects



Blake Outer Ridge (Eastern US)

Distribution of BSRs in GOM



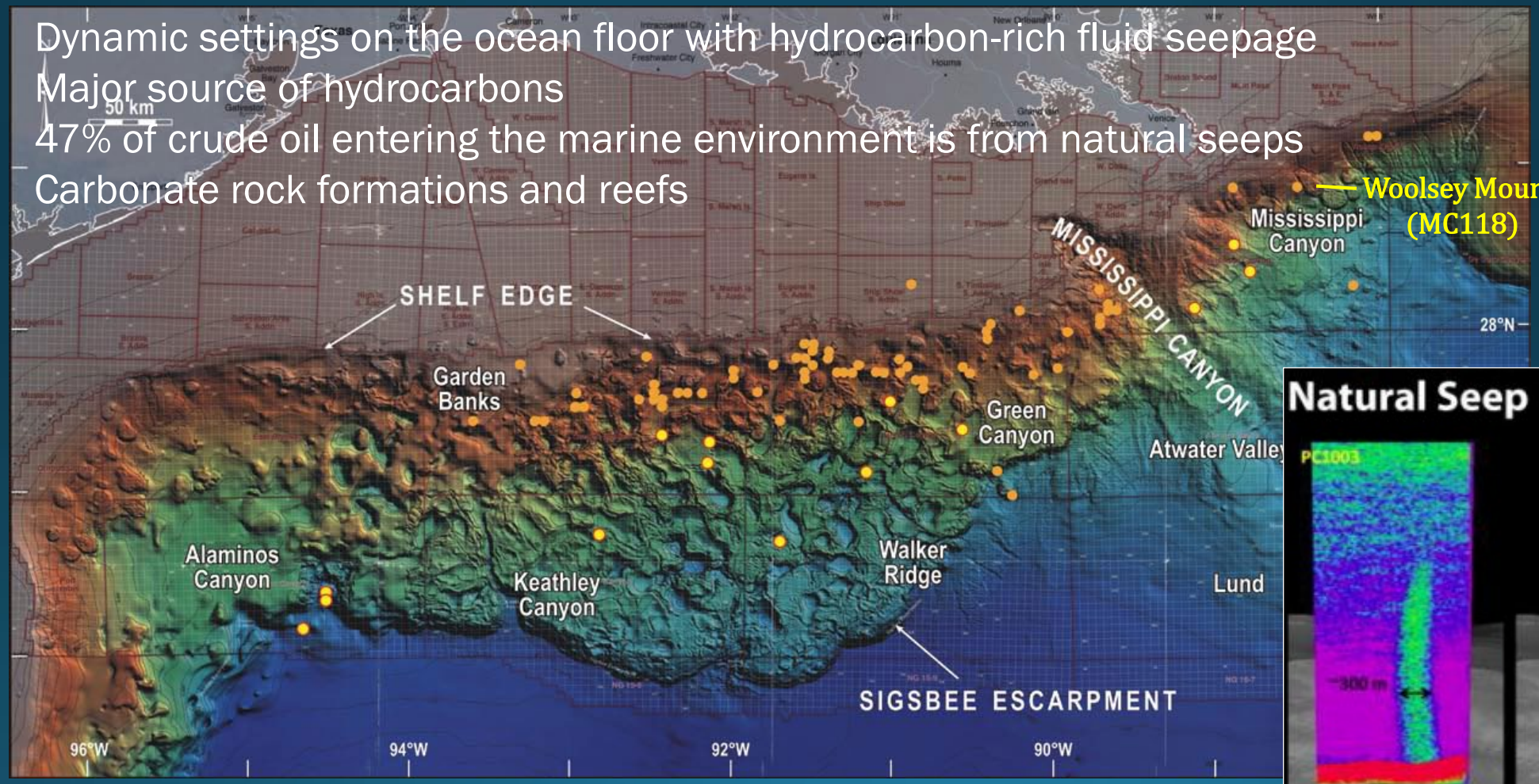
129 mapped
Discontinuous BSRs

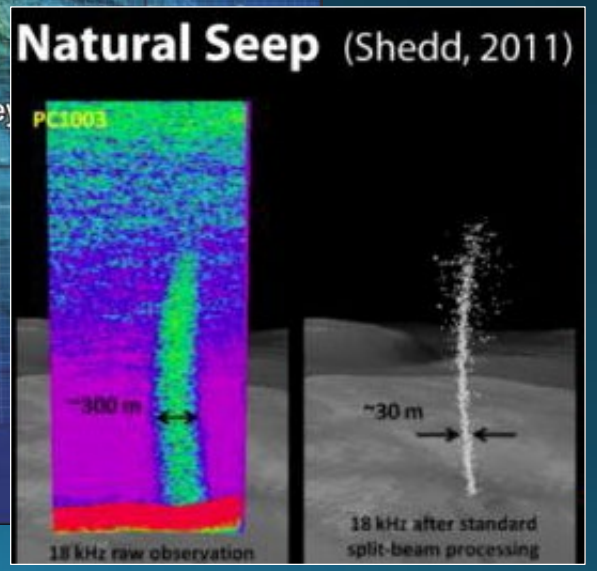
31 mapped
Continuous BSRs

73 mapped
Pluming BSRs

Cold Seeps in the Gulf of Mexico

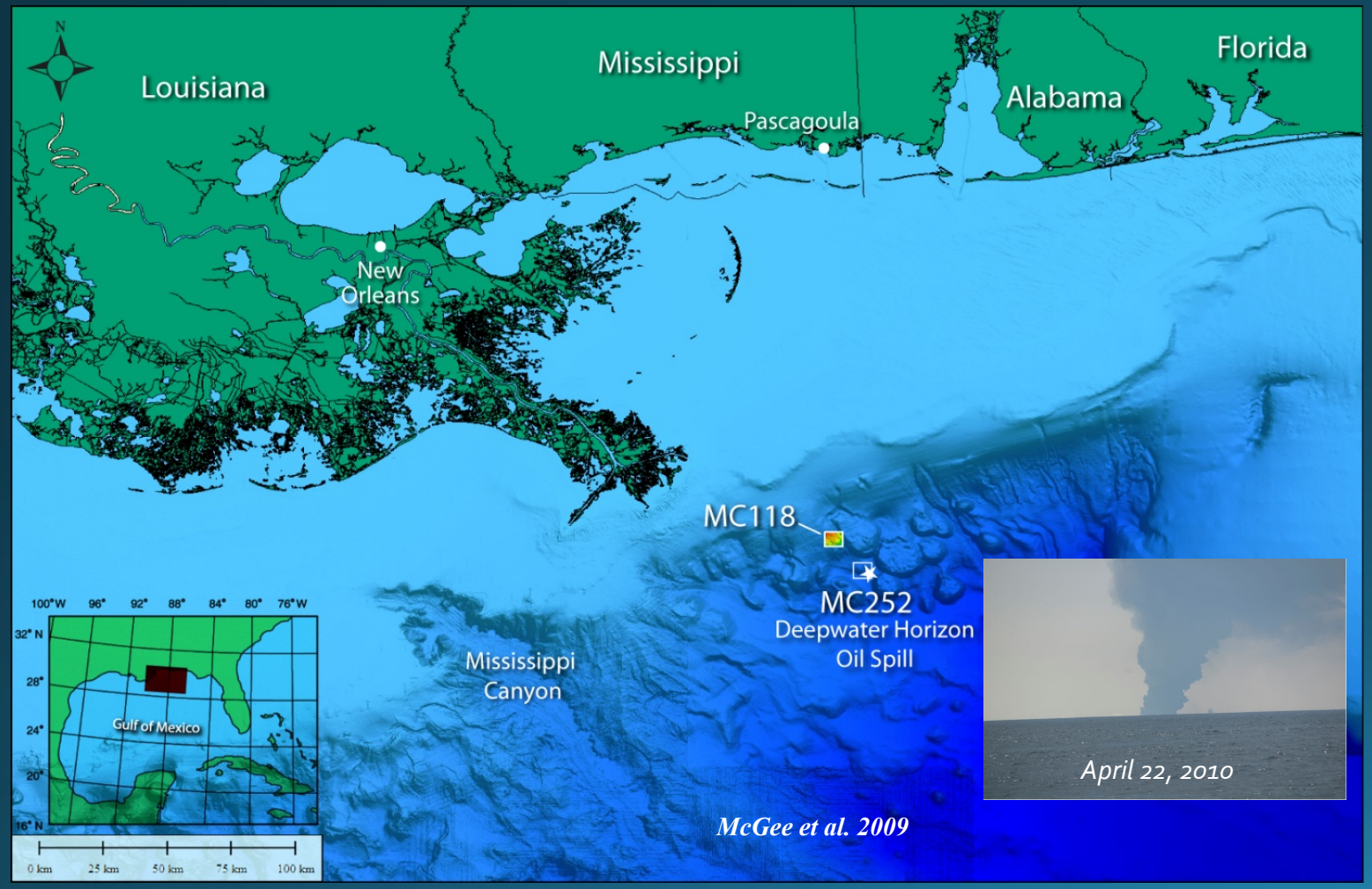
- Dynamic settings on the ocean floor with hydrocarbon-rich fluid seepage
- Major source of hydrocarbons
- 47% of crude oil entering the marine environment is from natural seeps
- Carbonate rock formations and reefs





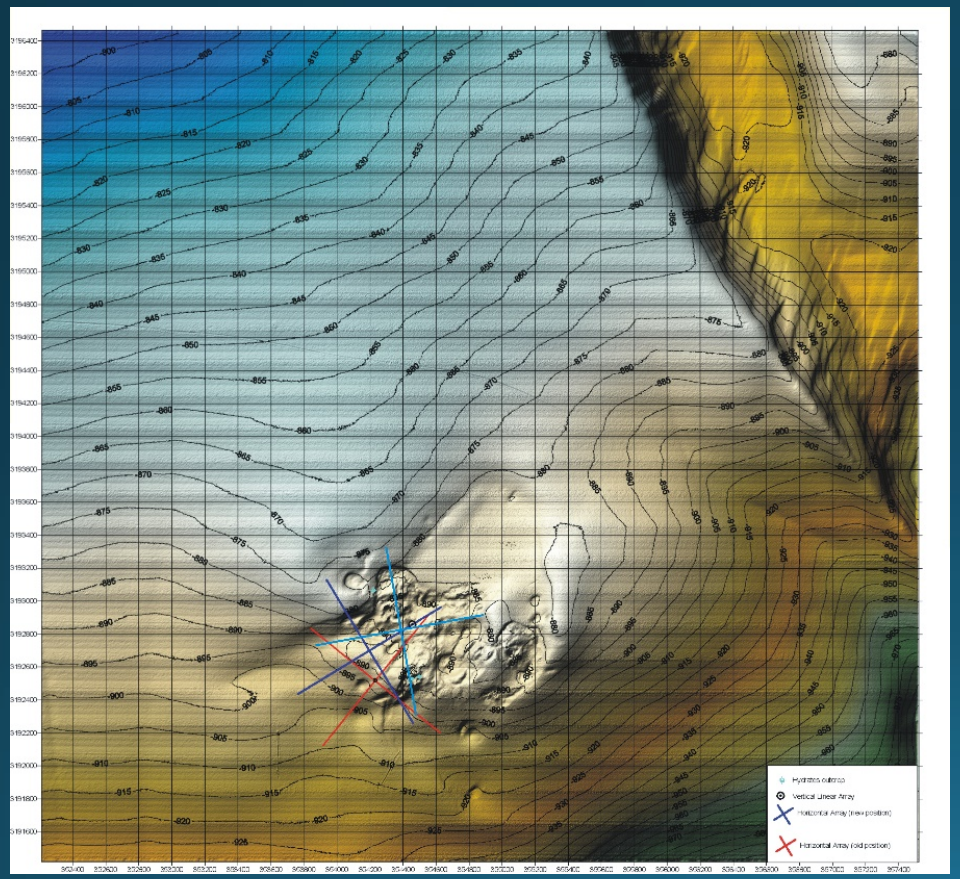
(Fisher et al., 2007)

Woolsey Mound - CSHS



- 900 m WD on the N continental slope of the GOM.
- Slope highly discontinuous, intersected by slumping, folding and faulting mainly driven by salt tectonics and sediment load delivered by the Mississippi River.
- Deepwater Horizon rig, Mississippi Canyon 252, April 22, 2010.

Woolsey Mound: Fault-Controlled, Transient, Thermogenic Hydrate System

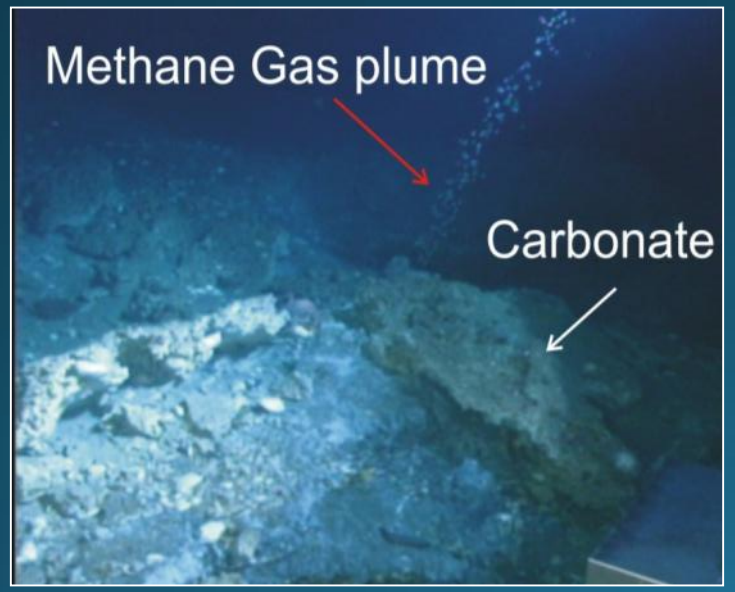


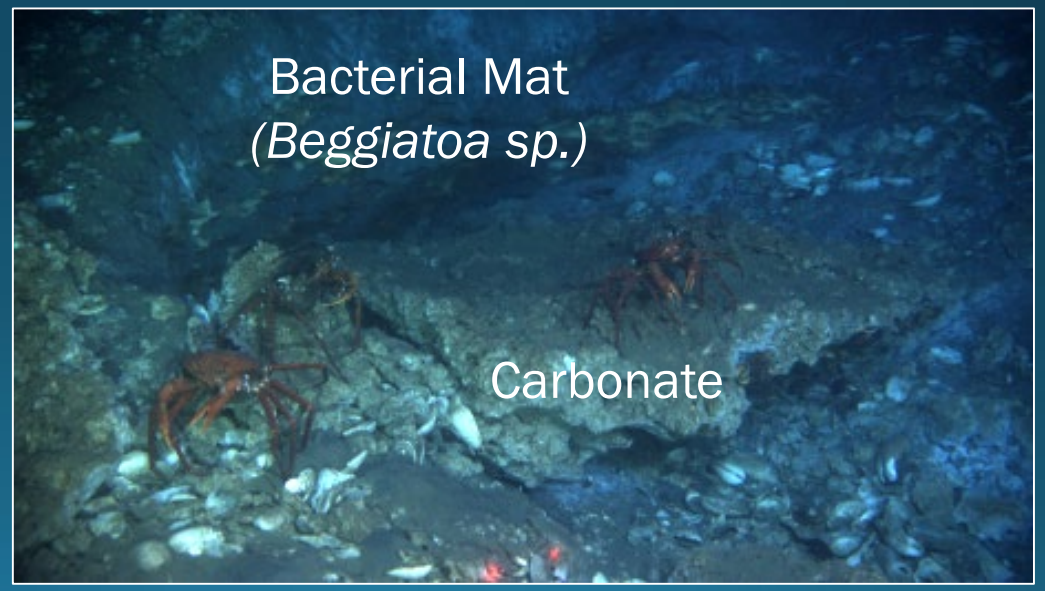
Macelloni et al., 2012

- Mid-slope of GOM
- Salt tectonically driven cold seep
- Gas venting at the seafloor
- Outcropping hydrate chemosynthetic communities, carbonate mounds, and bubble plumes
- Chemosynthetic communities
- Relatively shallow water depth (<1000 m).

Surface Expression of Seepage

- Methane-derived authigenic carbonate (MDAC) is the product of AOM (anaerobic oxidation of methane) by sulfate reducing bacteria (e.g. *Archaea sp., Beggiatoa sp.*)
- Requires persistent fluxes of methane through time
- Excellent archive for reconstructing fossil methane seepage history (paleomounds)

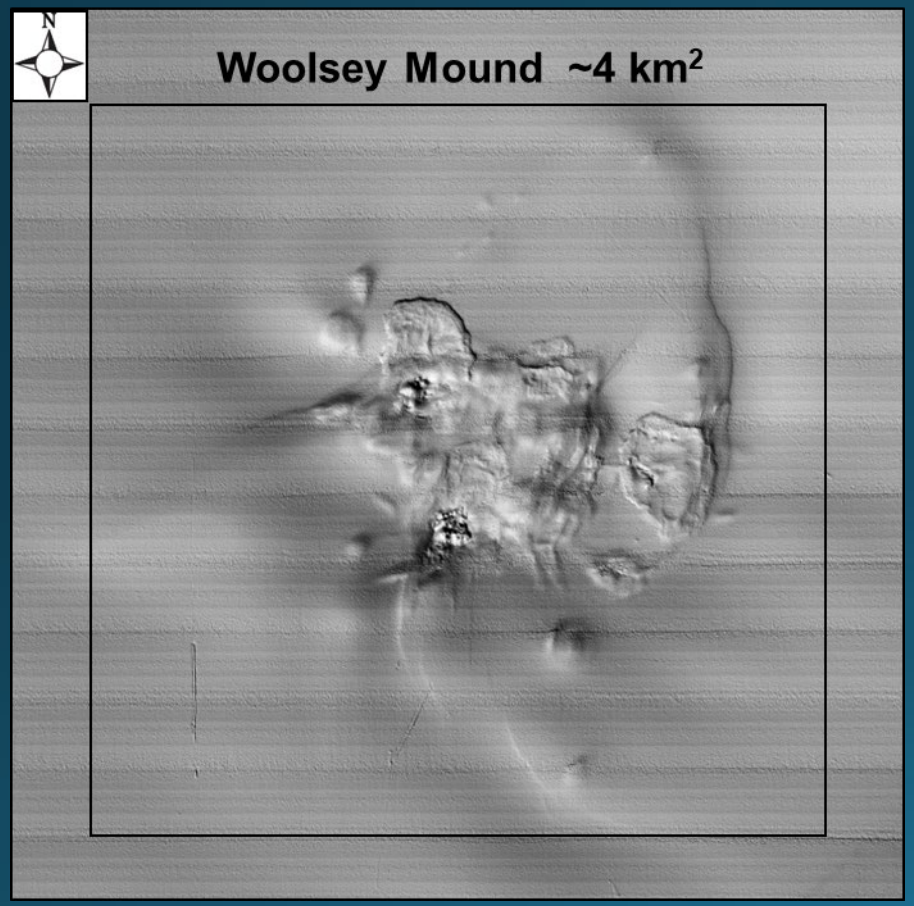




Simonetti , 2015

Woolsey Mound (pictures courtesy of C. Lutken, MMRI-University of Mississippi)

Indirect Evidence of Seepage



Simonetti et al., 2015

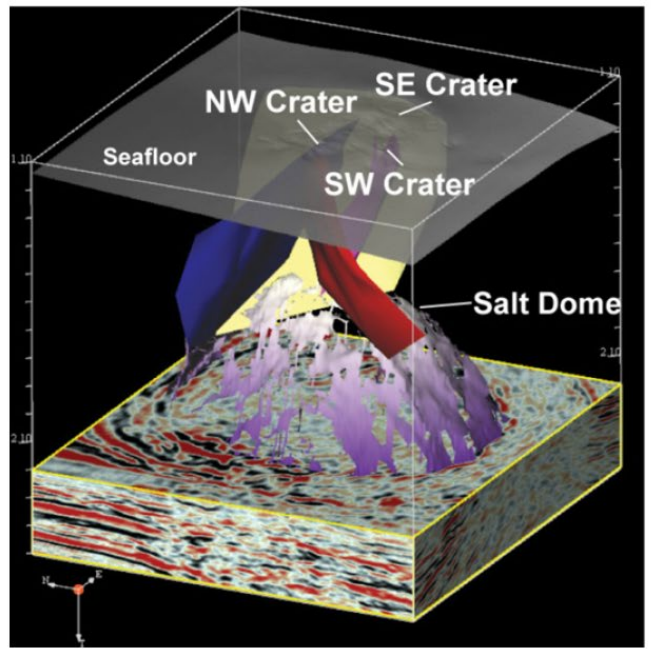
- Craters and pockmarks are seafloor sub-circular depressions resulting from abrupt gas (e.g. methane) release in the water column
- Require episodic fluxes of methane through time

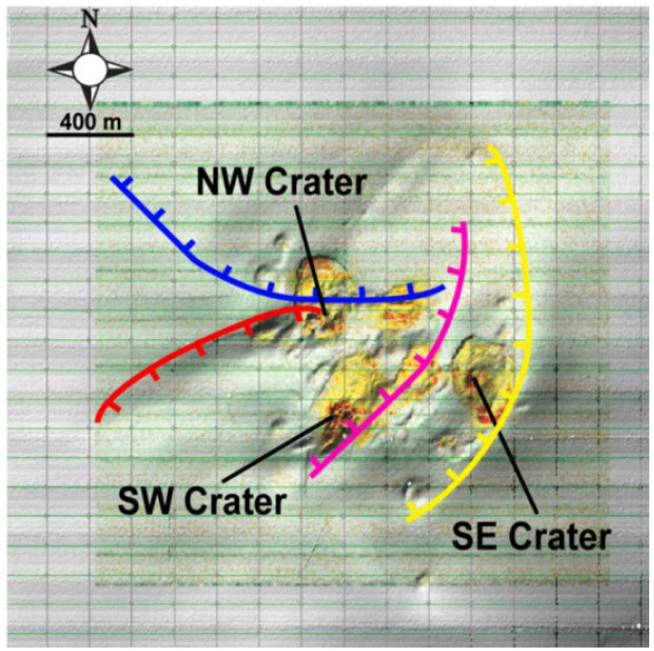
Woolsey Mound Hydrates

- Do not exhibit the classic regional BSRs on seismic sections.
- Seem to form around salt-related faults that provide likely migration pathways for the thermogenic hydrocarbons.
- Other methods need to be implemented in order to detect them and provide estimates of their volumetric extent.

MC 118, (Lutken et al., 2011)

Salt Dome and Major Faults





Macelloni et al. 2012

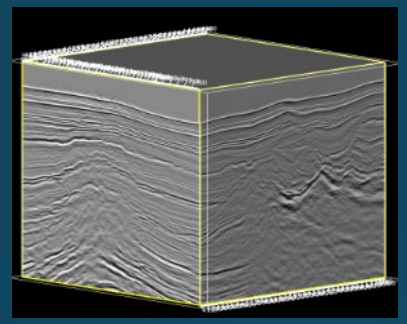
- Fluid flow and gas hydrates formation are segmented laterally along faults.
- Hydrate formation and dissociation vary temporally in the vicinity of active faults, and can seal them as conduits for thermogenic fluids.
- Periodic migrations of gases may perturb the GHSZ in terms of temperature and pressure, producing the observed lack of classical BSRs.
- Fluid expulsion events are suspected to occur episodically in the NW and SW complexes where they are probably responsible for crater formation.

4-D Seismic Monitoring

4-D PROCESSING SEQUENCE (cross-equalization):

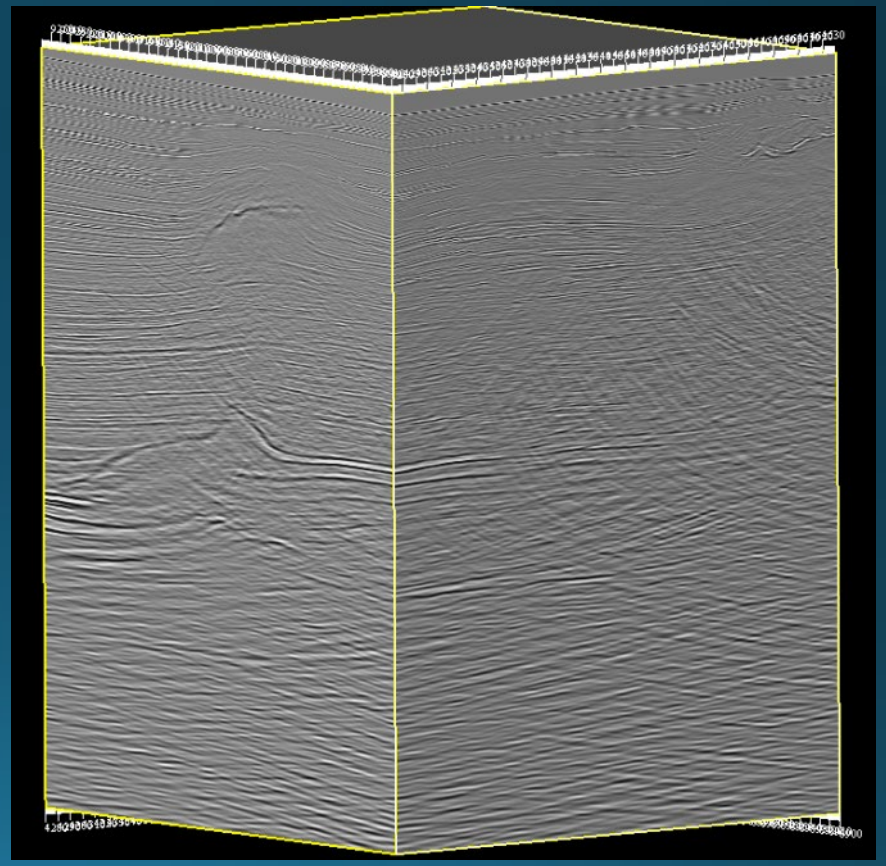
- ✓ re-sampling
- ✓ 3D geometry re-binning
- ✓ time shift correction
- ✓ gain X-normalization
- ✓ phase matching
- ✓ shaping filter

3 s TWTT



TGS-NOPEC, 2000

10 s TWTT

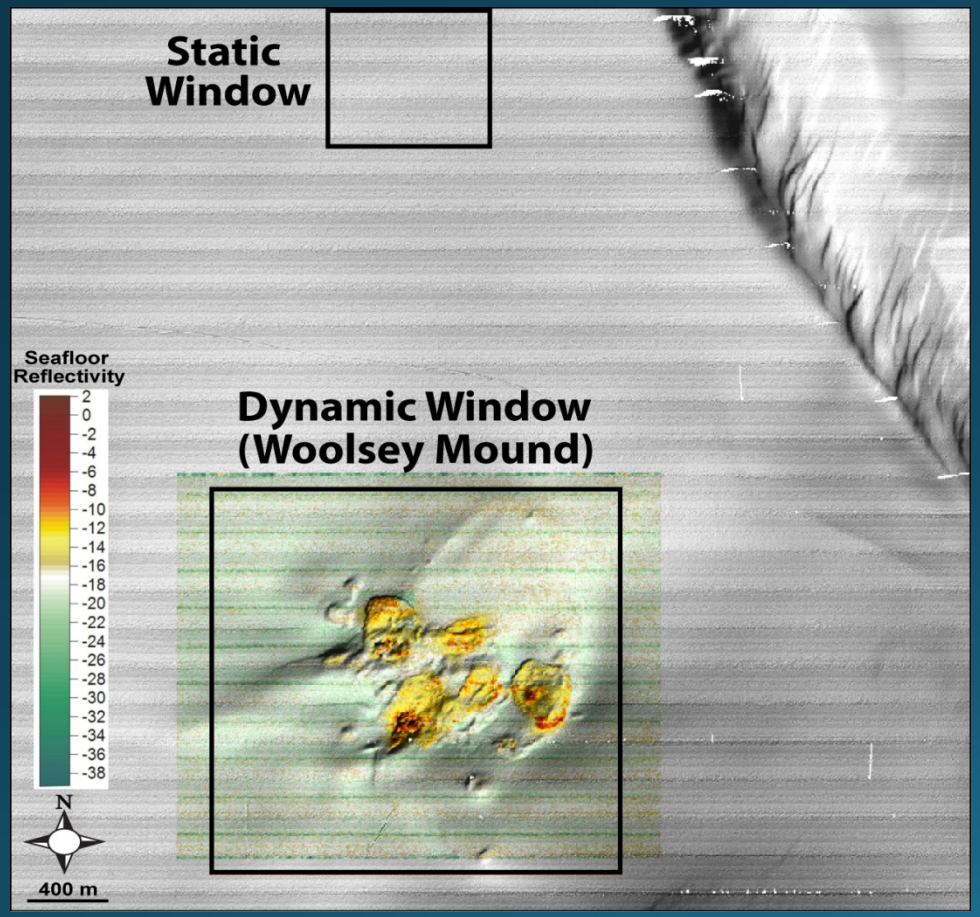


WesternGeco, 2003

Amplitude difference of the two datasets generates residual amplitudes (4-D anomalies)

Simonetti et al., 2015

Windows for Processing Sequence



Simonetti et al., 2015

Static Window:

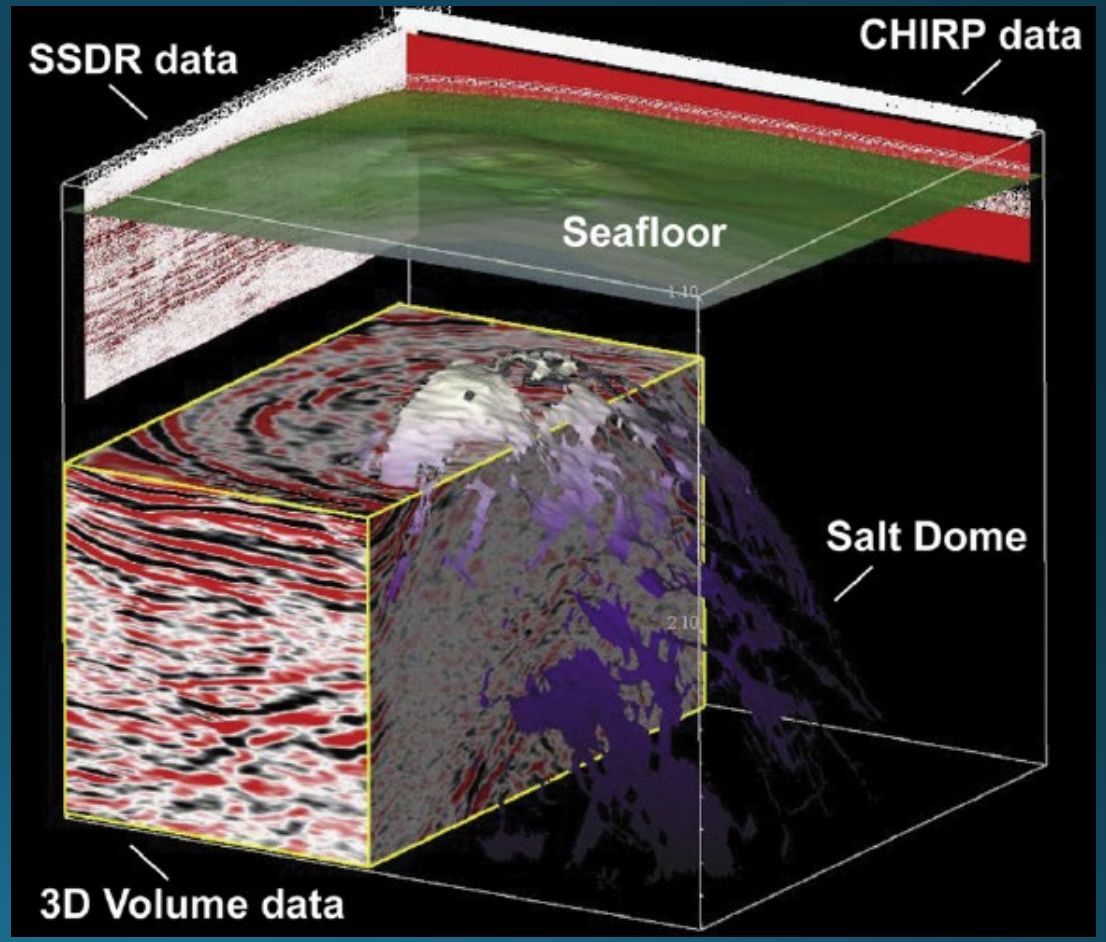
- significant subsurface changes in pore-fluid content are not expected to occur within a 3-year time scale

Dynamic Window:

- significant subsurface changes in pore-fluid content may occur within a 3-year time scale

Hypotheses

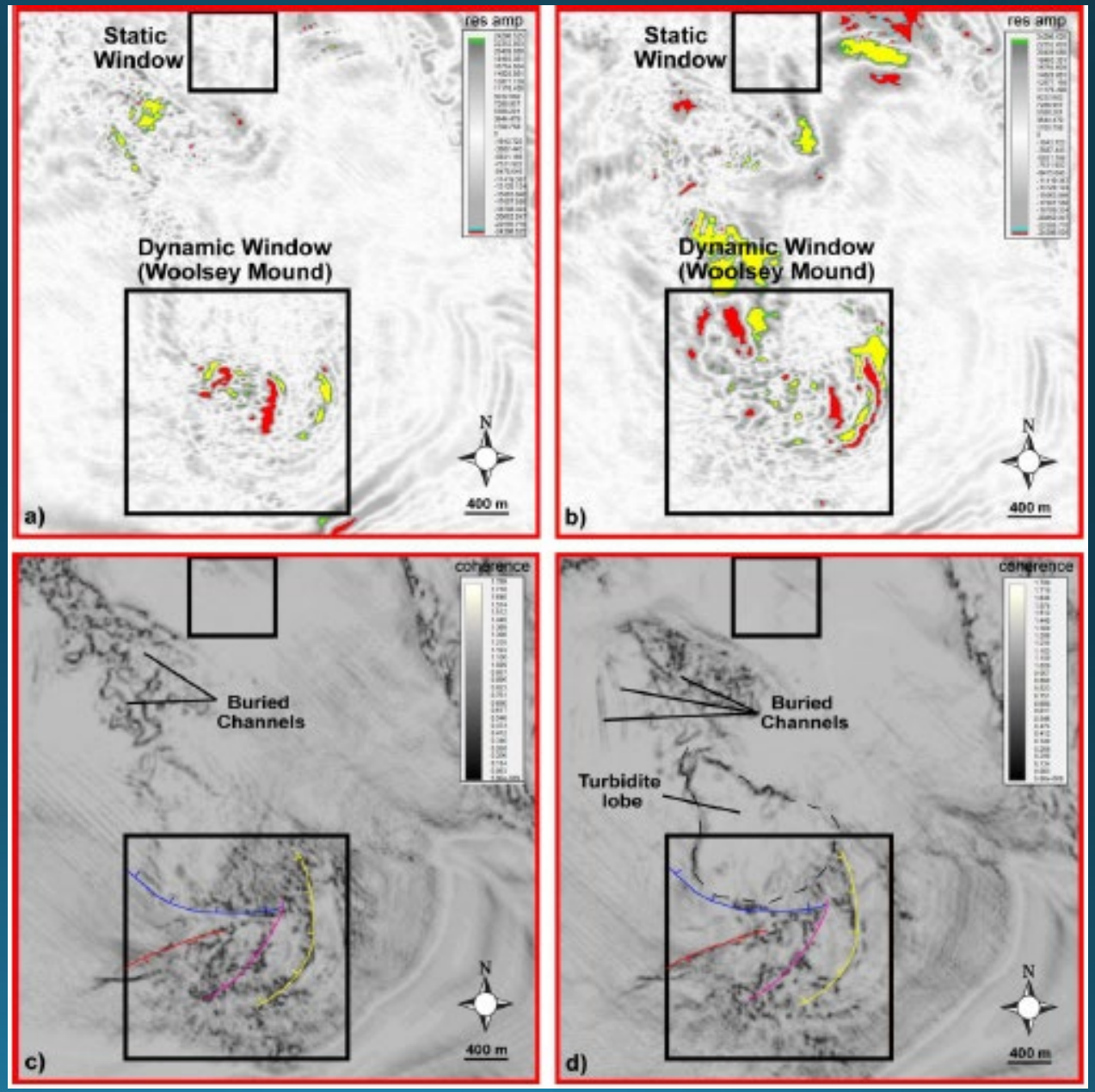
- GH are genetically related to the salt system through active normal faults, conduits for thermogenic gas
- GH formation and dissociation vary temporally in the vicinity of active faults, and can temporarily seal them as conduits for thermogenic fluids.
- GH at WM are controlled by a highly heterogeneous stability field leading to the general paucity of BSRs.
- Apparent temporal changes in seismic images of the subsurface are correlated with periodic fluid expulsion and hydrate dissociation.



Macelloni et al., 2012

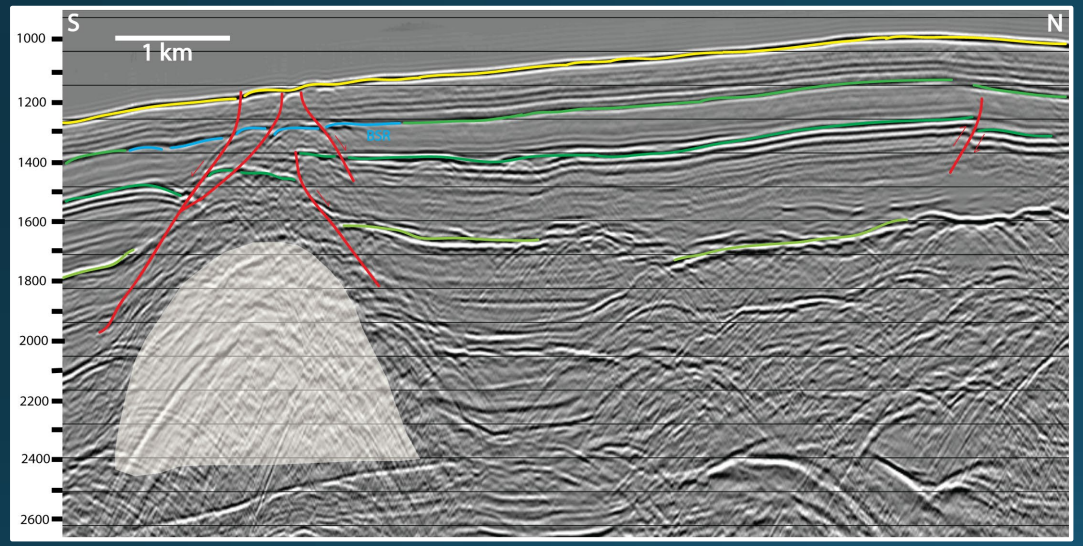
4-D seismic anomalies (time slices near the BHSZ)

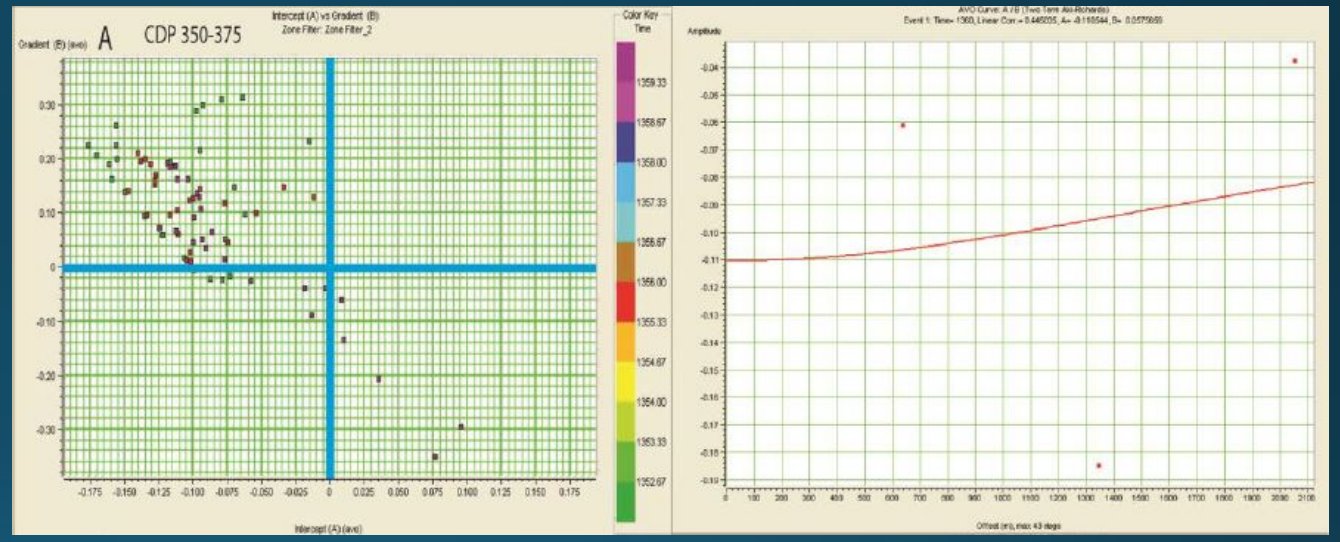
Subsurface Structures (time slices near the BHSZ)



Simonetti et al., 2015

AVO Analysis

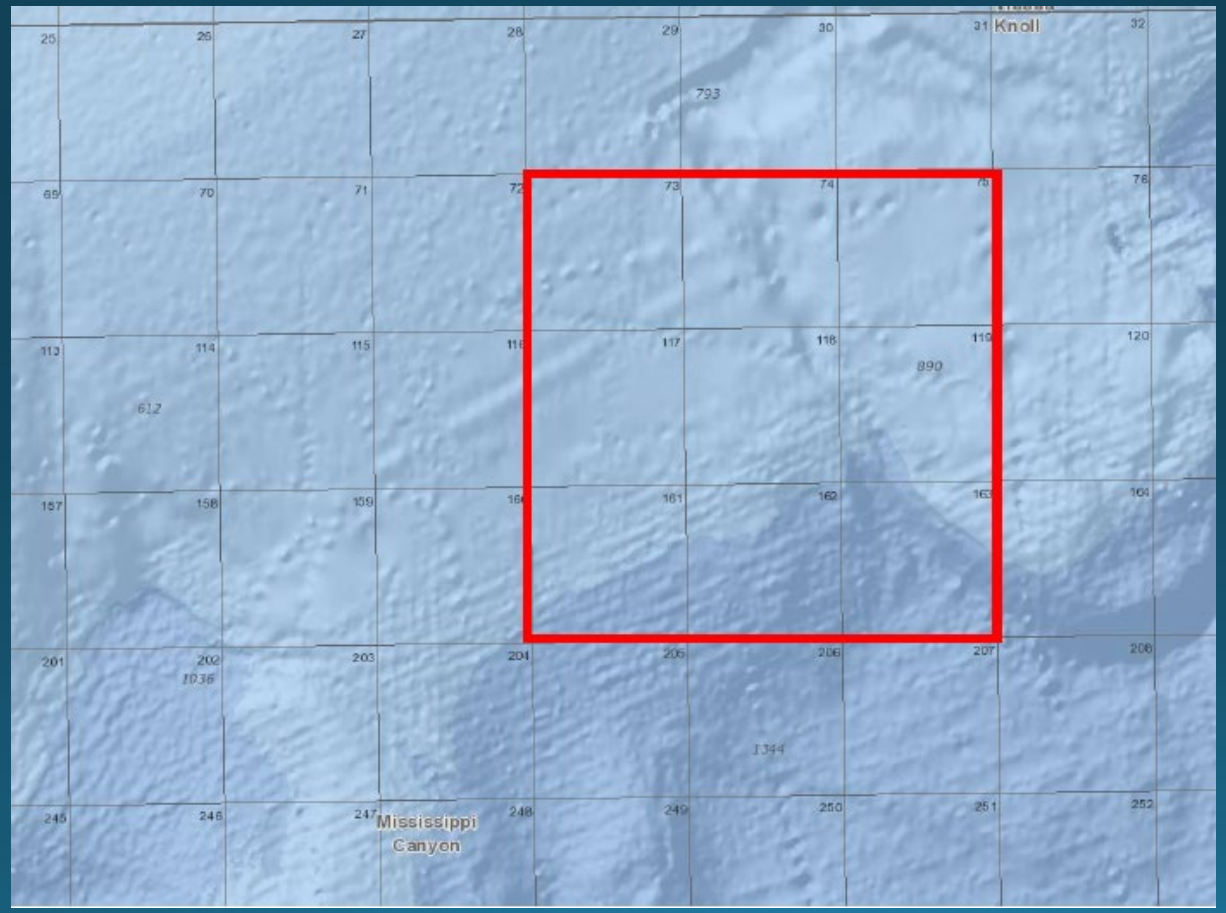




Shallow bright-spot reflectors representing the base of the hydrate stability zone (HSZ) should exhibit an amplitude variation with offset (AVO) if free gas is present.

AVO cross-plot indicates presence of Class IV gas sands. Free gas underlying relatively high-velocity unit.

Data to be Aquired: TGS-Nopec, 2010



Summary

- Salt has dominant influence on geologic evolution of Woolsey Mound
- Faults are both hydrate reservoirs and hydrocarbon migration pathways
- Shallow bright spot represent BHSZ
- The hydrate stability field is highly fluctuating through time and space
- 4-D seismic anomalies are spatially associated with faults and may represent changes in the subsurface pore-fluid content
- CSHS may operate independently from eustatic fluctuations, but driven by tectonics
- Results will provide fundamental numerical parameters of the development and evolution of a gas hydrate-bearing system and its response to natural perturbations over a time window comparable to human scale processes

Thank You!

Photo by Ian MacDonald, TAMU