EVALUATION OF HYDRATE RESERVOIR QUALITY IN US WATERS-WHERE TO NEXT?

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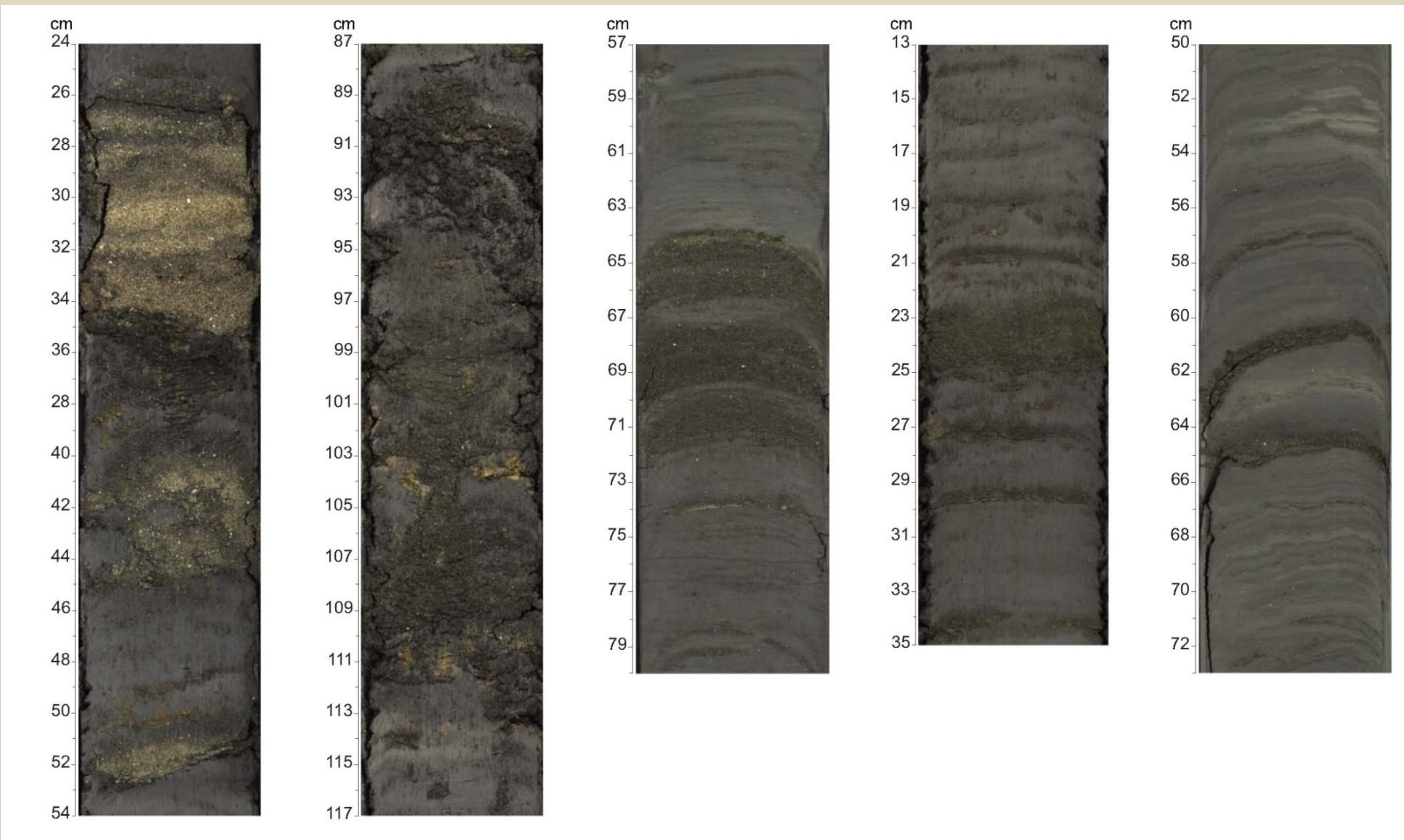


Diffuse versus Advective Systems

Disseminated verses Pore and Fracture Filling Gas Hydrate

- **Coarse Grained Lithologies in GHSZ: Marine Environment**

  Turbidite Systems

  Contourite Systems

  Volcaniclastic Systems

  Shelf, Fluvial, Alluvial… Systems (for Permafrost Environments)

- **Deformation Regime in GHSZ (enhances advection)**

  Salt Tectonics

  Accretionary Folds and Thrusts

  Faults (strike-slip, normal reverse)

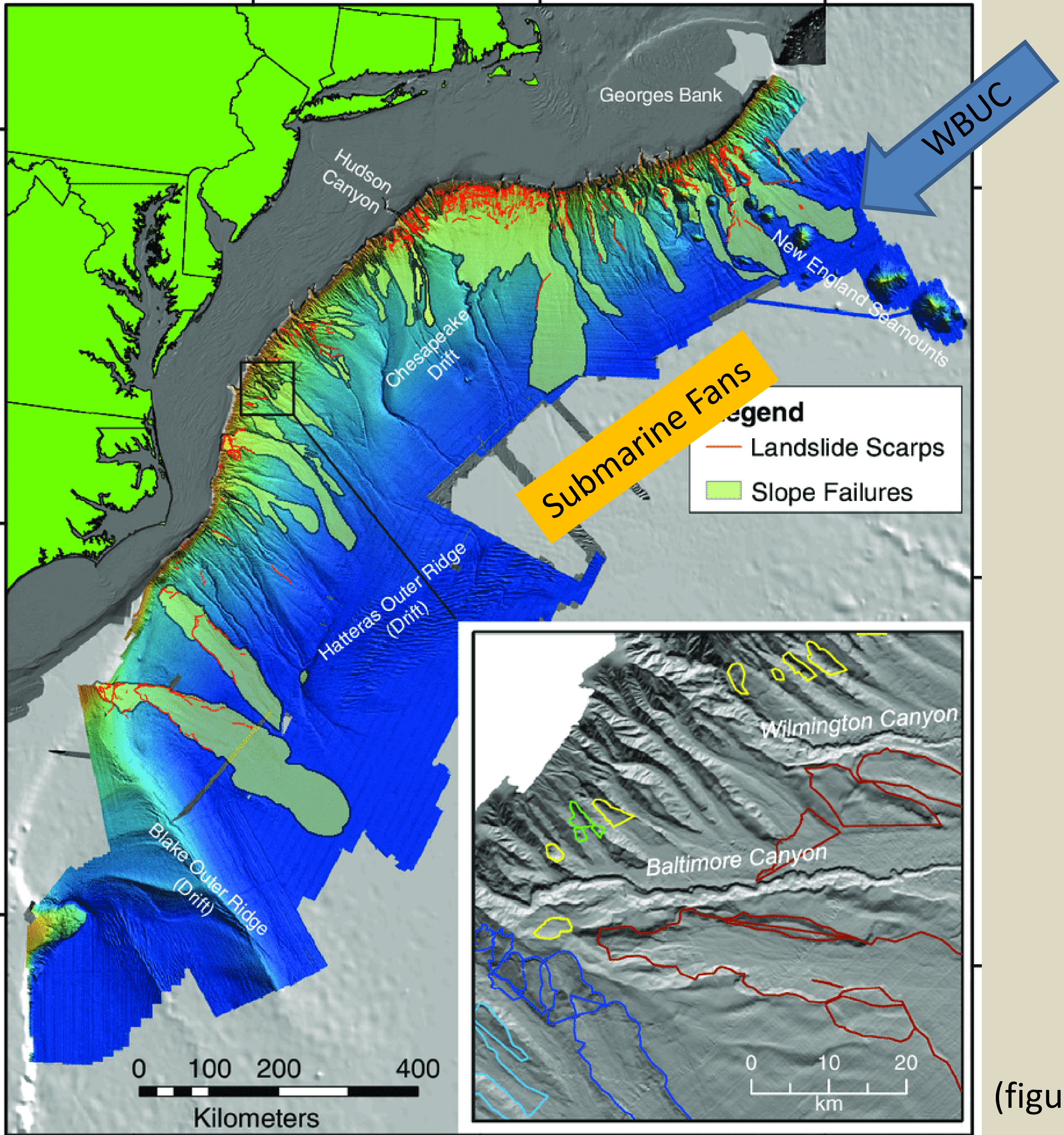
  Broad Regional Subsidence → Tilting

Strong advection results in methane losses at seeps

AOM can be an efficient biogeochemical filter-consuming methane

Controls for Concentrated Gas Hydrate Accumulation	GOM	ATLANTIC	PACIFIC CASC., CA, GULF of ALASKA	ALASKA NORTH SLOPE- Marine & Permafrost
Coarse Lithology	Turbidites	Contourites> Turbidites	Turbidites & Ashes	Shelf Sands Fluvial, Alluvial
Deformation Regime	Salt Tectonics	Regional subsidence-Tilting	Accretionary folds, strike-slip, normal, and reverse faults	Regional Subsidence-Tilting
Available Gas	Microbial + Thermogenic	Microbial + Thermogenic	Microbial + Thermogenic	Microbial + Thermogenic

Atlantic Margin



Submarine Fans:

- Glacial-driven sedimentation to the north
- Deepwater 4-5k m
- Reworked by Western Boundary Under Current (WBUC)
- Hatteras Outer Rise and Blake Ridge Drifts

(figure after ten Brink et al., 2014)

BOEM Atlantic Margin Gas Hydrate Assessment 2013, Frye, Shedd, and Schuenemeyer

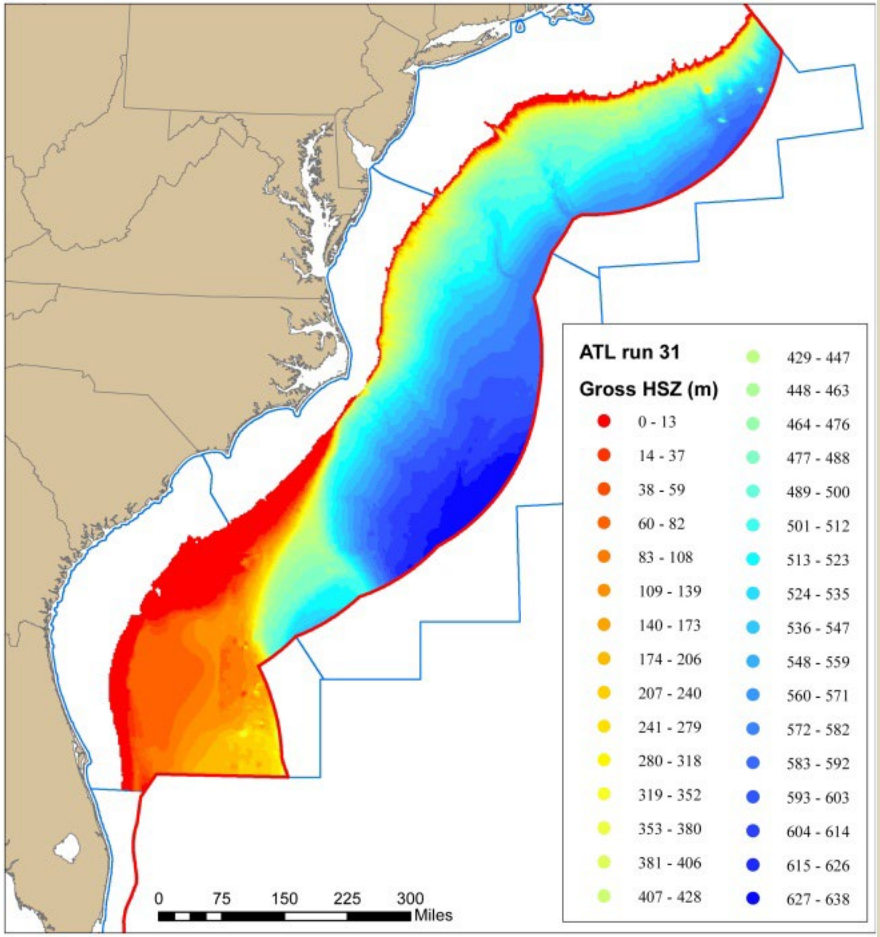


Figure 13. *Spatial output of the mean value of the gross HSZ thickness (units = meters).*

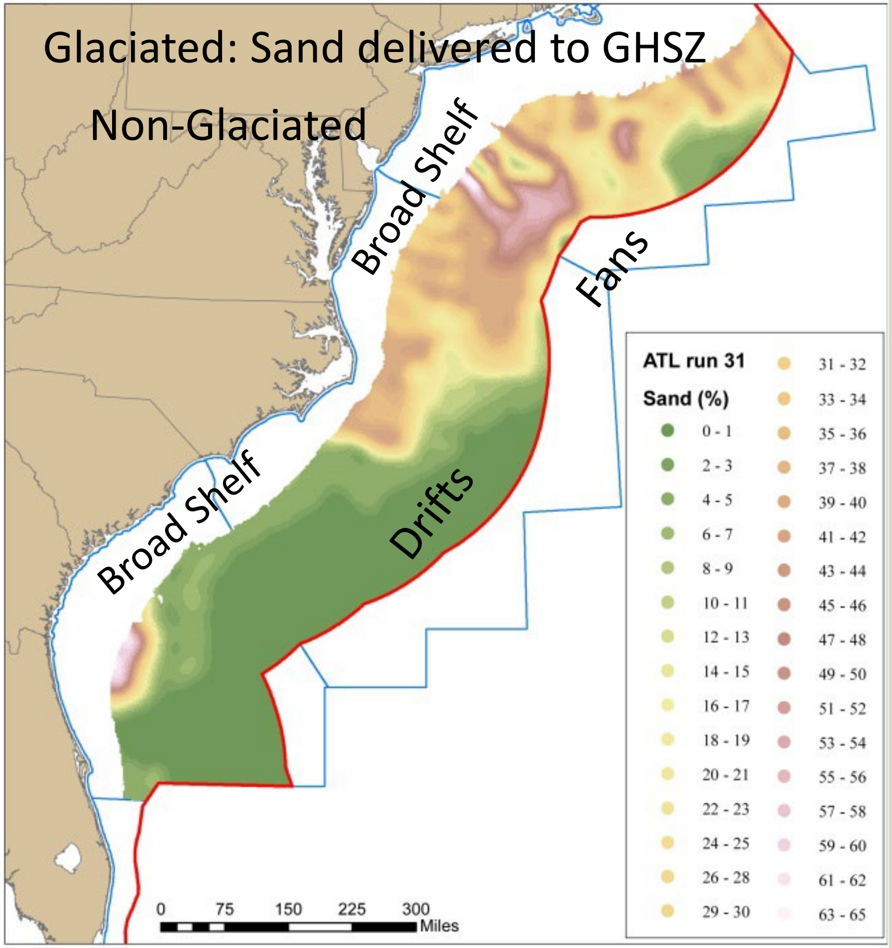


Figure 8. *Sand distribution map spatial input, reported as a percent of the upper 2000 ft of stratigraphic section.*

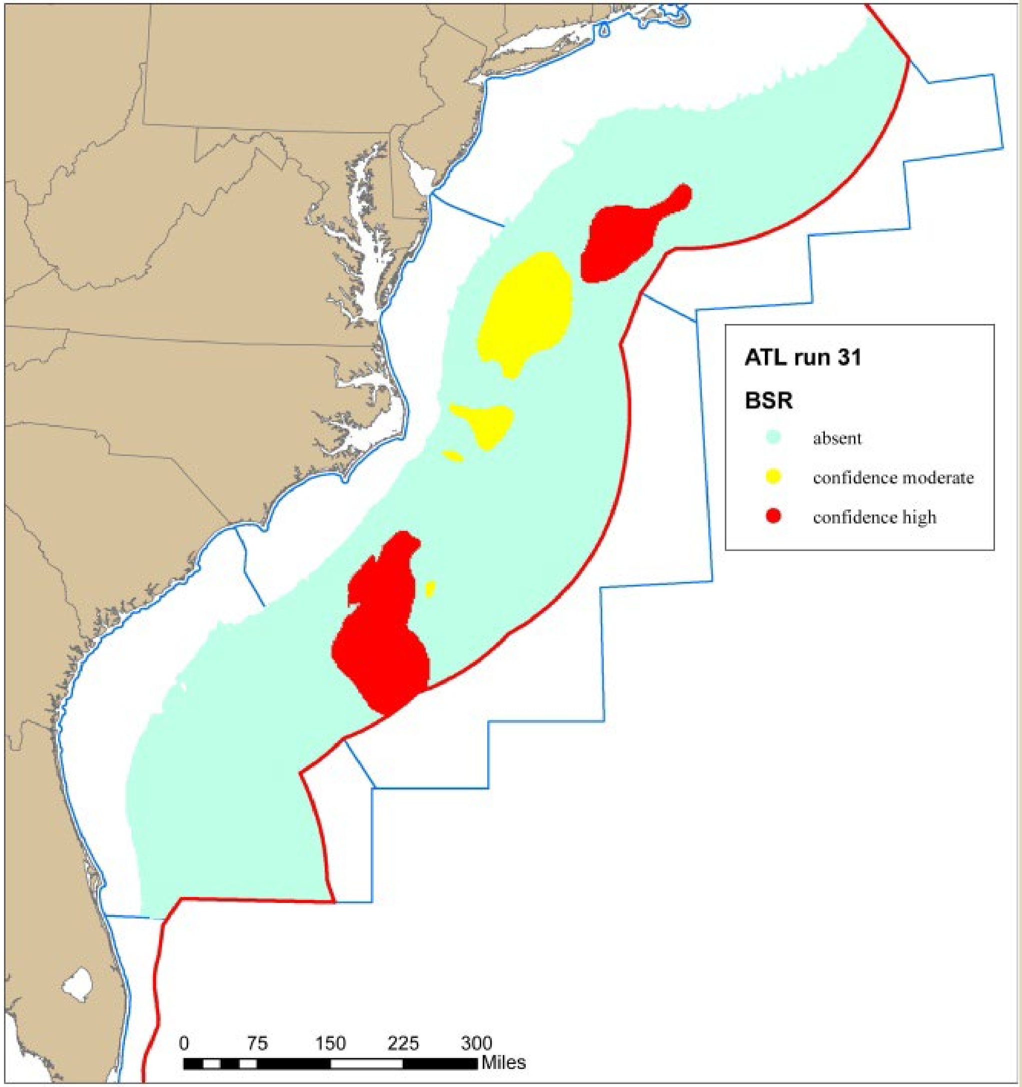
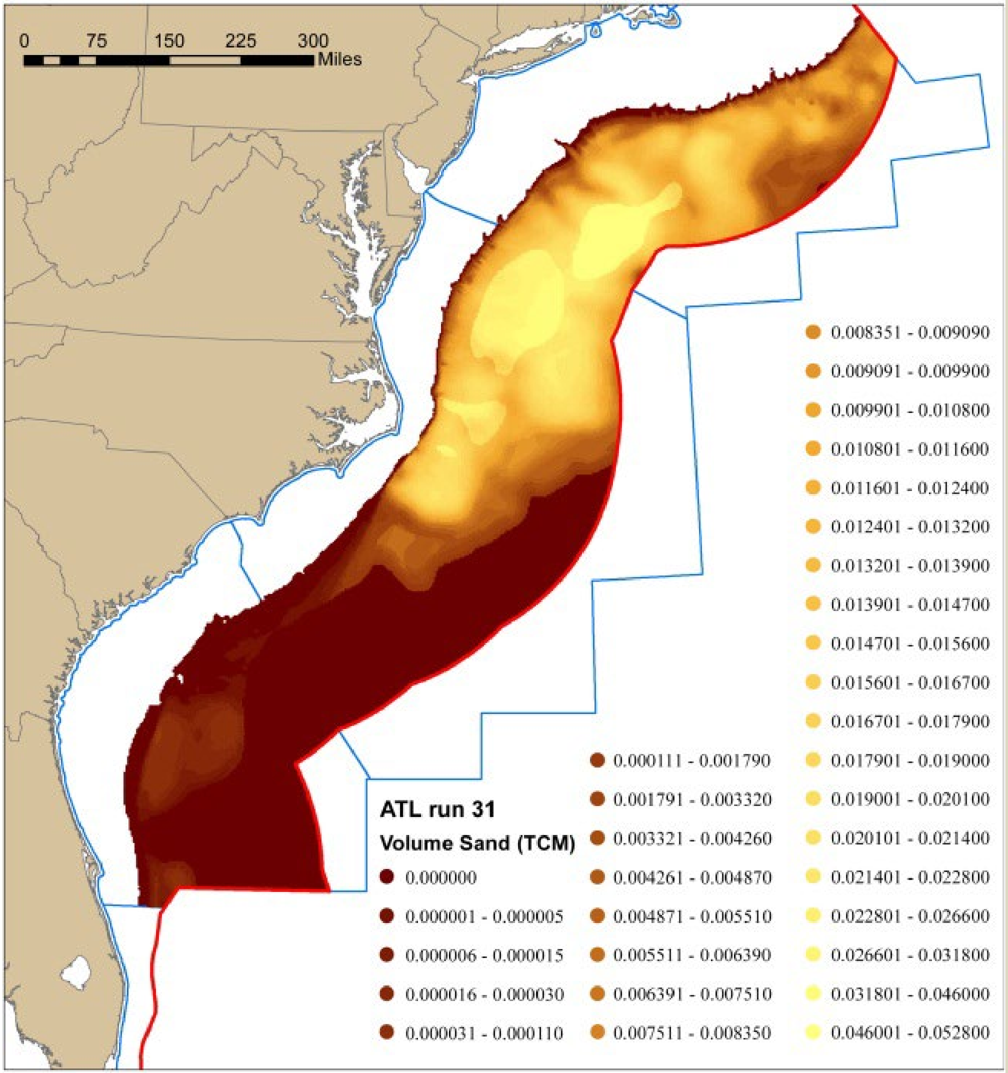


Figure 9. *Bottom Simulating Reflector (BSR) distribution spatial input.*

BOEM Atlantic Margin Gas Hydrate Assessment 2013, Frye, Shedd, and Schuenemeyer



"In general, the deepwater Atlantic OCS subsurface is dominated by **gentle regional dip and relatively few features that would serve to focus gas migration**, resulting in an environment that is likely dominated by vertical gas migration. However, we concur with observations made by Tucholke et al. (1977) and believe that in select areas of the Atlantic OCS, such as the positive relief anticlinal feature that comprises the Blake Outer Ridge, a not insignificant component of dip-driven (lateral) gas migration does take place."

Figure 40. Map view of the mean in place gas hydrate volume in sand reservoirs only. Units are trillion cubic meters (1 x 1012 m3) of methane per 9 km2 model cell expressed at surface temperature and pressure. Note that this value is calculated using a deterministic approach.

Gulf of Mexico Margin

Effectively Glaciated: Sand delivery to GHSZ

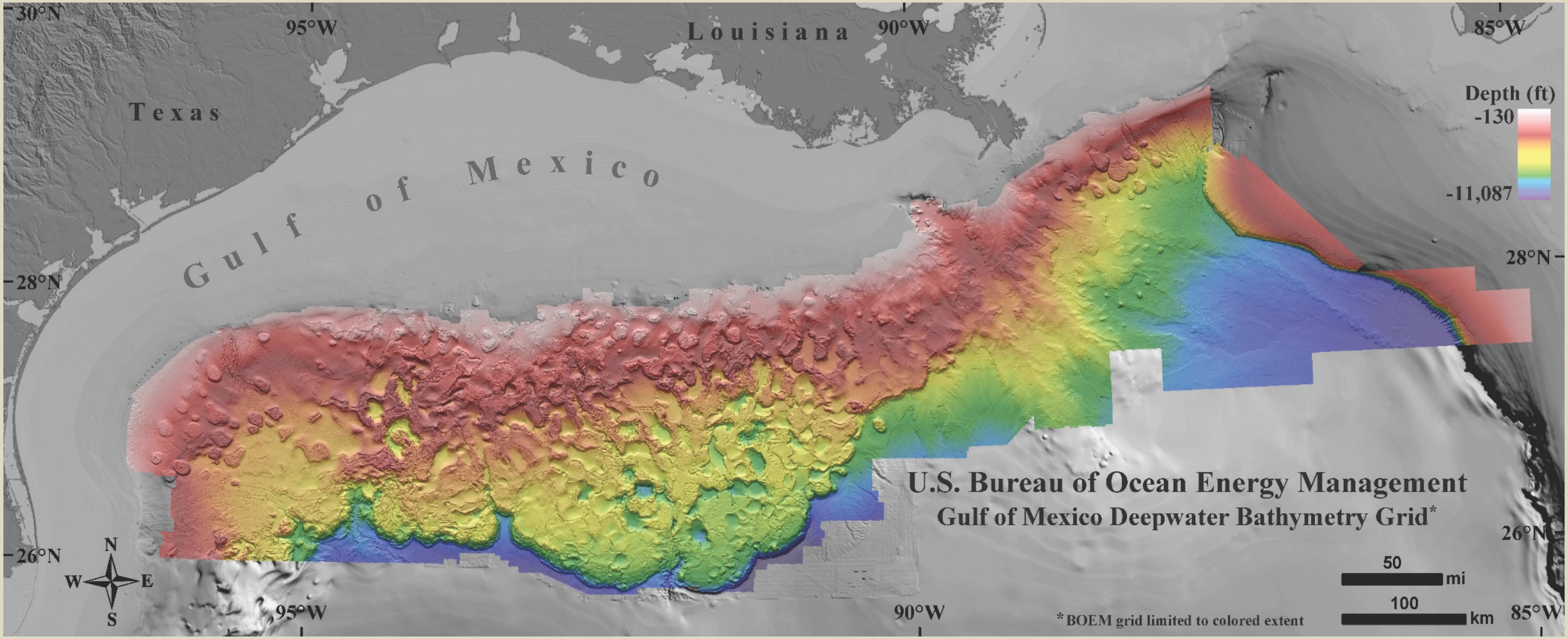
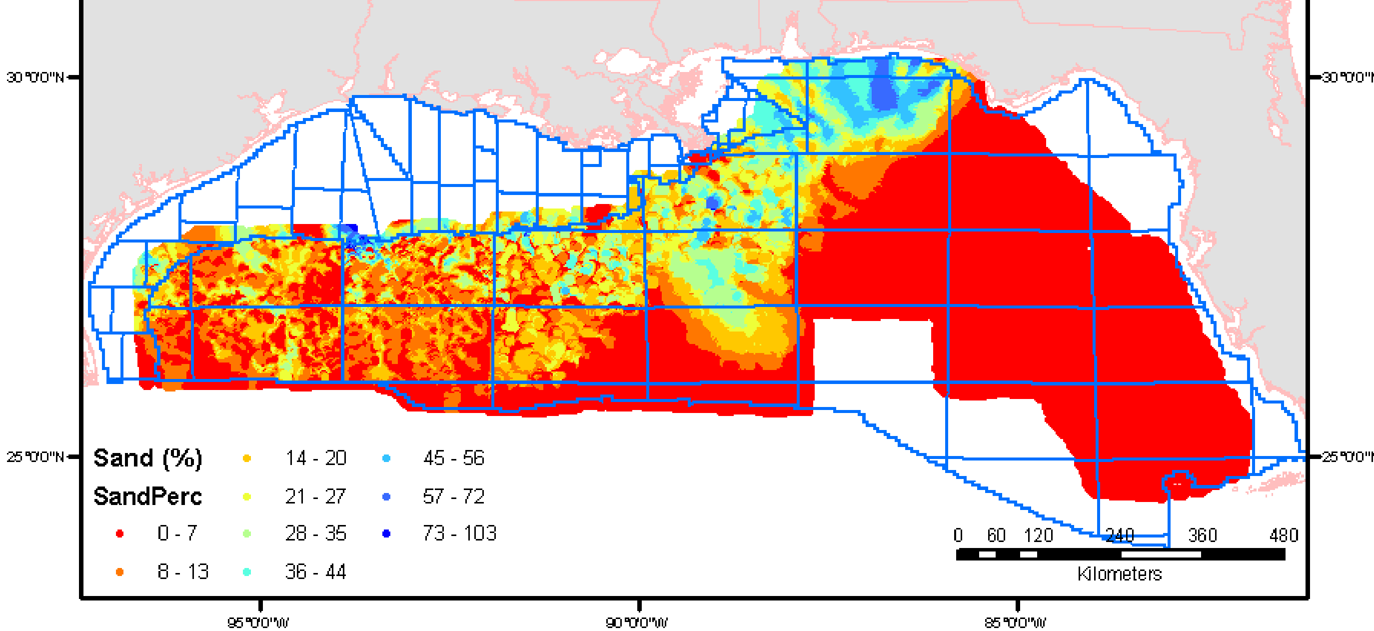


Figure 74. Distribution of sand in the shallow subsurface.



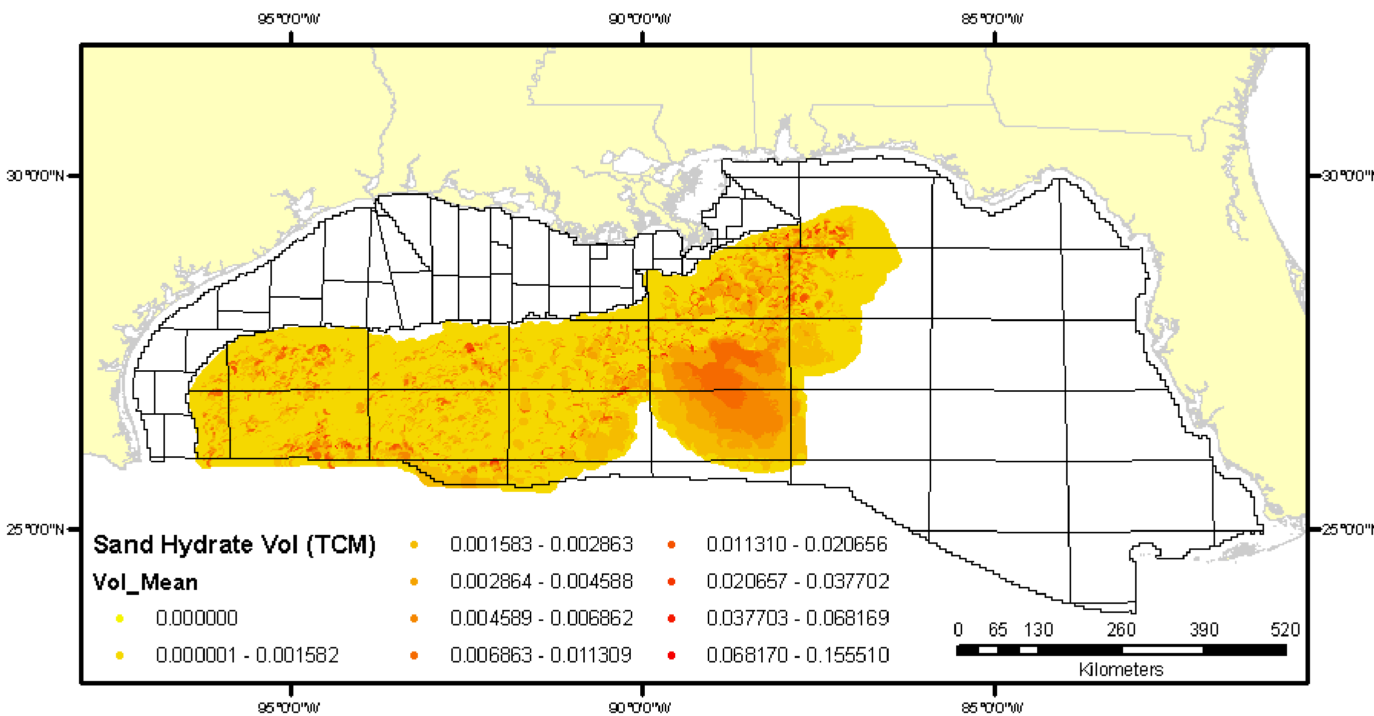
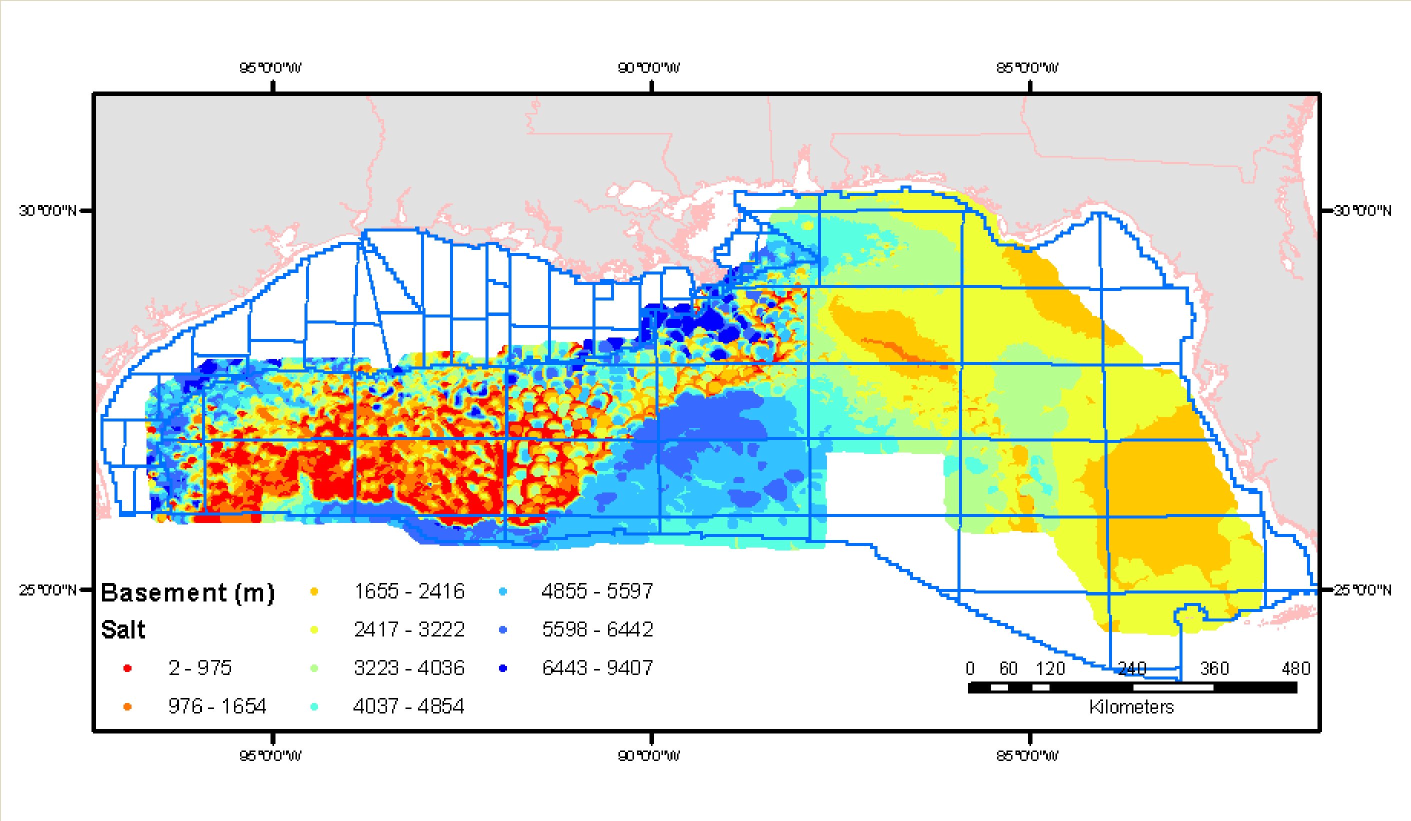


Figure 77. Sand-only gas hydrate resource volume, Gulf of Mexico (trillion cubic meters).

GOM Gas Hydrate Assessment OCS Report MMS 2008-004, Frye, 2008

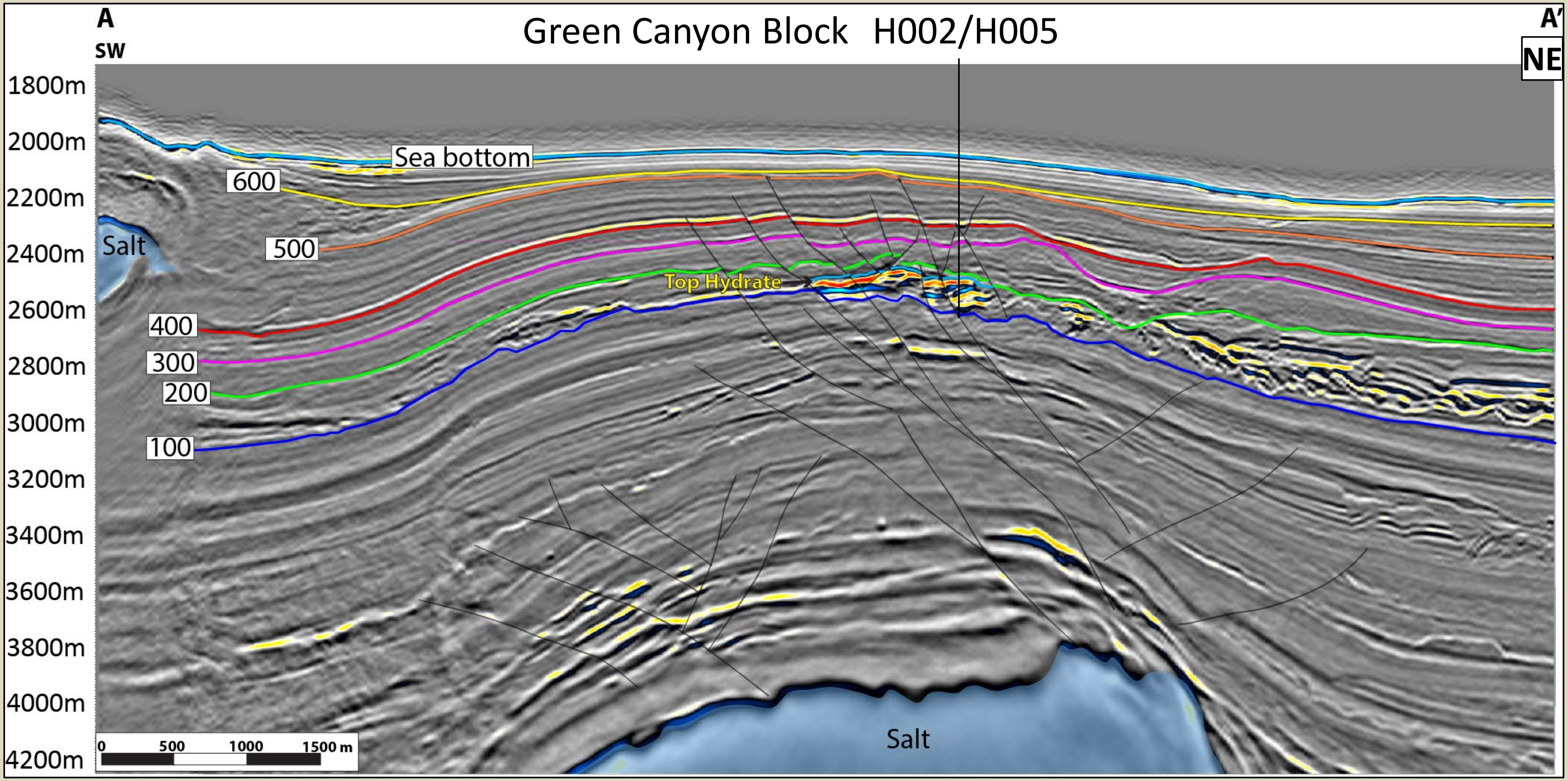


GOM Gas Hydrate Assessment OCS Report MMS 2008-004, Frye, 2008

Figure 71. Subseafloor depth to top of salt (or basement) in meters. The Sigsbee Escarpment represents the southern extent of shallow salt in the GOM basin. Dark blue colors in the upper slope indicate deep mini-basins.

Salt Tectonics

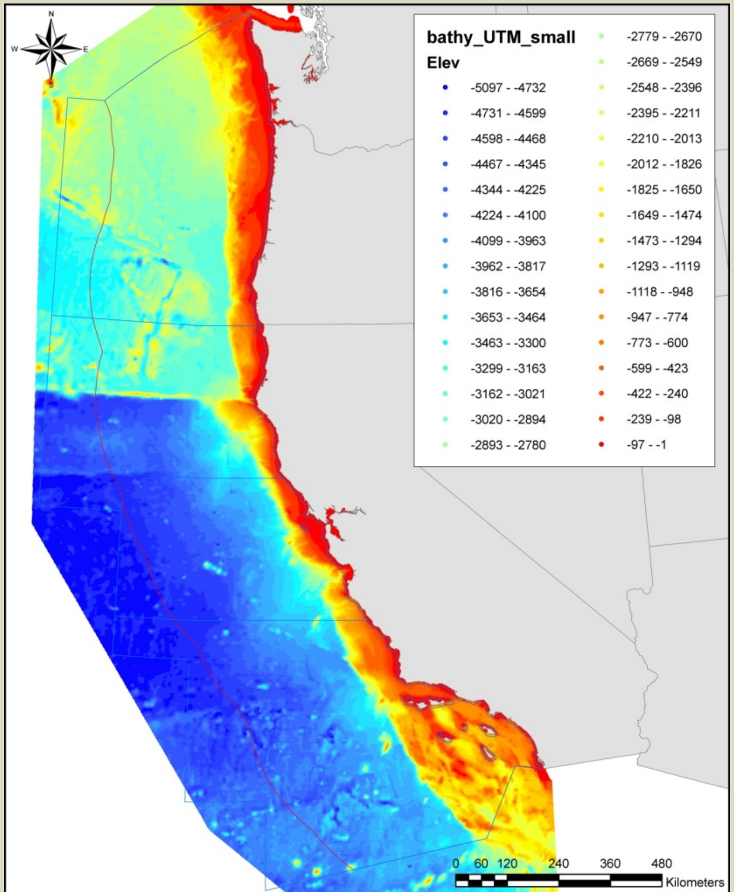
UT-GOM2-1 Expedition – Flemmings et al, 2017

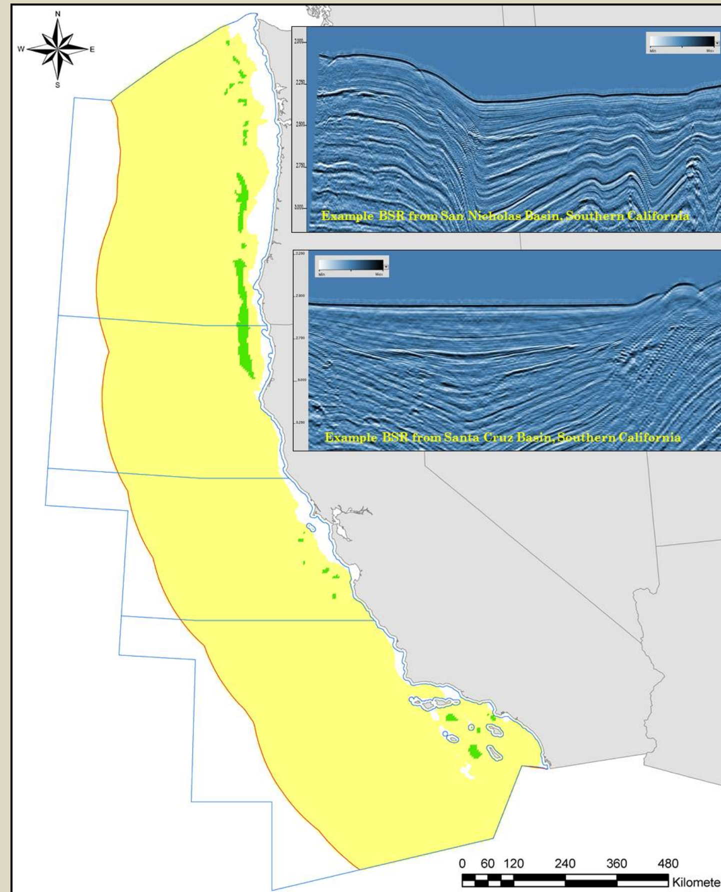


Seismic Image courtesy of WesternGeco

Pacific Cascadia and SAF Margins

Spatial Inputs – Bathymetry + BSR





Water Depth ⟶ HSZ

- ETOPO1 - NOAA

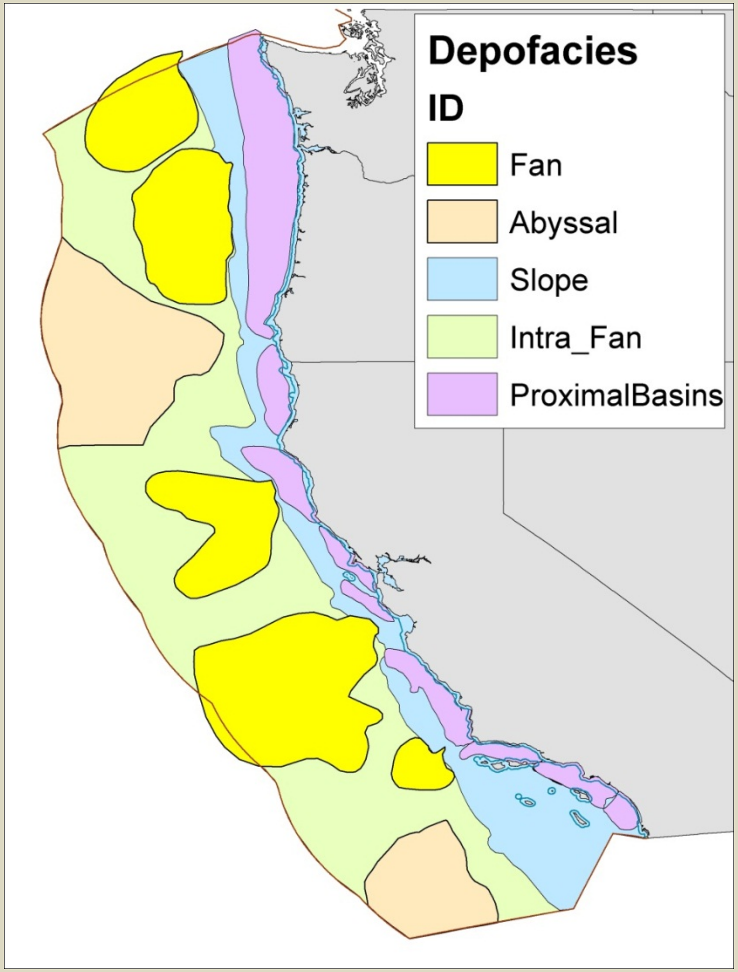
Amante, C. and B. W. Eakins, ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24, 19 pp, March 2009.

BSR ⟶ Migration Efficiency

*limited to areas of seismic data coverage/literature
*no advanced statistical forecasting

Field and Kvenvolden (1985); Trehu et al (2004)

Spatial Inputs – Depofacies



Depofacies → GH Concentration
Gas Generation

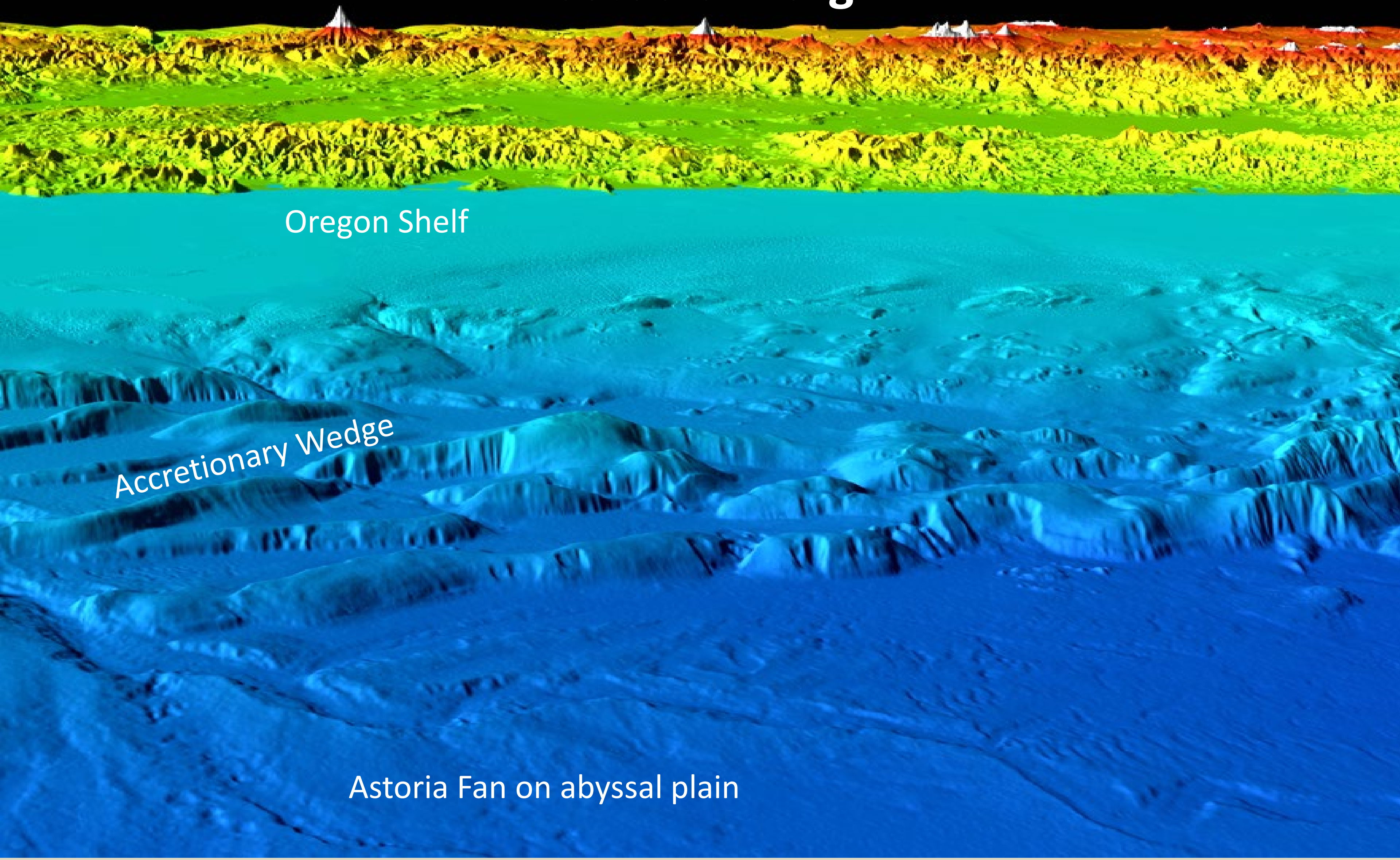
End Member Lithology – Sand and Shale

Pacific Margin Depofacies	
Facies name	**Description**
Proximal Basin	Sand-rich; rapid, focused sedimentation in structurally-controlled basins
Slope	Mud-rich; often a zone of coarse sediment bypass; intra-proximal basin
Submarine Fan	Sand-rich; coincident with named fan features; includes channel, levee, lobe, debris flow, etc.
Intra-Fan	Mostly mud-rich; occasional thin, low concentration turbidites
Abyssal Basement	Basement ridge, fractures, and seamounts with varying thickness of sediment cover; mostly sand-starved

		Beta parameters			
Name	ID	Shape 1	Shape 2	Mean	Std Dev
Proximal Basins	1	0.670	1.926	0.258	0.231
Slope	2	0.966	13.626	0.066	0.063
(Submarine) Fan	3	3.677	7.085	0.342	0.138
Intra Fan	4	1.747	57.802	0.029	0.022
Abyssal	5	1.788	120.140	0.015	0.011

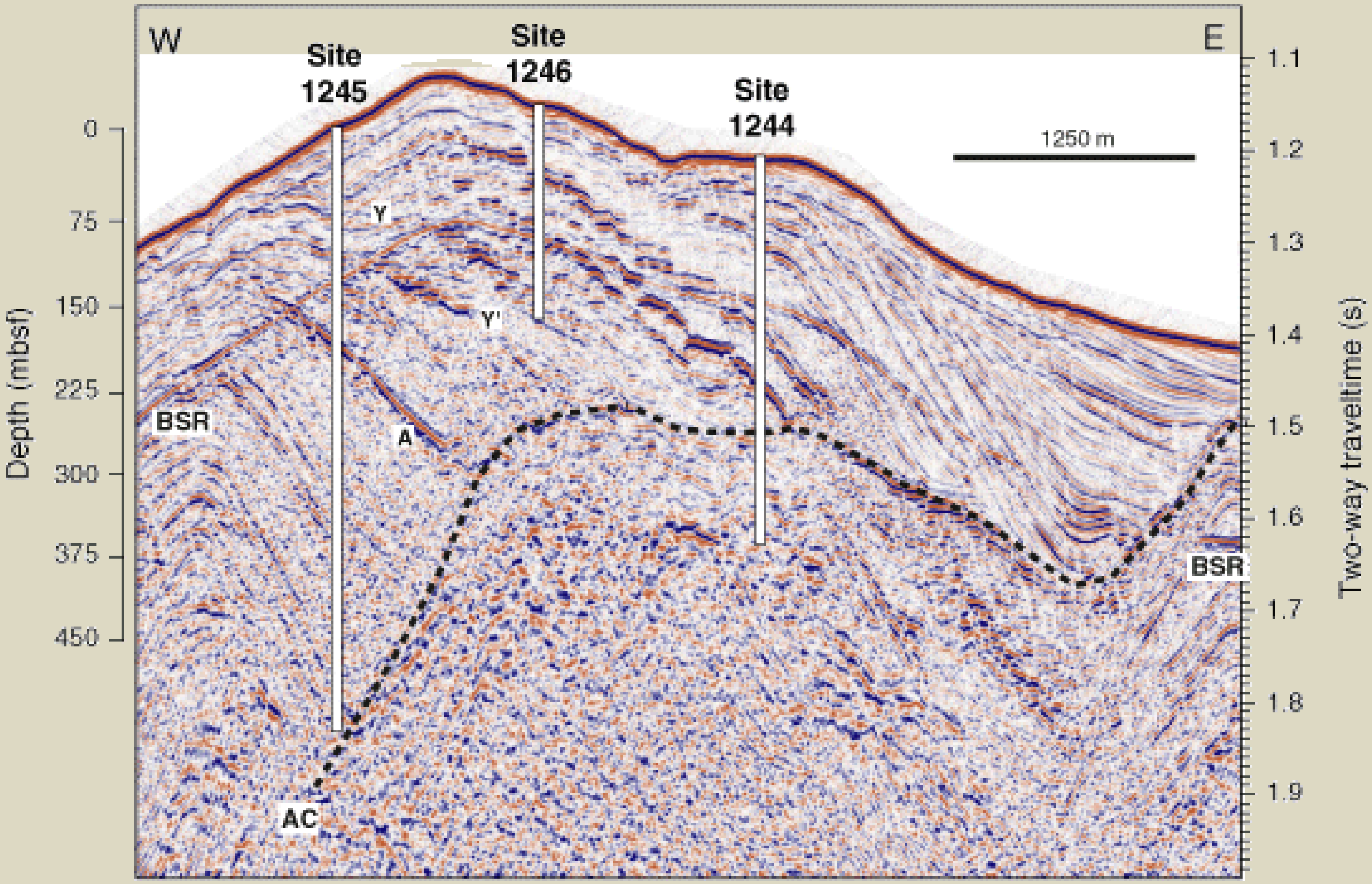
↑ Sand %

Cascadia Margin

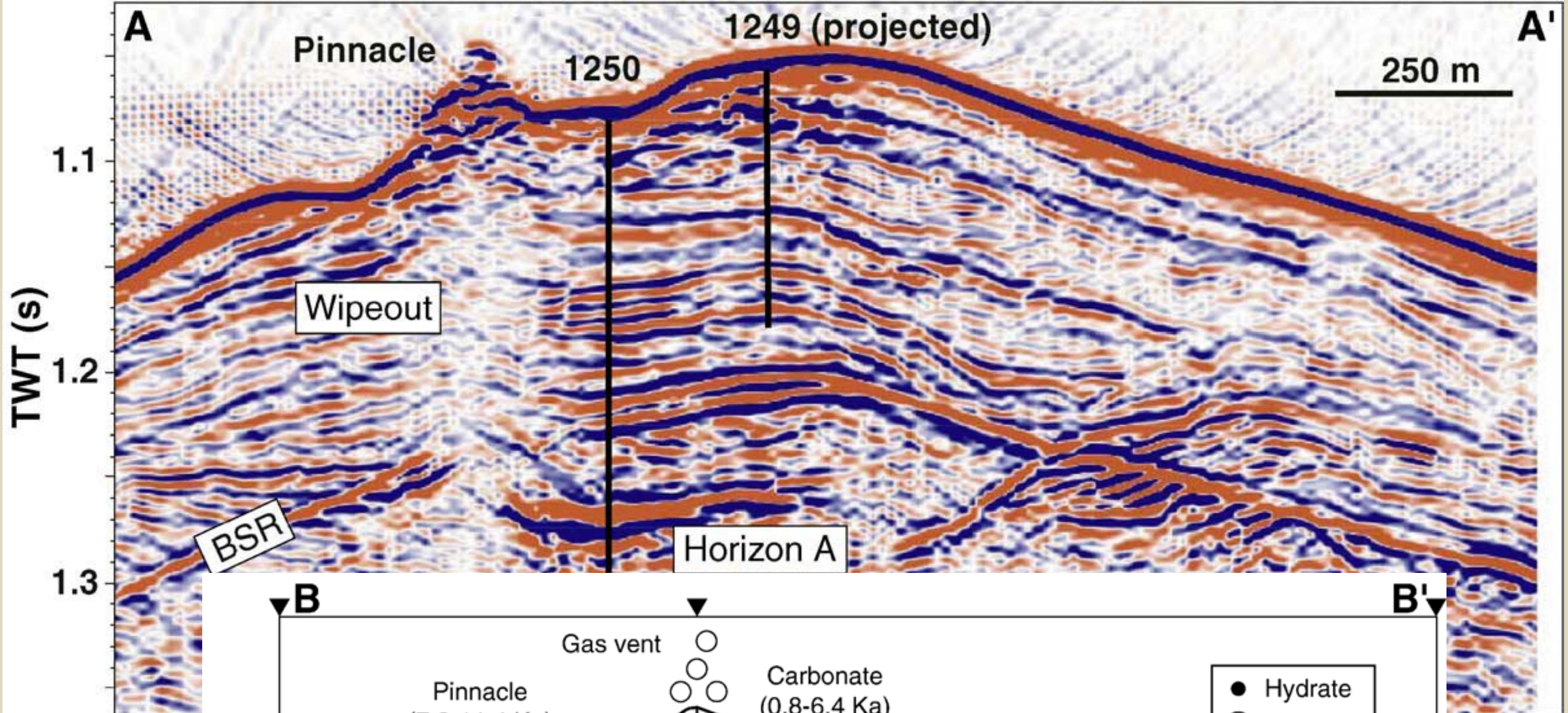


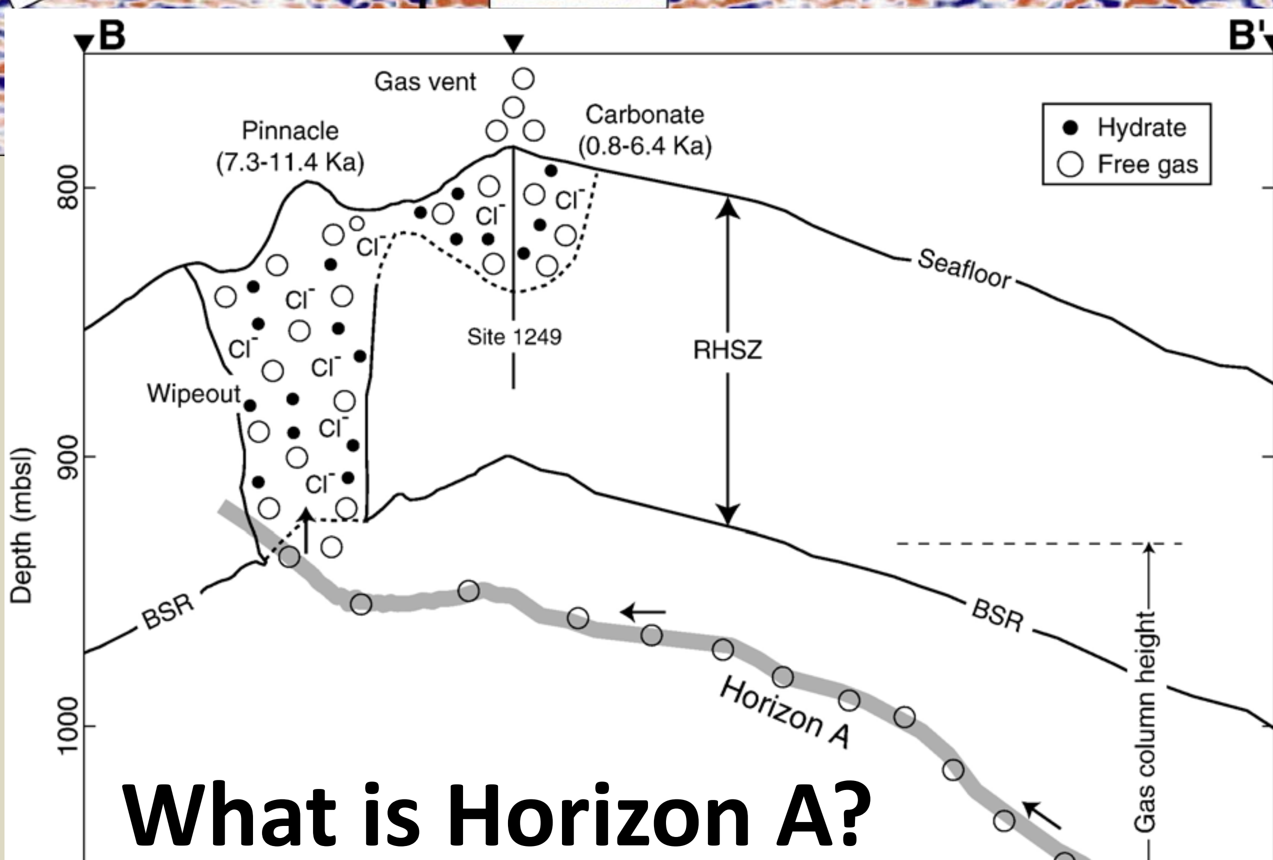
Deformation allows fluid migration to coarse grained reservoirs…

Hydrate Ridge, Cascadia Margin



Trehu et al., 2004





What is Horizon A?

Liu and Flemmings, 2006

Hydrate Ridge
Cascadia Margin

VOLCANIC GLASS-BEARING SEDIMENTS & ASHES

1248C-14H-3, 113-118 cm

Horizon A:
Ash bearing turbidites

1245B-21H-2, 84-103 cm

1250E-2H-2, 114-139 cm

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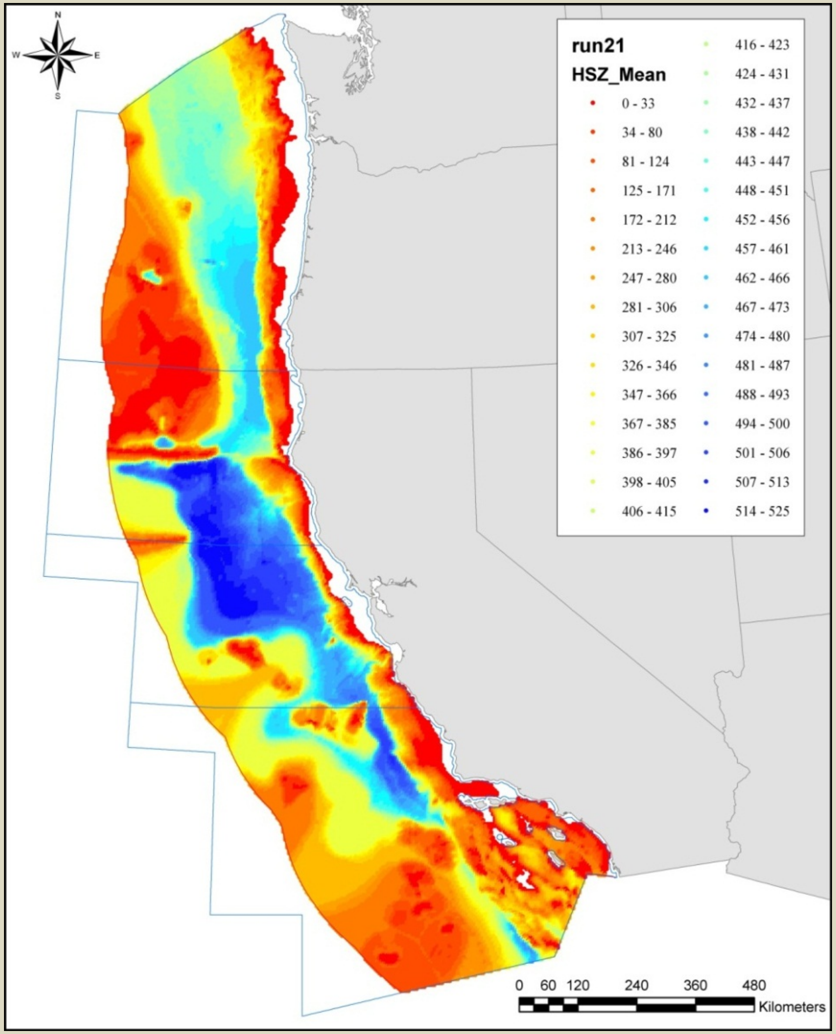
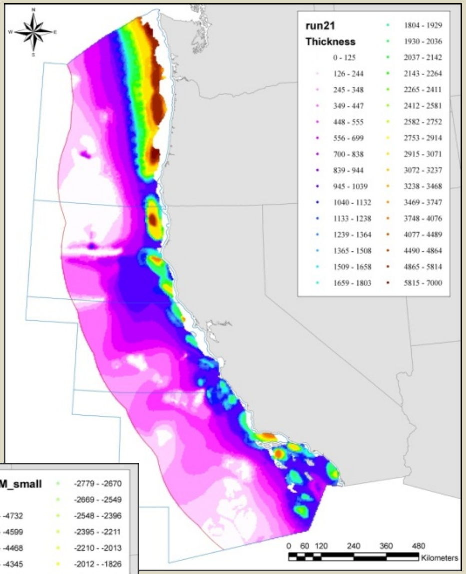
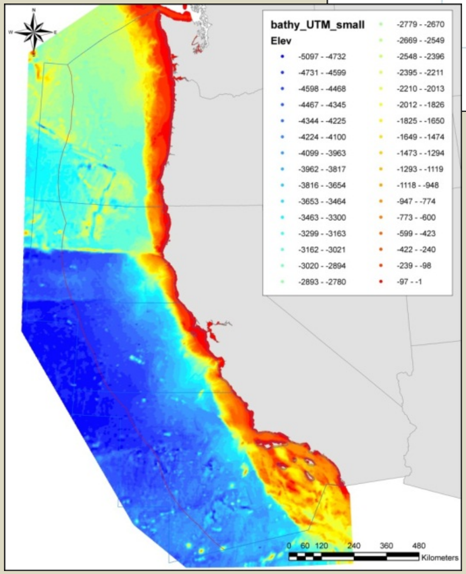
Spatial Outputs – Stability Zone



HSZ limited by thickness

(Not an issue in ATL)
(Similar to salt in GOM)





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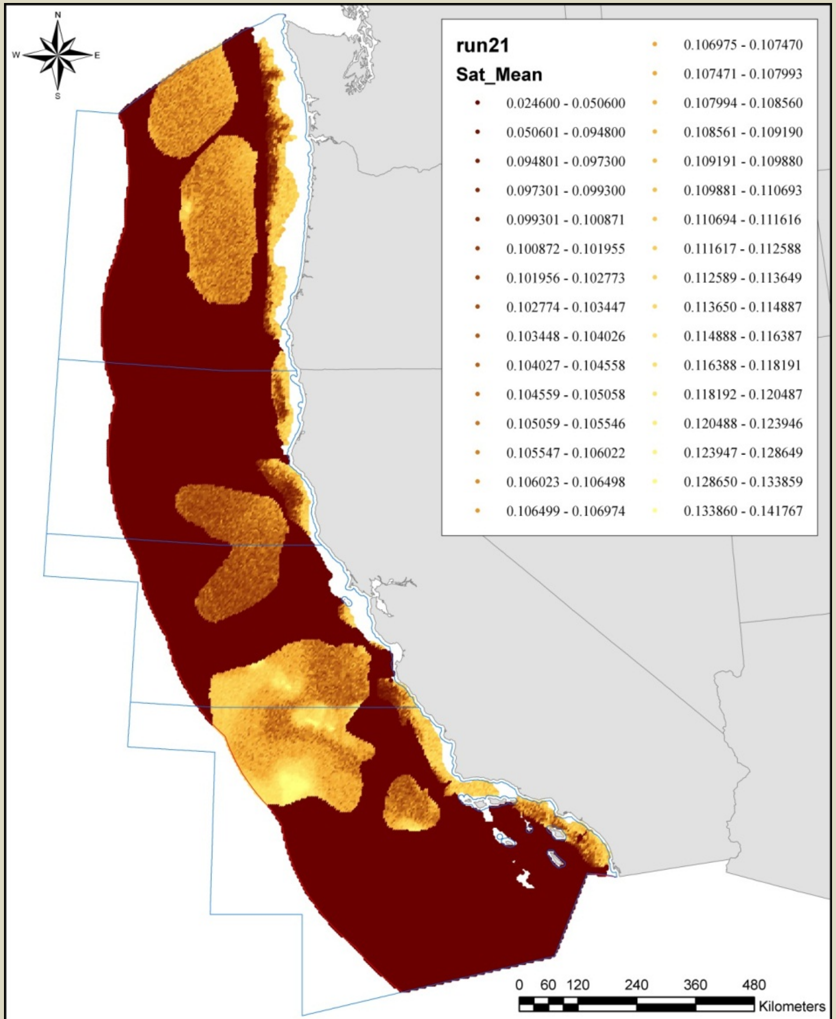
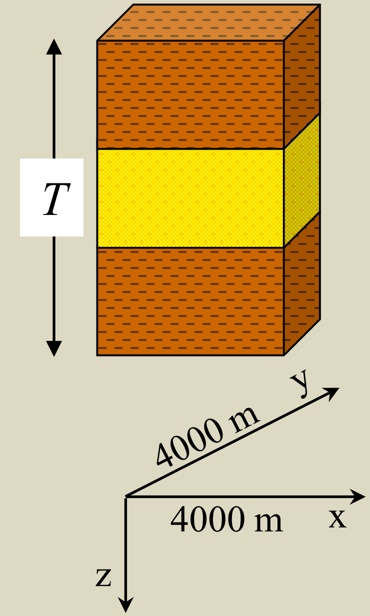
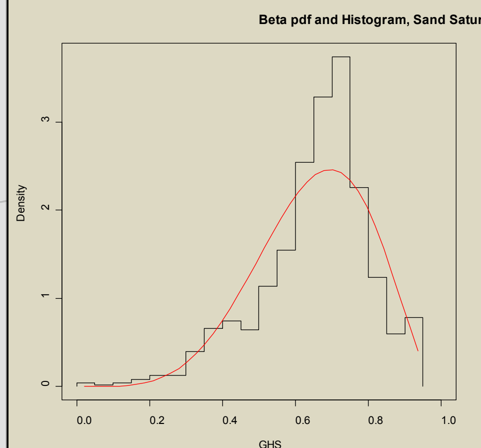
Spatial Outputs – Saturation

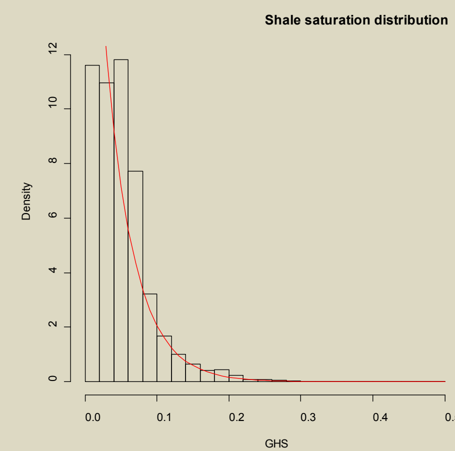


Sand Void = (Volume)(Porosity)
Volume Sand = (x)(y)[(T)(sand%)]
Porosity Sand = $f(d)$

Shale Void = (Volume)(Porosity)
Volume Shale = (x)(y)[(T)(1-sand%)]
Porosity Shale = $f(d)$

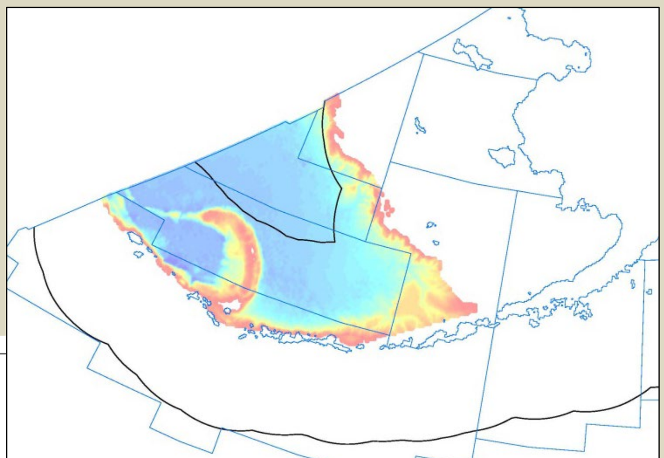


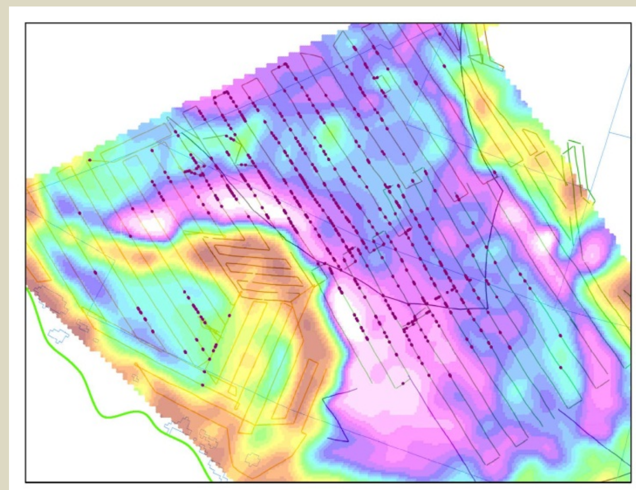


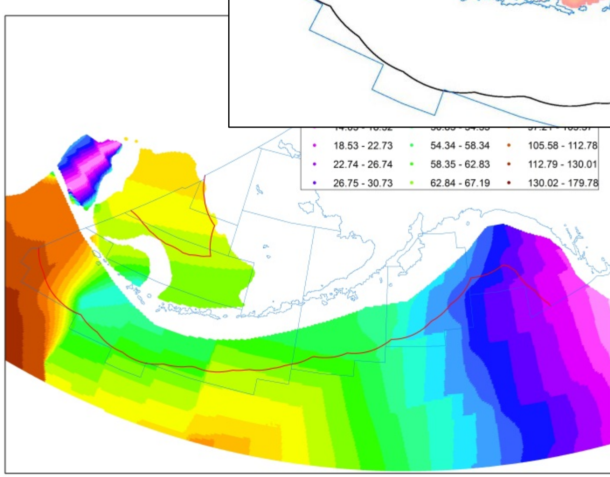


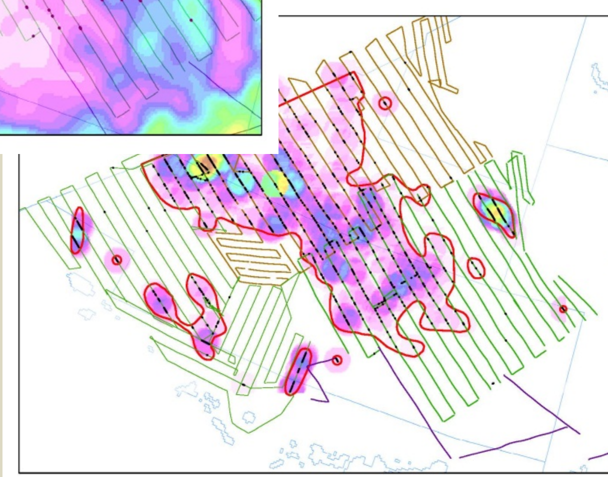
Path Forward: Pacific Reporting, Alaska DW (Bering, Beaufort, Trench, Gulf of Alaska)

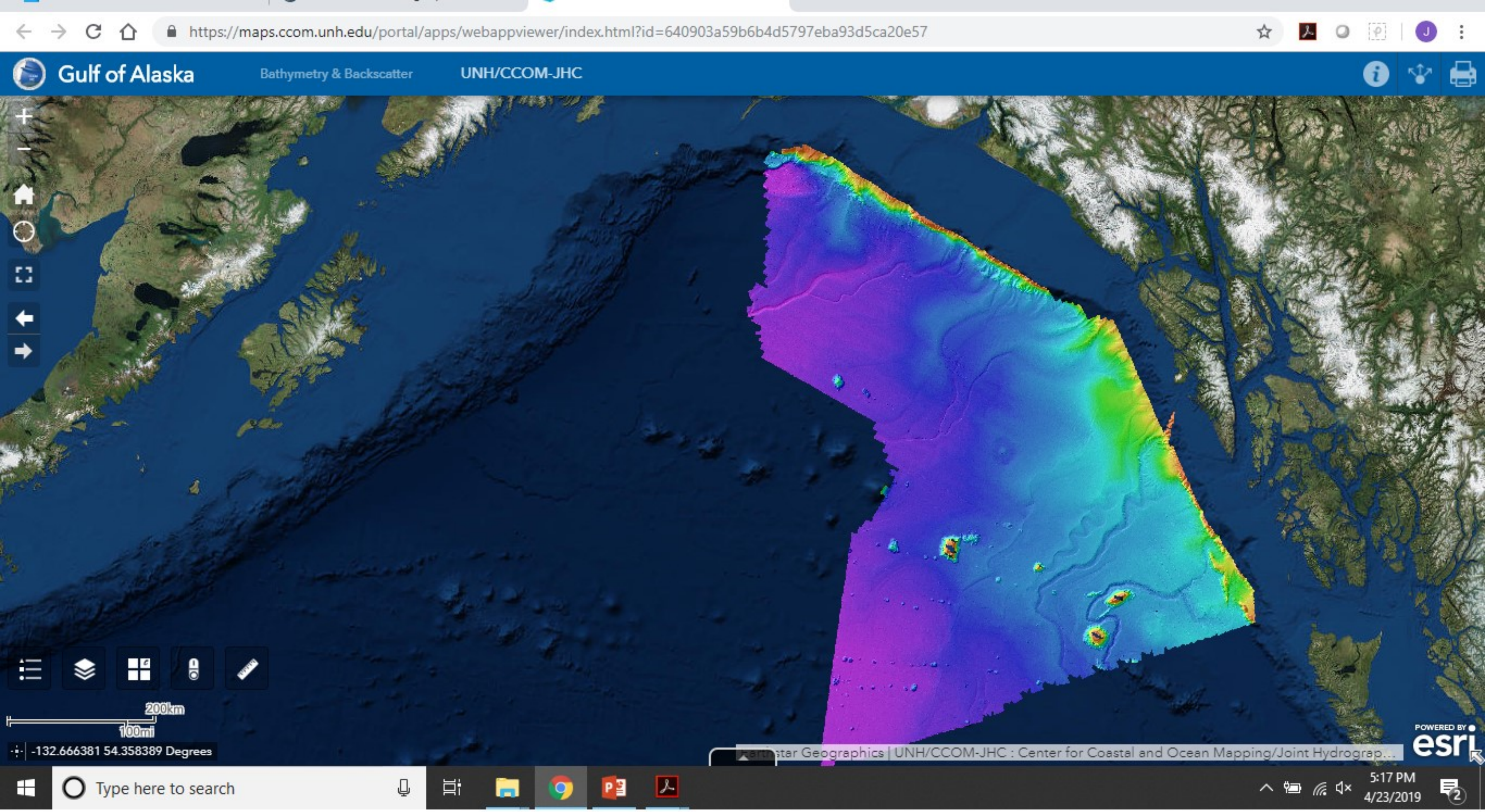
"Alaska plan - we are going to spend some time this year working on it, particularly the OCS area south of the trench and in the Gulf of Alaska. We have some work completed but unpublished in the Bering Sea. And we don't intend to do anything in the deepwater Beaufort Sea." –Matt Frye 4/22/19









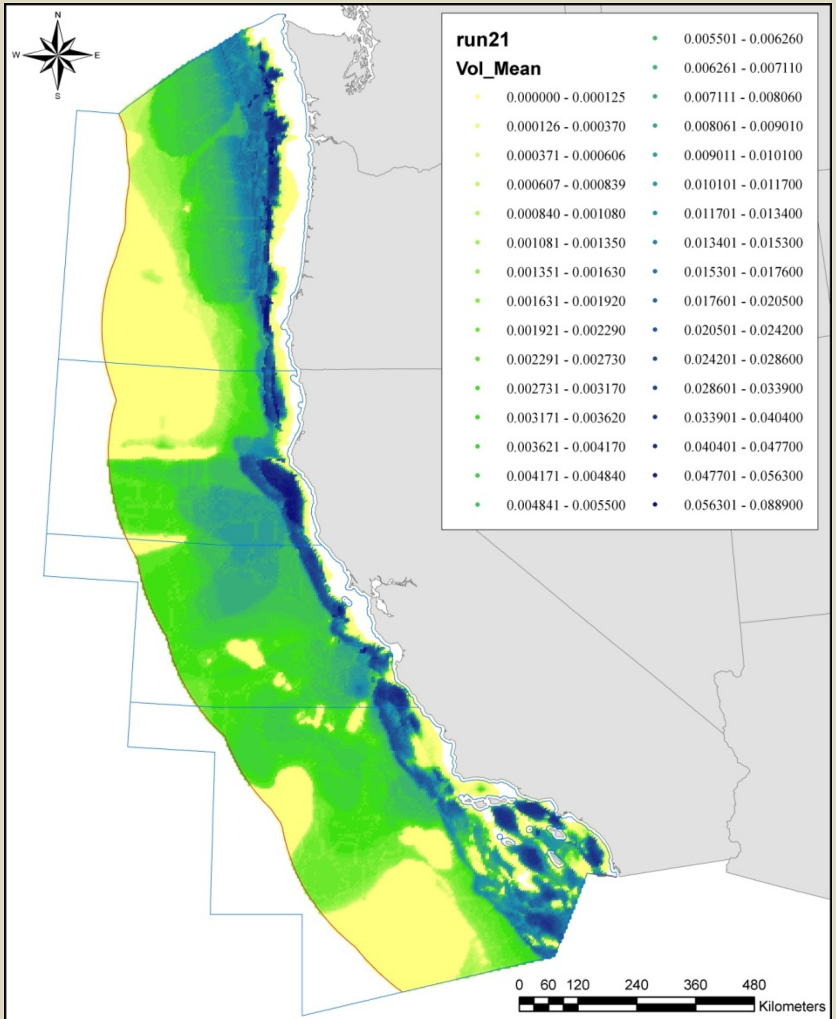


Glacial-fed Submarine fans → Accretionary Wedge

Lithologic Host-Deformation-Gas → GOM and PACIFIC Active Margins and Permafrost?

Controls for Concentrated Gas Hydrate Accumulation	GOM	ATLANTIC	PACIFIC CASC., CA, GULF of ALASKA	ALASKA NORTH SLOPE- Marine & Permafrost
Coarse Lithology	Turbidites	Contourites> Turbidites	Turbidites & Ashes	Shelf Sands Fluvial, Alluvial
Deformation Regime	Salt Tectonics	Regional subsidence-Tilting	Accretionary folds, strike-slip, normal, and reverse faults	Regional Subsidence-Tilting
Available Gas	Microbial + Thermogenic	Microbial + Thermogenic	Microbial + Thermogenic	Microbial + Thermogenic

Spatial Outputs – In Place Volume



Region	In-Place Gas Hydrate Resources					
	95%		Mean		5%	
	tcf	tcm	tcf	tcm	tcf	tcm
Atlantic OCS	2,056	58	21,702	614	52,401	1,483
Pacific OCS	2,209	63	8,192	232	16,846	477
Gulf of Mexico OCS	11,112	314	21,444	607	34,423	974

Largest accumulations in near-shore basins:

- Thick sedimentary sections
- Higher TOC
- Greater sand component
- Sufficiently old/mature column
- Enhanced migration efficiency