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Overpressure and compaction of porous marine sediments

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General abstract

We are interested in fundamental processes such as how porous, marine sediments compact and expel their fluid over time and how material properties (stiffness, permeability, anisotropy, etc.) evolve as compaction evolves. These processes control shallow biological communities, create opportunities for submarine landslides, and control how sound is transported, for example.

The study area is a sedimentary basin in the Northern Gulf of Mexico, where sedimentation rates were thought be low. However, this study shows that the deposition rate of the porous, low-permeability sediments was high enough to cause severe overpressure near the seafloor of the basin.

Motivation

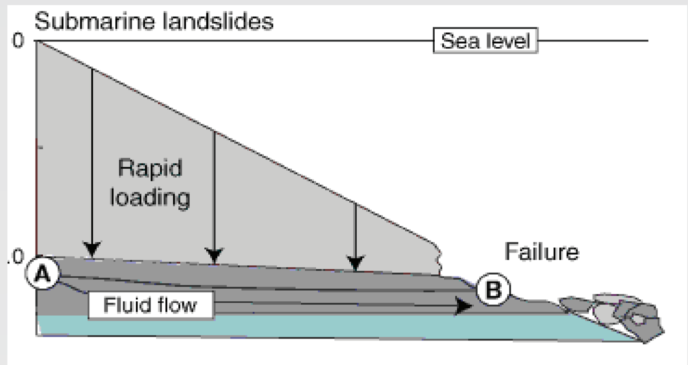

Figure 1: Lateral shallow subsurface fluid flow due to rapid loading of material causes submarine landslide.

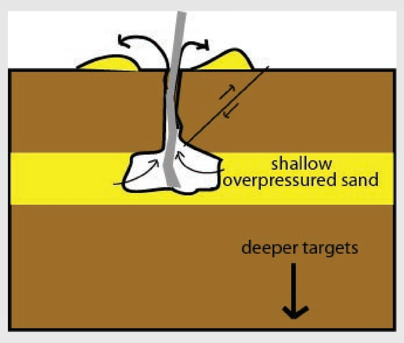

Figure 2: Fluid expulsion and formation of mud volcano at seafloor due to overpressured sand.

Figure 3: Blow-out of oil rig Ocean Odyssey in the North Sea on September 22, 1988.

Technical abstract

Mudstones[4] that directly underlie the turbidite fill of Brazos-Trinity Basin IV (deepwater Gulf of Mexico, offshore Texas) have overpressures[6] (u^*) of more than 70% of the hydrostatic effective stress (σ'_{vh}) [$\lambda^* = 0.7 = (u^*/\sigma'_{vh})$], that are largely driven by rapid deposition of the mudstone[4] itself. We compare a 120 meters thick package of identical mudstone[4] at Integrated Ocean Drilling Program (IODP) Sites U1319 and Site U1320. Site U1319 is at the distal margin of Brazos-Trinity Basin IV whereas Site U1320 lies at the basin center beneath 180 meters of turbidite fill. Preconsolidation stresses[8] determined from laboratory consolidation[1] tests and a single in situ pore pressure[7] measurement suggest that Site U1319 and Site U1320 are overpressured ($\lambda^* \sim 0.7$ and $\lambda^* \sim 0.8$, respectively). We use these data to define the in-situ effective stress. Assuming that void ratio is proportional to the log of vertical effective stress[9], we predict pore pressures[7] in the mudstone[4] at both sites using logging while drilling data. Our results are in good agreement with overpressure ratios from preconsolidation stresses[8] and direct pressure measurement. While overpressures[6] are greater at Site U1320, which we attribute to rapid deposition of the thicker overlying turbidites at Site U1320, a large fraction of this load has been dissipated by compaction and drainage. Such high overpressures[6] near the seafloor drive shallow fluid flow, reduce slope stability and may explain large submarine landslides.

Introduction

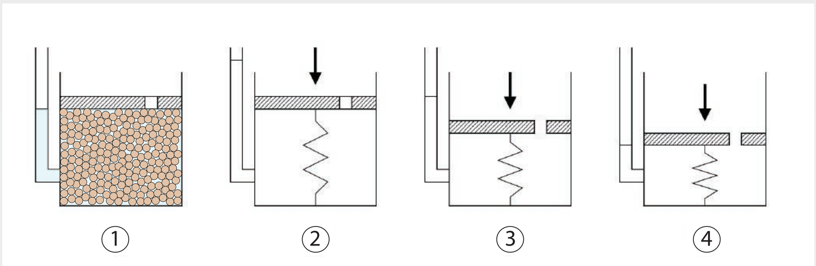

Figure 4: Process of consolidation[1] after Terzaghi's theory.

1) container filled with sediment and water, hole closed
2) load applied, hole still unopened
3) hole open, drainage of water, shortening of spring
4) no more drainage, spring alone resists applied load

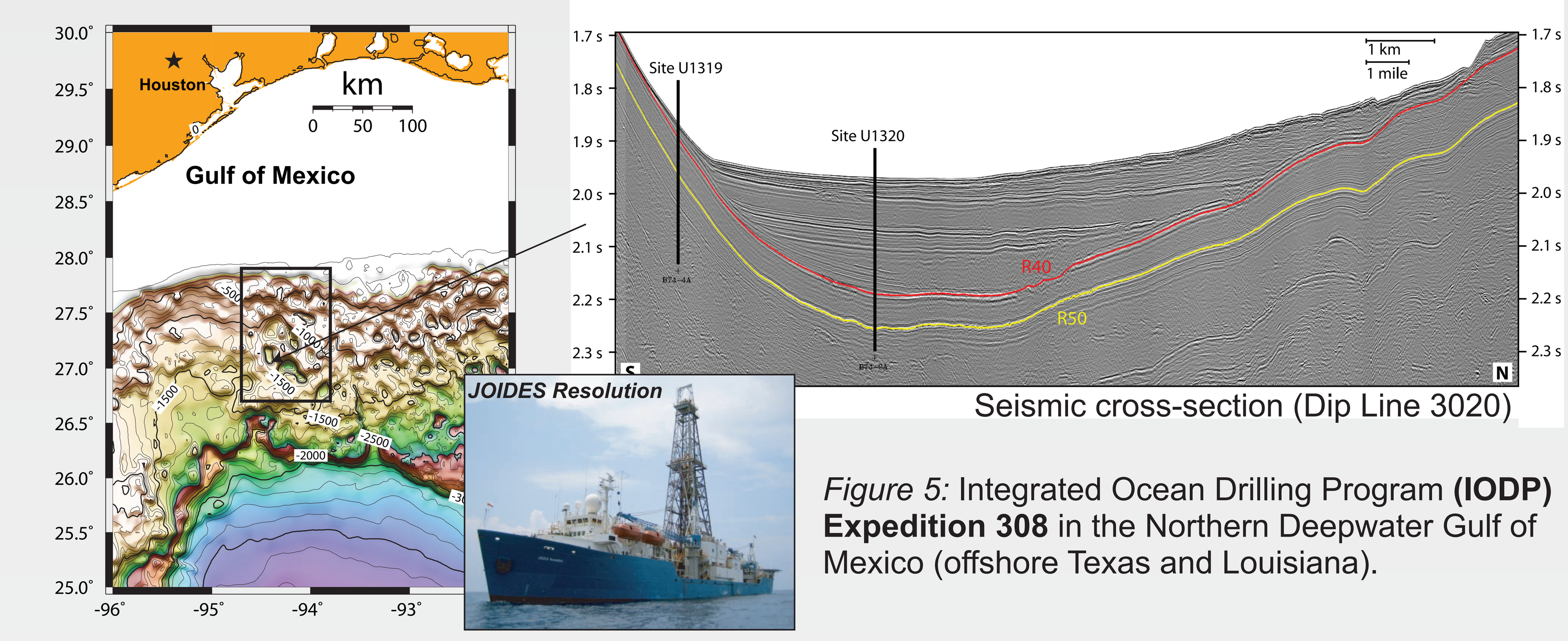

Figure 5: Integrated Ocean Drilling Program **(IODP) Expedition 308** in the Northern Deepwater Gulf of Mexico (offshore Texas and Louisiana).

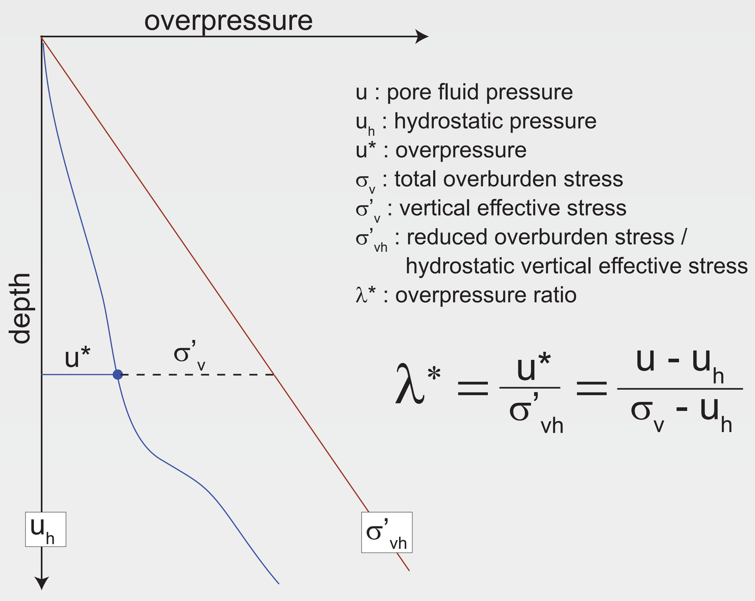

Figure 6: Definition of pressures and stresses.

Methods

1) geotechnical experiments

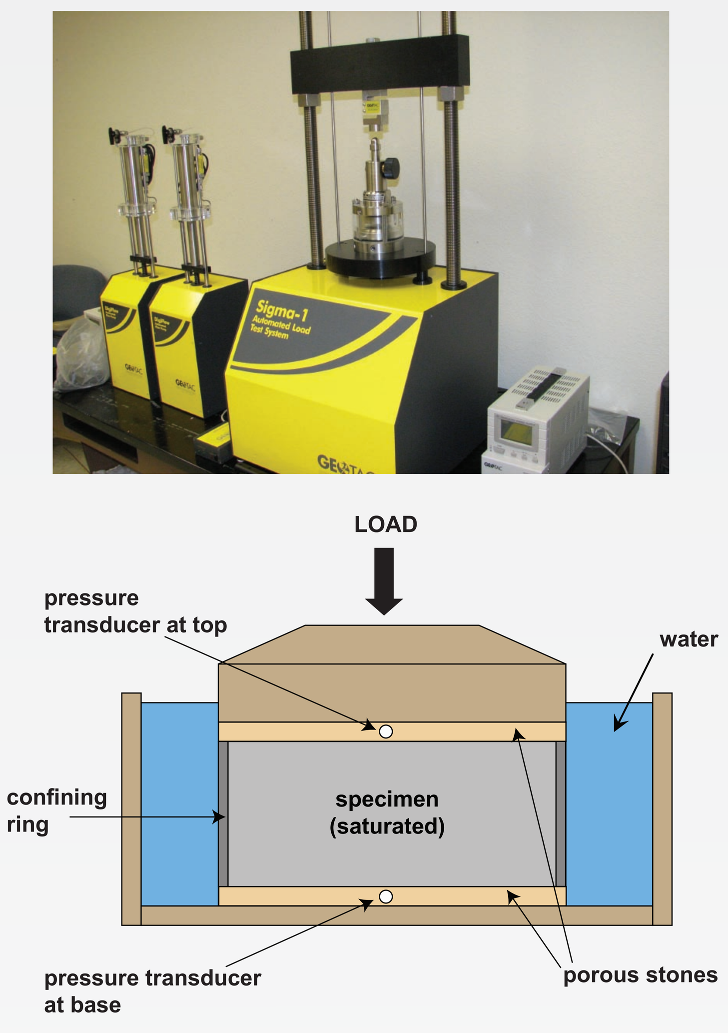

Figure 7: Uniaxial constant rate of strain consolidation[1] (CRSC) experiments are used to determine a variety of soil parameters (bulk compressibility, permeability[3], preconsolidation stress[8]).

2) in situ measurements

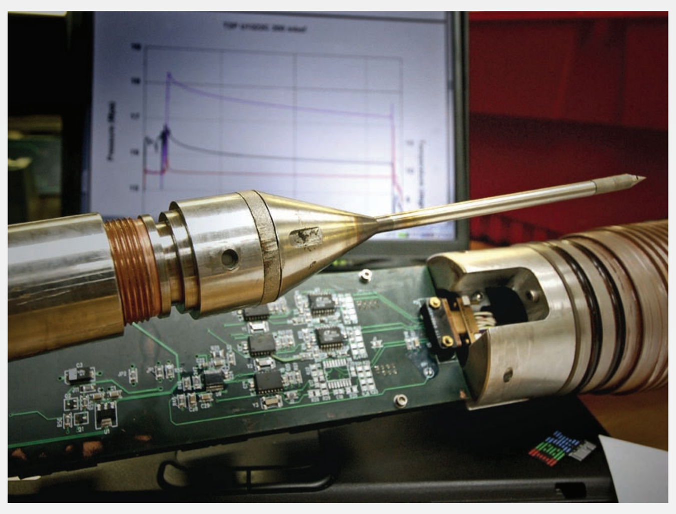

Figure 8: The Temperature-Two-Pressure (T2P) probe measures in situ pressure and temperature (Flemings et al., 2006; Flemings et al., 2008).

3) logging data

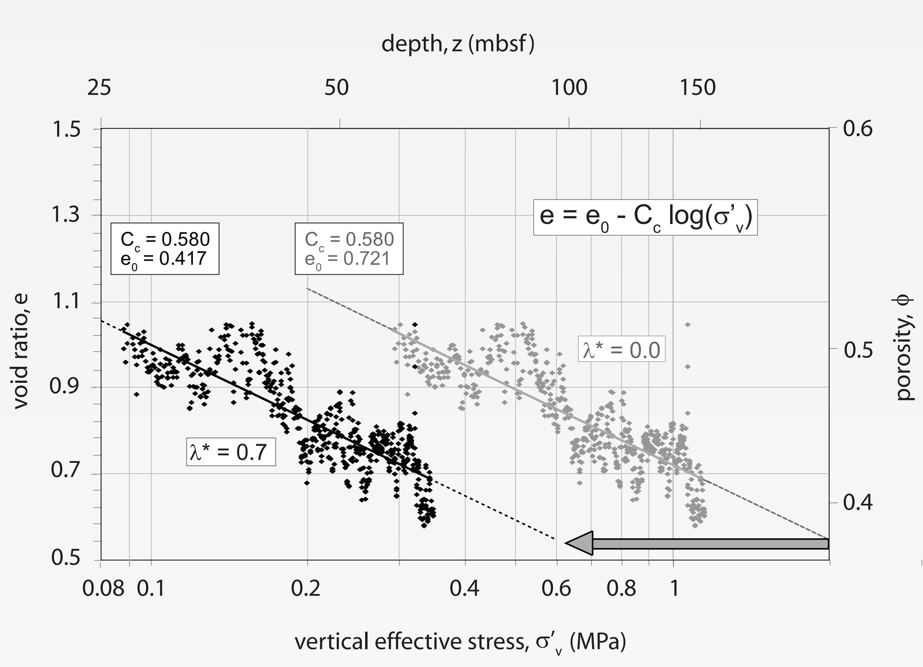

Figure 9: Relationship between void ratio10, calculated from logging while drilling bulk density, and log of vertical effective stress assuming an overpressure ratio of 0.7 at Site U1319.

Results

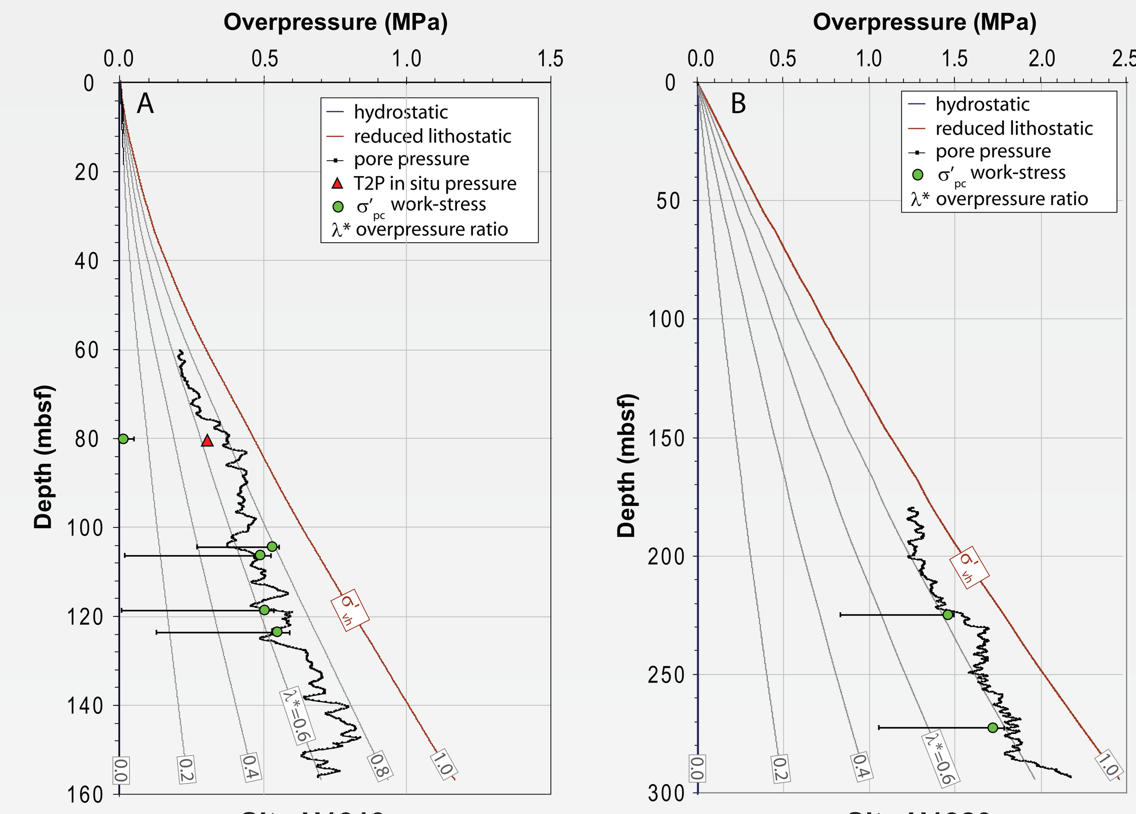

Figure 10: Pore pressure prediction at the basin margin (Site U1319) and basin center (Site U1320) assuming an overpressure ratio of 0.7 at the reference Site U1319.

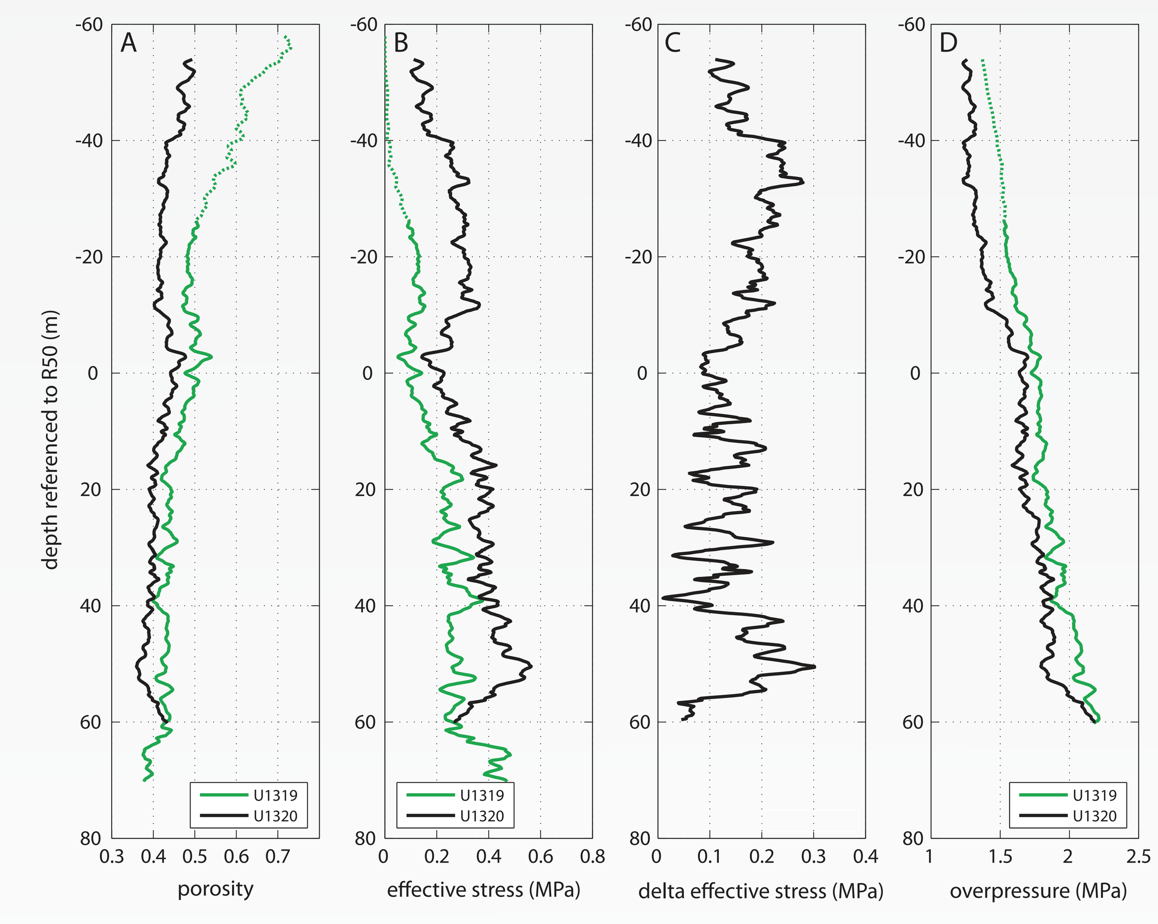

Figure 11: Consolidation[1] and drainage of mudstones[4]; data sets are referenced to seismic reflector R50.

Conclusions

Pore pressures equal 70% of the hydrostatic vertical effective stress at the basin margin (Site U1319) and and 80% of the hydrostatic vertical effective stress at the basin center (Site U1320). We interpret the high overpressures[6] are largely driven by rapid deposition of the low-permeability[3] mudstone[4] itself. A large fraction of the load, induced by the turbidite fill at Site U1320, has been dissipated by compaction and drainage. This implies that the overlying turbidite fill had relatively low overpressure[6], which is compatible with the sandy and permeable nature of these sediments.

Glossary

[1] **consolidation:** gradual reduction in volume of a fully saturated soil due to drainage of some of the pore water (see Fig. 4)
[2] **hydrostatic pressure:** pressure at a given depth in a static liquid caused by the weight of the liquid itself acting on an unit area at that depth (see Fig. 6)
[3] **intrinsic permeability:** ability of sediment/rock to let fluid pass through; representative of the properties of the porous medium (not the fluid)
[4] **mudstone:** fine grained sedimentary rock, composed of clay and silt sized particles (Fig. A)
[5] **overburden stress:** total weight per unit area above given depth (see Fig. 6)
[6] **overpressure:** pore fluid pressure in excess of hydrostatic pressure
[7] **pore fluid pressure:** water pressure between the solid grains (see Fig. 6)
[8] **preconsolidation stress:** maximum vertical effective stress a sample has experienced; gives an estimate of minimum in situ pore pressure
[9] **vertical effective stress:** grain to grain contact of soil particles; difference between total overburden stress and pore fluid pressure (see Fig. 6)
[10] **void ratio:** ratio of volume of the pores to volume of the solids

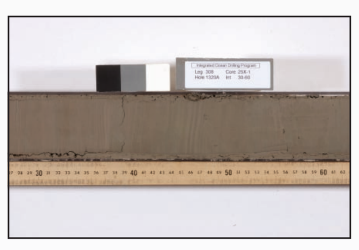

Figure A: Core photo of mudstone.

References

Schneider, J., Flemings, P.B., Dugan, B., Long, H., and Germaine, J.T. (in review). Overpressure and compaction near the seafloor of Brazos-Trinity Basin IV, Northwest Deepwater Gulf of Mexico, *Journal of Geophysical Research*.

Flemings, P. B., H. Long, B. Dugan, J. T. Germaine, C. John, J. H. Behrmann, D. E. Sawyer, and I. E. Scientists (2008), Pore pressure penetrometers document high overpressure near the seafloor where multiple submarine landslides have occurred on the continental slope, offshore Louisiana, Gulf of Mexico, edited, p. 16, *Earth and Planetary Science Letters*.

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