High-resolution seismic imaging of depositional characteristics at gas hydrate research sites in the Gulf of Mexico

Seth S. Haines[1]*, T. S. Collett[1], P. E. Hart[2], B. Shedd[3], P. Weimer[4], M. Frye[5], R. Boswell[6]
[1]U.S. Geological Survey, Central Energy Resources Science Center, Denver, Colorado, United States; [2]U.S. Geological Survey Pacific Coastal and Marine Science Center, Santa Cruz, California, United States; [3]U.S. Bureau of Ocean Energy Management, New Orleans, Louisiana, United States; [4]University of Colorado, Boulder, Colorado, United States; [5]U.S. Bureau of Ocean Energy Management, Sterling, Virginia, United States; [6]U.S. Department of Energy National Energy Technology Laboratory, Morgantown, West Virginia, United States
*Corresponding author: shaines@usgs.gov

Abstract

High-resolution seismic data acquired by the U.S. Geological Survey (USGS), with support from the U.S. Bureau of Ocean Energy Management (BOEM) and the U.S. Department of Energy (DOE), in 2013 at two geologically distinct study sites in the offshore Gulf of Mexico basin provide an opportunity for detailed characterization and for comparison of the depositional settings of sediments that host high concentrations of gas hydrate at each site. Gas hydrate exists at Green Canyon Block 955 (GC955) within sand layers deposited in a proximal marine channel-levee setting, whereas at Walker Ridge Block 313 (WR313) gas hydrate deposits occur within thin distal levees and sheet sands deposited in a mini-basin environment. A refined understanding of the depositional environment at these sites in turn provides valuable insights regarding reservoir characteristics and controls on gas hydrate occurrence.

The GC955 site is located just basinward of the Sigsbee Escarpment. In this area, sand reservoir faces deposited in a channel-levee system are interspersed with fine-grained clastic strata. During and after deposition, the accumulated sediments experienced structural deformation driven by uplift of adjacent and underlying salt deposits, likely also including channel margin slumping. The primary reservoir, at a depth of approximately 400 m below the seafloor, is approximately 100 m thick and is composed of sand-rich proximal levee sediments known from well log data to host high saturations of gas hydrate along with water (above, below, and interspersed with gas hydrate) and free gas (below gas hydrate). The high-resolution seismic data reveal that the proximal levee deposits occur in discrete "pods" of sediments that resulted from a sustained period of alternating deposition, scouring, and re-deposition of sediments. A complex fault network has evolved in response to salt uplift and localized differential sediment compaction, which has further compartmentalized the reservoir and surrounding sediments, and also provided conduits for fluid flow. Based on published observations of channel-levee reservoir characteristics, we suggest that reservoir hydraulic communication is likely variable within each pod (scale up to approximately 100 m thick and up to approximately several hundred meters laterally), and that communication is possible but uncertain between pods. We interpret that the observed distribution of free gas and gas hydrate at GC955 is controlled by a combination of lithologic and structural factors, and that the fine-scale distribution of gas hydrate within the main reservoir sediments is controlled at least in part by reservoir quality (in particular the porosity and permeability of sand layers), coupled with the area's non-uniform gas charge.

At WR313, the 2013 high-resolution seismic data augment what is known from previous studies, allowing meter- to tens-of-meters-scale analysis of hydrate-bearing, distal sands deposited in a mini-basin setting. Through a combination of seismic interpretation and sonic data modeling, we are able to investigate geologic controls on hydrate occurrence, such as sand layer continuity. Large-scale faulting has not impacted the gas hydrate-bearing sediments of interest at WR313, and the lack of local internal structural complexity makes the fine-scale linkage of well data to seismic data more viable and meaningful than at GC955. The vertical resolution of the high-resolution seismic data (wavelength approximately 15 m) is much greater, and thus closer to the vertical scale of the well-log data, than older 3D industry seismic data. As such we are able to improve upon earlier interpretations of sedimentary layer continuity and lateral lithologic and pore-fluid heterogeneity within horizons. For example, the thin (less than 20-meter-thick) sand-rich layers are cut by one or more bypass channels that appear to contain predominantly fine-grained clastic sediments. Well-log data show the sand-rich layers to comprise thin (meter- and sub-meter-scale) sands with vertically similar hydrate saturations (though not necessarily reservoir communication) where intervening fine-grained layers are less than approximately 3 m thick, and seismic data indicate lateral

consistency at scales of tens to hundreds of meters. The relative roles of sand occurrence and reservoir quality, and the implications for vertical and lateral reservoir communication, are subjects of ongoing study.