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Confining system integrity assessment by detection of natural gas migration using seismic diffractions

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ABSTRACT

Successful carbon capture and storage (CCS) requires secure CO_2 confinement within a geologic reservoir. If associated with a depleted hydrocarbon reservoir, the sealing capability can be determined by examination of the shallow subsurface for hydrocarbon leaks. Numerous seismic signatures have been reported to be hydrocarbon indicators. The interpretation can be advanced by using seismic diffractions, which could indicate subtle hydrocarbon accumulations not detectable by conventional techniques. In this work, we investigate the potential of seismic diffractions for use in shallow gas detection. We extract diffractions from the ultra-high-resolution 3D P-Cable seismic dataset acquired along the Gulf of Mexico inner continental shelf. Interpretation of this dataset revealed numerous seismic signatures associated with hydrocarbon accumulations (e.g., a prominent gas chimney). We analyze scattering features of the detected hydrocarbon accumulations and confirm the correlation between confidently interpreted gas accumulations and seismic diffractions. Based on that, we suggest using diffractions for confining system integrity assessment. Diffraction analysis allows operating with subtle seismic signals that facilitates exploration of reliable CO_2 storage sites.

1. Introduction

Effective implementation of a carbon capture and storage (CCS) program requires a superior reservoir as well as a high quality confining system (e.g., top seal or caprock). Therefore, detailed investigation of confining systems, their integrity and sealing properties are an important component of prospecting for potential CO_2 storage sites.

Miocic et al. (2016) evaluated natural CO_2 reservoirs, in which the carbon dioxide has been trapped for million years, and discussed the main factors determining the storage security, which included thickness of the confining system, reservoir depth, and gas density. Faults and fractures were reported as the main conduits for migration of CO_2 within the subsurface. Preliminary assessment of storage security can be done by seismic data analysis. In addition to identifying reservoirs and evaluating of stratal thicknesses, seismic can detect faults in the confining system and overlying strata (Juhlin et al., 2007; Alcalde et al., 2013). In combination with geomechanics, this information is critical for determining the optimal configuration of a potential storage site (Vidal-Gilbert et al., 2010; Teatini et al., 2014; Ward et al., 2016; White et al., 2016).

If associated with a depleted hydrocarbon reservoir, confining properties may be determined by investigating the overlying strata for hydrocarbon accumulations. A minimal indication of hydrocarbons suggests reasonable sealing properties. Conversely, an increase of detected gas concentrations above the reservoir can indicate poor confining properties.

Løseth et al. (2009) presented an extended overview of seismic features associated with hydrocarbon leakage. Hydrocarbon saturation causes amplitude anomalies (bright spots, polarity reversals, dim spots), which have been exploited as hydrocarbon indicators for decades (Brown and Abriel, 2014). These features are mostly related to reservoir units. However, they also may be observed in rocks with low permeability, which constitute caprocks and seals (Løseth et al., 2009).

One prominent seismic signature associated with hydrocarbon leakage is a gas chimney, which is a vertical zone with discontinuous reflectors (Heggland, 1998; Singh et al., 2016). The migrating gas causes irregular changes in the compressional velocity field that yields scattering and degradation of reflected waves (Arntsen et al., 2007). Zhu et al. (2012) investigated seismic imaging of a target in offshore China and concluded that wave scattering caused by shallow gas was the primary phenomenon causing the reflected waves degradation.

A local hydrocarbon accumulation can create an acoustic impedance contrast sufficient for scattering seismic energy. The linkage between hydrocarbon accumulations and seismic diffractions has been documented in various case studies (Rauch-Davies et al., 2014; Klokov et al., 2014; Ogiesoba and Klokov, 2015; Schoepp et al., 2015; Klokov

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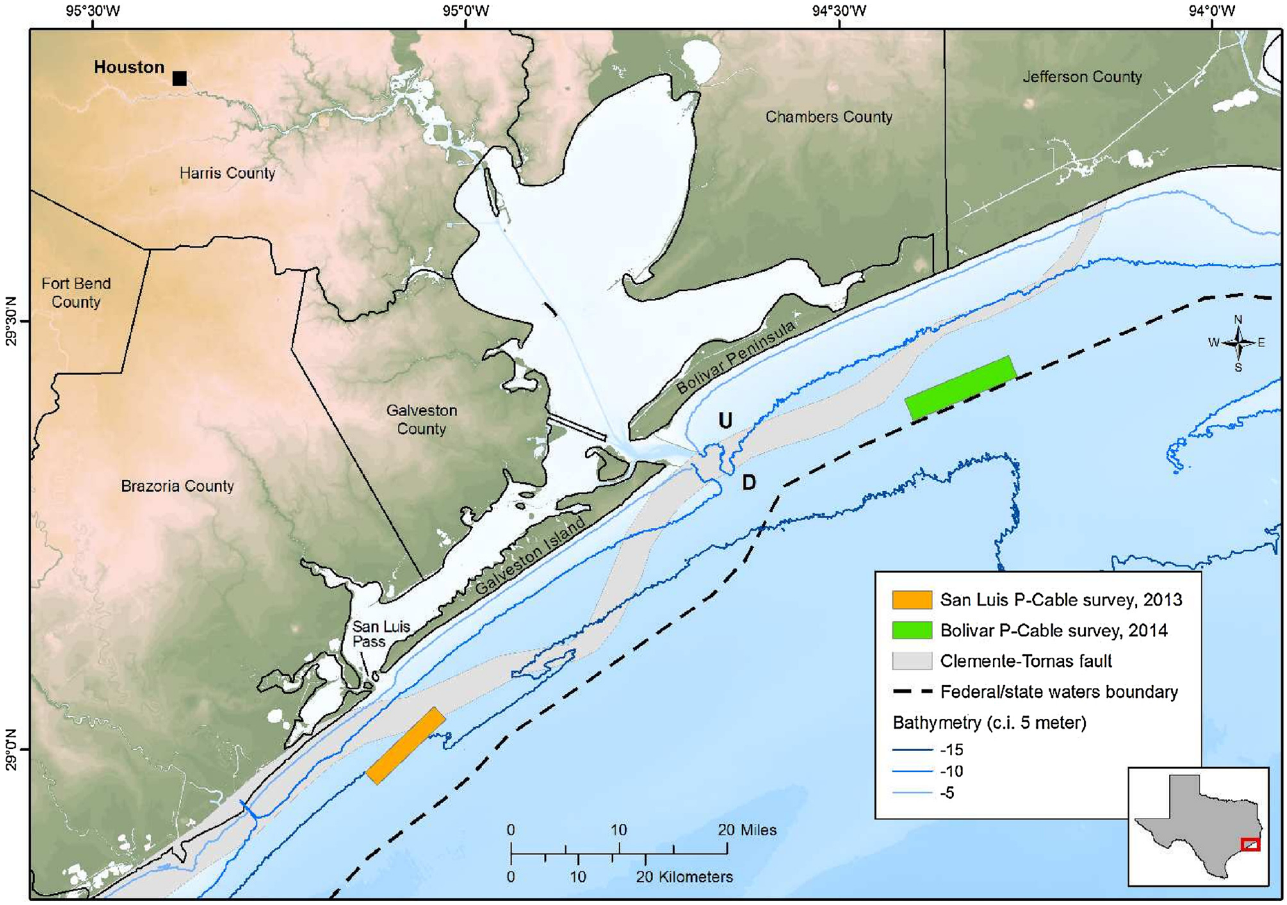

Fig. 1. Map of the Texas Coastal Bend and Texas State Waters showing P-Cable survey location. Clemente-Tomas Fault outline is from Seni et al. (1997); fault located where it offsets the top of the Miocene geologic section.

et al., 2015) that makes diffraction analysis a complementary tool for hydrocarbon identification. In opposition to conventional methods, diffraction analysis allows operating with much weaker seismic signals and, thereby, identification of subtle hydrocarbon accumulations or even just increases in hydrocarbon concentration. Klokov et al. (2017) analyzed seismic diffractions from ultra-high-resolution 3D (UHR3D) seismic data acquired on the inner shelf of the Gulf of Mexico (near Bolivar Peninsula, Fig. 1) using a P-Cable™ acquisition system (Petersen et al., 2010; Lippus, 2014) to evaluate fluid migration above potential reservoirs. Diffraction anomalies have been reported and interpreted as evidence of hydrocarbon migration.

In this work, we further investigate the potential of seismic diffractions for use in shallow gas detection. We utilize a P-Cable dataset acquired in the Texas State Waters near the San Luis Pass (Fig. 1). Interpreting the same dataset, Meckel and Mulcahy (2016) described various seismic anomalies associated with hydrocarbon accumulations. We compare these anomalies with seismic diffraction signatures to examine scattering features of hydrocarbon saturated zones. Then, we interpret weaker diffraction signals to identify subtle hydrocarbon accumulations not imagible with conventional seismic attribute analysis.

2. Geological settings

Addressing seismic attribute analysis of the same dataset used in the current study, Meckel and Mulcahy (2016) mapped and interpreted two Quaternary age sequence boundaries and related incised valley systems that were associated with two glacial lowstands (approximately 140 ka and 20 ka, respectively). They based their interpretation of the local geology on the many preceding studies (Berryhill et al., 1987; Paine, 1991; Anderson et al., 1996; Abdullah et al., 2004; Simms et al., 2007). Following from the interpretation of Abdullah et al. (2004), a significant portion of the Pleistocene section of the study area is composed of a delta lobe of the paleo Brazos River. The lobe is interpreted to have been deposited during oxygen isotope stage 5e early in the Wisconsin interstadial (Shackleton et al., 2003) and have aggradational to progradational clinoform configurations. The 20 ka sequence boundary identified by Meckel and Mulcahy (2016) is above lobe 5e; whereas, the 140 ka sequence boundary is below. The incised valleys correlated with the two sequence boundaries include seismic facies typical of fluvial channels (e.g., scours, point bars, lateral accretions). The interfluvial deposits outside the incised valleys comprise seismic facies, which were interpreted as coarse-grained channel scour deposits of a meandering channel and transgressive estuarine to marine, fine-grained mud fill. The natural gas accumulations in the coarser grained deposits are the focus of the current study.

3. Data acquisition and processing

The P-Cable technology provides a specific acquisition configuration that allows imaging of near- subsurface with extremely high