GEOGULF2021
AUSTIN
October 27–29, 2021

High Order Stratigraphic Framework of Intraslope Growth Faulted Subbasins Offshore Matagorda Bay, Texas

J. Franey and T. Meckel

Bureau of Economic Geology, Jackson School of Geosciences,
University of Texas at Austin, Austin, Texas 78758

ABSTRACT

Carbon capture and storage (CCS) is currently one of the leading atmospheric emission mitigation technologies. To have meaningful impact on the atmosphere CO_2 concentrations, megatons (10^6) of CO_2 must be removed from the carbon cycle permanently. This requires subsurface geologic storage sites that are both volumetrically significant and secure over geologic time-scales. The northern Gulf of Mexico (GOM) can serve as a major location for CCS. Miocene strand-plain systems in the GOM are an ideal stratigraphy for such storage due to their proximity to emission sources, quality sand reservoirs, and depth relative to overpressure.

This study focuses on a suite of strike parallel subbasins within the lower Miocene offshore of Matagorda Bay, Texas. Each subbasin has potential to serve as a future carbon sequestration site. Accurate mapping of subbasins' stratigraphy is necessary to understand the variable thickness and associated risk of reservoir-sealing shale intervals, recognizing that injection beneath thicker, more uniformly distributed shales is more favorable. These intervals must be mapped at high resolution (4^{th} order cyclicity) to understand the individual components in assessment and risk analysis.

This research generates a novel dip-steered seismic volume, which is leveraged to improve seismic attribute calculations and mapping at the 4^{th} order. The dip-steered seismic volume records the seismic dip in the inline and crossline direction of seismic features at the intersection of every inline, crossline, and seismic sample. This volume is used to generate a model of dense, 3D, auto-tracked horizons across each subbasin. The models better connect high resolution, but sparse, well log data and low resolution, but continuous, seismic data. Thickness distributions and shale interval maps generated from the models aid in risk assessment. Based on the resulting

Franey, J., and T. Meckel, 2021, High order stratigraphic framework of intraslope growth faulted subbasins offshore Matagorda Bay, Texas: GeoGulf Transactions, v. 71, p. 101–108.

shale thicknesses, the suite of subbasins should be further considered as future storage sites.

INTRODUCTION

The area of interest of this study is a suite of subbasins located offshore Matagorda Bay, Texas, within the lower Miocene 2 interval (Fig. 1). This interval consists of a siliciclastic wedge approximately 600 m thick which was deposited in a strand plain depositional environment between the North Padre delta to the south and the Calcasieu delta to the north (Galloway, 1989; Xu et al., 2016). The study area consists of five 'subbasins' (Fig. 2). Each subbasin is bounded landward by a listric growth fault extending through the Miocene interval separating Miocene deposits from underlying Oligocene deposits. The subbasins are bounded basinward by another listric growth fault which in turn marks the landward edge of another more distal subbasin. Subbasins are bounded laterally by structural ridges that form perpendicular to strike. The formation of these subbasins is caused by interplay of Oligocene-Miocene clastic deposition and halokenesis of allochthonous salt deposits. The sediment fill of each subbasin consists of interbedded sands and shales. The sand bodies have the potential to act as reservoirs for injected CO_2 and the overlying shales act as the top seal. Accurate mapping of the distribution of shale thicknesses at a high resolution (4th order) will improve assessing the risk associated with the top seal for a carbon injection site.

METHODS

To accomplish the seismic interpretation necessary for 4th order analysis of each subbasin and have an accurate assessment of shale thickness and spatial distribution, a few novel seismic techniques are used. A dip-steered seismic volume records the dip of seismic features as vectors at the intersection of every inline, crossline, and seismic sample interval. A dip-steered volume can enhance imaging of seismic data and allow for improvement of some seismic attribute calculations (e.g., curvature, similarity, dip fields), fault tracking, and gridding of seismic horizons (Ishak et al., 2018; Abdullah and Pranowo, 2020). Processing a seismic volume to create a dip-steered volume involves the calculation of the degree of dip in both the inline and crossline directions. These vectors are estimated using principal component analysis and eigenvalue decomposition of the seismic amplitude field (Fig. 3). These dip vectors are then used to aid in creating a model of dense, 3D, auto-tracked horizons. The intervals between horizons in this model are at a higher resolution than seismic reflectors and capture changes in thickness of shale intervals.

Well log data aids in the stratigraphic interpretation of the model. Well logs within a subbasin are correlated and interpreted as sand or shale intervals (Fig. 4). These interpretations are assigned to intervals within the model. Distributions of the interpreted 4th order shale and sand thicknesses and associated thickness maps are generated for each interpreted stratigraphic interval.

RESULTS

A simple use case can serve as an example of the benefits of the methods presented in this study. In this scenario, there are two possible injection sites for a CO_2 sequestration site within a subbasin. Both sites have identical pore volume, cost of injection, and high-quality trap. The only difference between the two potential sites is the shale interval that would act as a top-seal for the reservoir. Only one of these two reservoirs can be chosen for injection. Figure 5 shows a histogram of thickness distributions for each of the shales. These distributions are each made up of 10 samples, representing the 10 previous wells drilled in the area. The distributions show

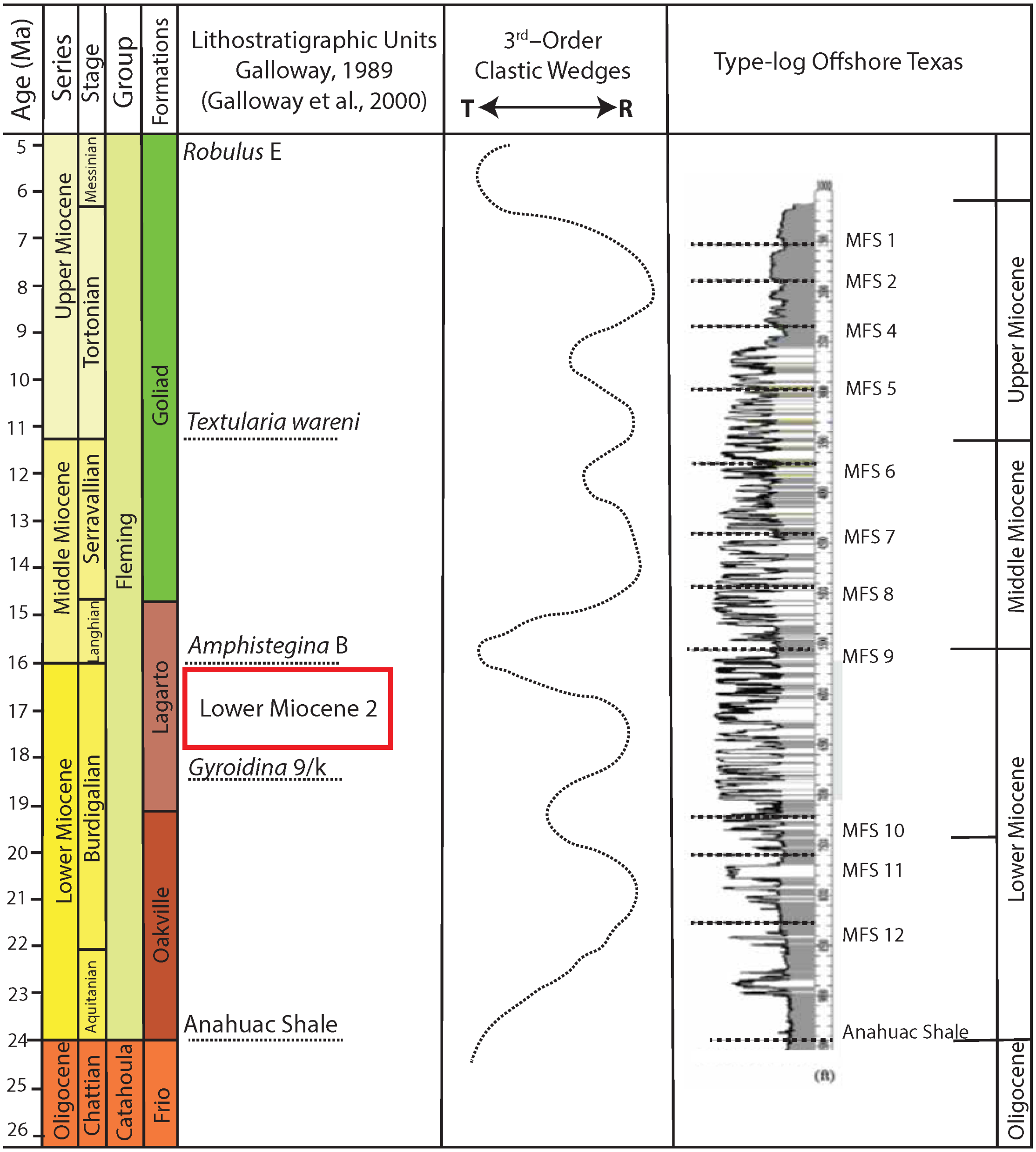

Figure 1. Correlation chart showing the Miocene section of the northwest shelf of the Gulf of Mexico (modified after Olariu, 2019). Study interval shown with red box.

that interval 1 has a higher median thickness compared to interval 2. Understanding that a thicker shale interval is associated with less risk in terms of potential leakage of CO_2 from the reservoir, it would seem injection of CO_2 beneath interval 1 would have a lower associated risk than injection beneath interval 2.

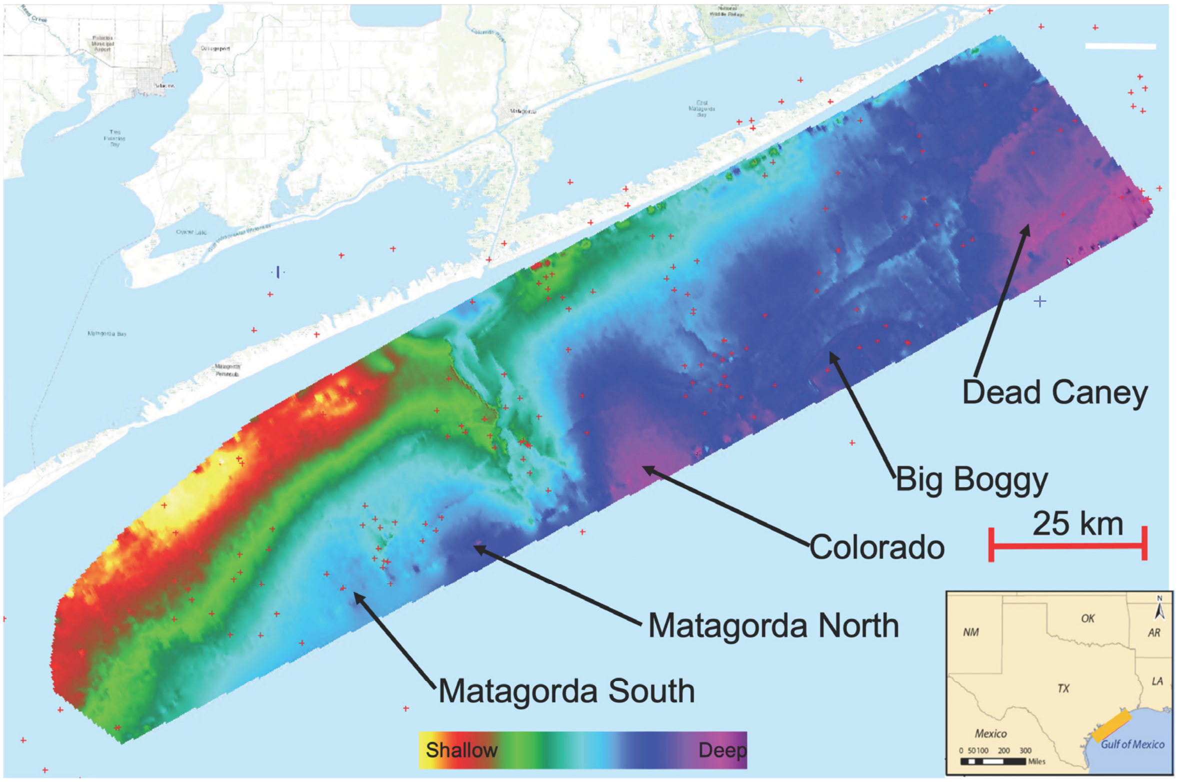

Figure 2. Structure map of the subbasins within the study area.

However, concerns about potential failure of the top-seal promote further analysis of the shale intervals. The workflow presented in this study is followed and high-resolution thickness maps are generated for the two intervals. Figure 6 shows the thickness maps of both interval 1 and interval 2. These high-resolution maps generated using dip-steered seismic data have the potential to change the risk assessment of the two seals. Though interval 1 has a higher median thickness, the map shows a higher degree of undulation in the shale thickness. The center of interval 1 thins to 30% of the median thickness. Interval 2 is much more uniform in its spatial distribution. This new information may change the relative risk associated with these two intervals, and it may become more favorable to inject beneath interval 2 shale. Though its median thickness is less than the TST 1 interval, its uniform distribution lowers the risk of leakage.

SUMMARY AND CONCLUSIONS

The methods presented to access the thickness of shale intervals at a high resolution has proven to be useful and worthwhile for subbasins offshore Matagorda Bay, Texas. The creation of dense, 3D auto-tracked models allow interpreters to combine the high resolution of well log data with the spatial coverage of a seismic survey. Well log properties can be applied to intervals much finer than a single seismic reflection. The use of dip-steered seismic data has shown to have great potential to improve risk assessment for CO_2 storage sites. Accurate assessment of the sealing capacity of a carbon injection reservoir is an important aspect for consideration. Reservoirs must be considered stable for geologic periods to be viable injection targets. Thin

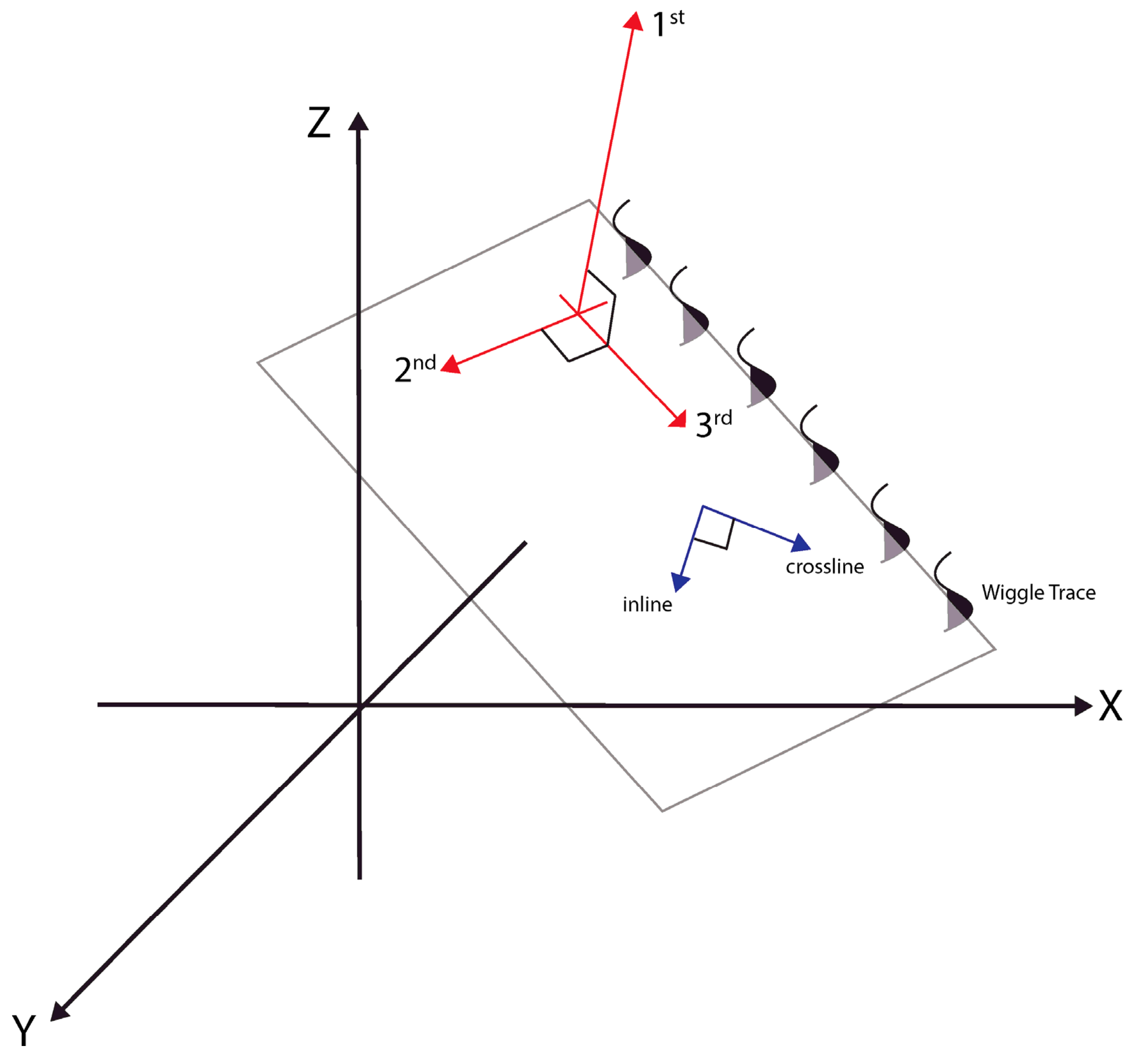

Figure 3. Schematic for principal component analysis of a seismic amplitude field. The first principal component is a vector in the direction of the highest change in amplitude, which is perpendicular to the dip. The second and third principal components are perpendicular to the first and define the plane of the seismic event. With these vectors defined, the dip can be calculated in the inline and crossline direction.

shales pose a risk of failure during the injection of CO_2 from the increase of pressure (Yang et al., 2019). Shales must also withstand pressure changes as the CO_2 migrates from the injection site to the updip seal of the reservoir (Leetaru et al., 2009).

Carbon sequestration is an important technology to reduce the total amount of greenhouse gases currently in the Earth's atmosphere. As industries and countries strive towards net zero emissions targets, it is likely that carbon sequestration will play an integral role in these pursuits. Identification and characterization of potential CO_2 reservoirs is necessary before large amounts of CO_2 gas are captured and transported.

A suite of Miocene subbasins exist offshore Matagorda Bay, Texas, that have been identified as potential CO_2 sequestration sites. Analysis of the sediment fill of these subbasins is important

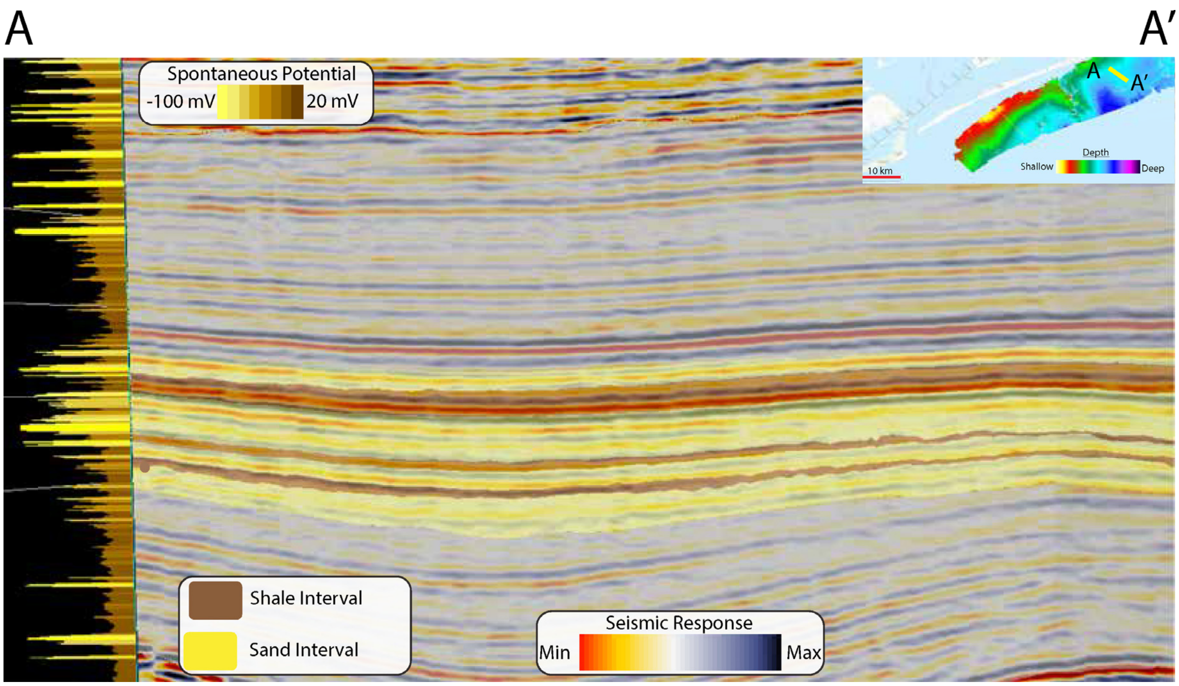

Figure 4. Interpretation of sand and shale intervals based on well log data. High spontaneous potential response in a log indicates presence of clays and is associated with shales, while a low spontaneous potential response is associated with sands.

for twofold reasons. (1) accurate mapping of the thickness of sands and shales present in the subbasin is important for economic risk assessment of storage sites and (2) the suite of subbasins analyzed in this study are a subset of many more Miocene subbasins that exist along strike, each having the potential to act as secure, long-term storage of CO_2.

REFERENCES CITED

Abdullah, A., and W. Pranowo, 2020, Layer-steered filter for enhancing seismic reflection interpretability: Journal of Petroleum Exploration and Production Technology, v. 10, p. 3235–3239, <https://www.doi.org/10.1007/s13202-020-00994-2>.

Galloway, W. E., 1989, Genetic stratigraphic sequences in basin analysis II: Application to northwest Gulf of Mexico Cenozoic Basin: American Association of Petroleum Geologists Bulletin, v. 73, p. 143–154, <https://www.doi.org/10.1306/703c9afa-1707-11d7-8645000102c1865d>.

Galloway, W. E., 2000, Stratigraphic systems: Origin and application. Eos, Transactions of the American Geophysical Union, v. 81, p. 401, <https://www.doi.org/10.1029/00eo00302>.

Ishak, M., M. Islam, M. Shalaby, and N. Hasan, 2018, The application of seismic attributes and Wheeler transformations for the geomorphological interpretation of stratigraphic surfaces: A case study of the F3 Block, Dutch Offshore Sector, North Sea: Geosciences, v. 8, no. 3, 21 p., <https://www.doi.org/10.3390/geosciences8030079>.

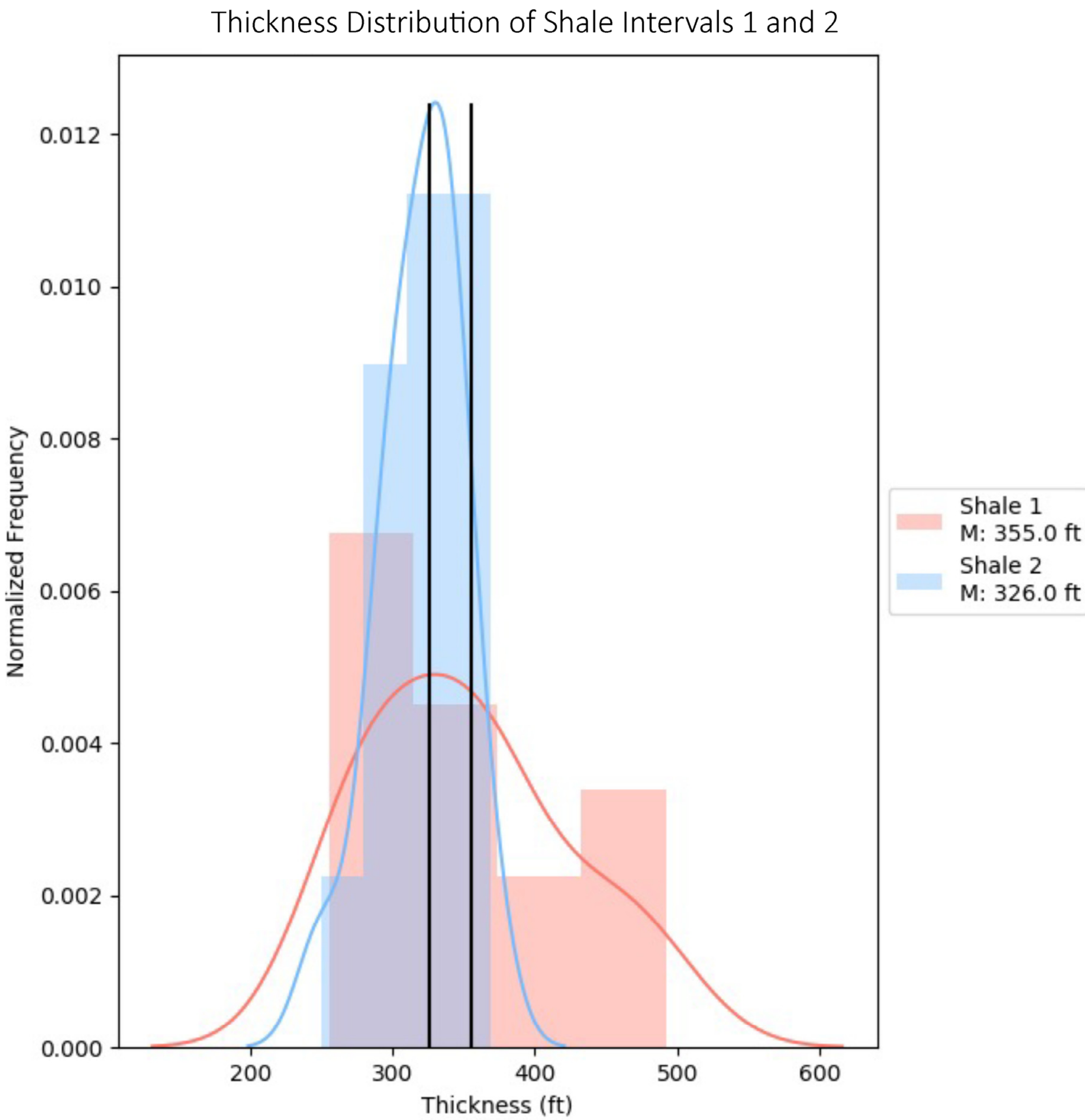

Figure 5. Thickness distribution of shale intervals 1 and 2 for the use case. Each distribution is made of 10 samples (i.e., well data). From these distributions it appears that interval 1 has less associated risk regarding sealing capacity due to the higher median thickness.

Leetaru, H. E., S. M. Frailey, J. Damico, E. Mehnert, J. Birkholzer, Q. Zhou, and P. D. Jordan, 2009, Understanding CO_2 plume behavior and basin-scale pressure changes during sequestration projects through the use of reservoir fluid modeling: *Energy Procedia*, v. 1, p. 1799–1806, <https://www.doi.org/10.1016/j.egypro.2009.01.235>.

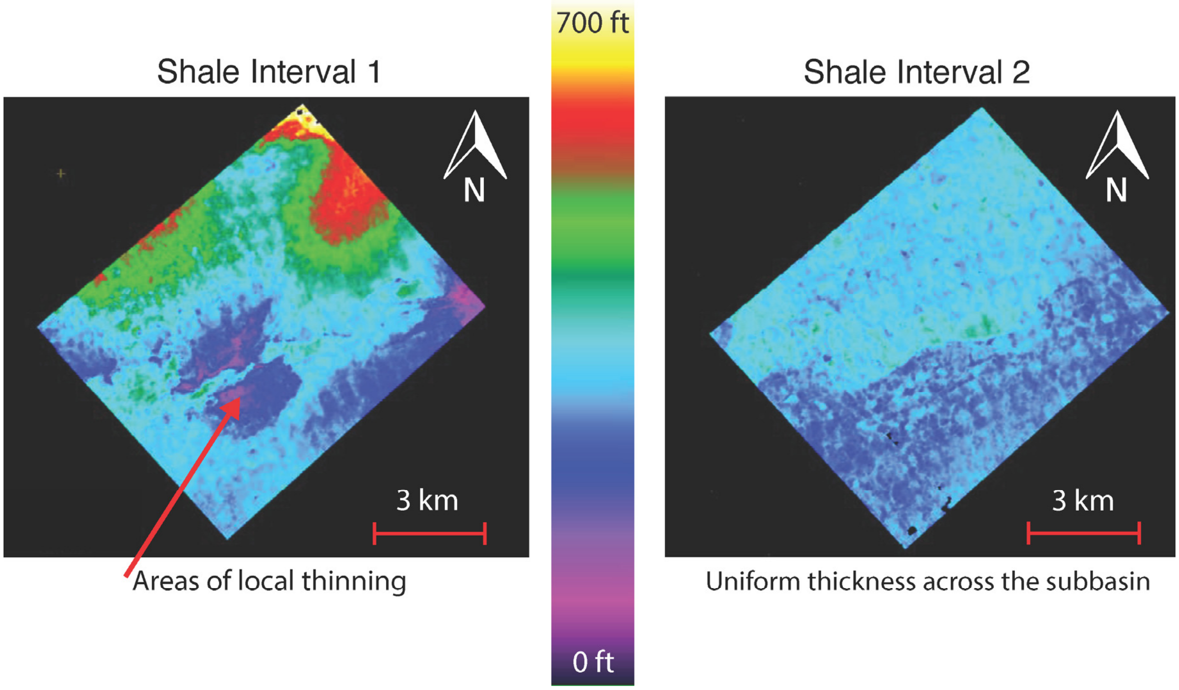

Figure 6. Comparison of the spatial variability in thickness distribution between shale intervals 1 and 2 for the use case. Interval 1 shows high variability with some areas less than 80 ft of shale. Interval 2 is more uniform across the subbasin and thus may be associated with a lower risk in terms of sealing capacity for CO_2 injection.

Olariu, M. I., M. DeAngelo, D. Dunlap, and R. H. Treviño, 2019, High frequency (4th order) sequence stratigraphy of early Miocene deltaic shorelines, offshore Texas and Louisiana: Marine and Petroleum Geology, v. 110, p. 575–586, <https://www.doi.org/10.1016/j.marpetgeo.2019.07.040>.

Xu, J., J. W. Snedden, D. F. Stockli, C. S. Fulthorpe, and W. E. Galloway, 2016, Early Miocene continental-scale sediment supply to the Gulf of Mexico Basin based on detrital zircon analysis: Geological Society of America Bulletin, v. 129, p. 3–22, <https://www.doi.org/10.1130/b31465.1>.

Yang, Z., T. Xu, F. Wang, Y. Diao, X. Li, X. Ma, and H. Tian, 2019, A study on the CO_2–enhanced water recovery efficiency and reservoir pressure control strategies. Geofluids, 2019 vol., p. 1–17, <https://www.doi.org/10.1155/2019/6053756>.