

Burrow-associated porosity and permeability enhancement in a naturally-fractured carbonate reservoir: The Buda Formation of Texas, USA.

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Summary

The global increase in hydrocarbon demand, and the inherent need for identifying commercial hydrocarbon-hosting zones, have turned the geoscience community into looking for unconventional reservoirs, or mature fields with untapped potential. Herein, we characterize the Buda Formation, a mature, tight (low-porosity matrix), highly bioturbated, and naturally-fractured carbonate reservoir in Texas (USA), where limited hydrocarbon and water resources have been produced since the 1920s. The drilling/production strategy in this reservoir has been to target natural fractures, however, highly-bioturbated levels within the formation can play a key role in providing permeable pathways for enhanced production. Herein, we analyzed the effects of bioturbation on the porosity and permeability of the Buda Formation, and the results show that (in addition to the natural fractures) burrows (and borings, to a lesser extent) substantially increased the porosity and permeability of this unit, thus, potentially contributing to enhanced hydrocarbon (or groundwater) storage and production. These biogenic structures might also have favored the development of natural fractures and stylolites in the Buda Formation. However, further studies are required to prove this hypothesis.

Theory

Bioturbation imprints additional heterogeneity in the sediment texture, and thus, could substantially change the porosity and permeability of the host sediment, and evolved rock. Several studies have analyzed the negative effect of bioturbation on porosity and permeability in reservoir rocks (e.g. Qi et al., 2012; Alqubalee et al., 2022; Mode et al., 2022), whereas many others have shown enhanced reservoir quality linked to the activity of bioturbators and/or to bioturbation-related diagenetic processes (e.g. Buatois et al., 1999; Gingras et al., 2004; Baniak et al., 2013; Hsieh et al., 2015; Golab et al., 2017; Friesen et al., 2017; Eltom & Hasiotis, 2019; Miguez-Salas et al., 2022). Moreover, there is an embryonic but growing realization that burrowing activity may also stimulate natural fracturing (e.g. Bednarz & McIlroy, 2012; Knaust et al., 2020), thus, further contributing to reservoir quality enhancement.

Method

Field descriptions, transmitted-light petrography (Nikon Labophot-Pol microscope), back-scattered electron microscopy (Phenom-World Phenom XL scanning electron microscope), and micro-CT (G.E. V/TOMEX/M scanner) analyses were conducted on outcrops and bioturbated

and/or bored samples of the Buda Formation, respectively. These analyses were aimed to compare the effects of the ichnogenic structures on the appearance, mineralogy, texture, and porosity of the Buda Formation distributed along the Dryden-Comstock-San Antonio-Austin transect. In addition to the porosity analysis, micro-CT data from a selected number of samples was used for permeability estimations through simulations managed with the Avizo Fire Xlab Hydro software.

Results and Conclusions

Field and lab investigations of the Buda Formation revealed that burrows and borings occurring in this unit, in particular, pervasive boxwork-like networks assigned to *Thalassinoides* isp. from firmground surfaces have significantly higher porosity and permeability than the rock matrix (Figure 1), thus, improving the reservoir quality of the carbonate reservoir. Though some burrows may decrease porosity and permeability (e.g., cemented *Chondrites* isp.; Figure 2), they are rare and randomly distributed in the rock formation. In general, the higher the bioturbation degree in the Buda Formation the higher the reservoir quality. In addition, our observations suggest that some of these biogenic structures (burrows and borings) may have also favored the generation of natural fractures and stylolites (Figure 3), thus adding additional pathways for fluid migration and storage. Nevertheless, in addition to micro- and macroscopic observations of the rock formation, detailed geomechanical studies to explore a possible genetic relationship between burrows (and borings) and discontinuity structures (e.g., fractures, stylolites) are required.

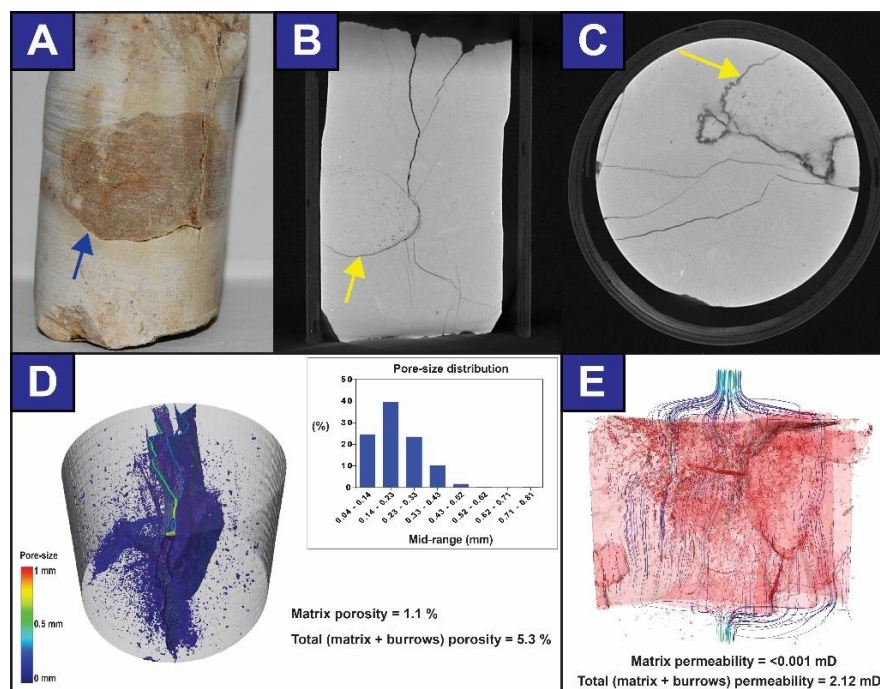


Figure 1. Burrow-related porosity and permeability in a sample with passive-filled *Thalassinoides* isp. A. B-01 core-plug showing clay-filled *Thalassinoides* isp. (arrowed). B. Micro-CT sagittal-view of the B-01 core-plug, showing the clay-filled *Thalassinoides* isp. (arrowed), and fractures. C. Micro-CT transaxial-view of the B-01 core-plug, showing

the clay-filled *Thalassinoides* isp. (arrowed) and fractures. D. Porosity data. E. Permeability data and digital visualization of the fluid flow through the pore network.



Figure 2. Photomicrograph displaying high porosity *Thalassinoides* isp. (delineated by the segmented, curved yellow line) contrasting the completely calcite-cemented *Chondrites* isp. below.



Figure 3. Fracture (red arrow) and stylolite (yellow arrow) associated with firmground *Thalassinoides* isp. (Th).

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