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Outcrop and Subsurface Characterization of Microbialite Facies in the Ordovician Arbuckle Group of Missouri and Kansas

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Introduction

Ordovician Arbuckle Group has been a major oil producer in Kansas since its first discoveries in the 1880's. Production has been largely limited to the upper few meters that represent fractured karstic reservoirs. Remaining sections of the Arbuckle Group of Kansas are largely unexplored for hydrocarbon resources. Reservoir characterizations by Steinhauff et al. (1998) and Franseen et al. (2003) have suggested that deeper reservoirs may exist where reservoir quality is driven by lithofacies characteristics. Some of the more important reservoirs have been shown to contain microbial components in their fabrics, including thrombolites, stromatolites and peloidal wackestones to grainstones.

Purpose and Methodology

This study examines outcrops of microbialites from central and southern Missouri as analogs for the subsurface Arbuckle in central Kansas. These Missouri sections provide a clearer picture of the distribution, characteristics and controls on microbial facies distribution in the region during the Cambro-Ordovician. Seven outcrops were described in central and south-central Missouri. In addition, a mineral exploration core from southwest Missouri (H-13) was examined. Lithologies, depositional cycles, bedding characteristics, porosity types, and microbialite fabrics were described. Over seventy-five thin sections were prepared and examined for allochems, degree of dolomite crystallinity, and estimation of porosity and permeability. For comparison, four cores were described from Rice, and Ellsworth Counties along the Central Kansas Uplift. Lithofacies descriptions included allochems, microbial fabrics, dolomite crystallinity, porosity and porosity type. Reservoir quality in terms of porosity and permeability is related to the original depositional fabric and matrix. Point counting was used to determine porosity and estimates of permeability from thin sections followed methods in Teodorovich (1949).

Background and Setting

The Arbuckle Group was deposited during the Late Cambrian and Early Ordovician Sauk sequence (Sloss, 1963) across Kansas and Missouri. The resulting deposits are a thick sequence (hundreds of meters) of dolomitized cyclically-deposited carbonates with varying amounts of sandstone and chert. Microbial fabrics occur throughout the Arbuckle strata in Missouri and Kansas (Figure 1 & 2). In Missouri, the oldest Ordovician unit exposed is the Gasconade Formation, which is comprised of brown to gray, fine to coarse crystalline, cherty dolomite. The Lower Gasconade contains gray oolitic and stromatolite chert beds. A widespread silicified microbial biostrome divides the lower and upper members of the Gasconade. The Upper

Gasconade is primarily massive-bedded dolomite with very little chert. The overlying Roubidoux Formation is composed of dolomite and sandy dolomite with beds of sandstone, and cherty dolomite and abundant stromatolite and thrombolite fabrics. The upper Arbuckle is represented by the Jefferson City and Cotter Formations. These are chiefly brown to gray, fine to medium crystalline dolomite with chert, sandstone and shale beds. These units contain stromatolites and a few thrombolite facies. Similar stratigraphy and lithofacies are present in subsurface Kansas.

Microbialite Characterization

Outcrop and subsurface examples of Arbuckle microbialites are characterized at the micro ($<=10^{-3}$m), meso (10^{-2}m), and macro-scale ($>=10^{-1}$m). Micro-scale examinations of the Arbuckle Formation in Missouri and Kansas indicate dolomite overprint of original lithologies; however, depositional facies are still recognizable because the dolomitization was not entirely fabric destructive. The degree and size of dolomite crystallinity correlates in part to original carbonate micro- and meso-scale textures. Mudstones and wackestones tend to be overprinted by fine- to medium-crystalline dolomite while packstones and grainstones have a medium to coarse dolomite overprint. Many original carbonate lithofacies contain microbial fabrics, including algal clots, algal-trapped silt and/or fossils, intercrystalline and vuggy "laminar" pores (Figure 2B). These features are mostly visible at the micro-scale level. Clotting in thrombolites is also recognizable at the micro-scale as "dirty," very-fine crystalline dolomite (Figure 2D).

Meso-scale "stromatolite" textures are found within many lithofacies including in laminated carbonate mudstone, peloidal wackestones, and chert. These stromatolite textures range from pseudocolumnar to columnar-laminated growth forms. Stromatolite-associated lithologies are interpreted as forming in supratidal to shallow subtidal facies. "Thrombolite" textures defined at the meso-scale occur with burrowed, peloidal mudstone to packstone lithofacies with medium to coarse-crystalline dolomite overprint. These thrombolite fabrics have higher porosity in the form of intercrystalline and vuggy porosity types. They often occur in the basal parts of meter-scale depositional cycles, and are interpreted as forming in lower intertidal to lower subtidal environments.

Stromatolite macro-scale growth forms include mats, stacked hemispherical (SH) (Figure 1) and biohermal laterally-linked hemispheres (LLH) (Figure 2A). LLH forms range from 1.7 to 2m in thickness and 3m in width. SH type stromatolites range from 0.1m to 0.2m in thickness and 0.03m to 0.4m in height. The stromatolitic laminae at the meso-scale in the outcrops are mostly subspherical and have gentle to steep convex laminae shapes. Similar stromatolites can be seen in the subsurface cores. The pseudocolumnar stromatolites are flat laminated to undulatory. Mud cracks and anhydrite nodules and chicken-wire can be found amongst these stromatolites. Columnar-laminated stromatolites grade into the pseudocolumnar stromatolites, interpreted as a result of a decrease in water depth. Macro-scale thrombolite facies include, dendritic (Figure 2C) and chaotic growth forms. Chaotic thrombolites typically grade upwards into dendritic thrombolites and are capped by algal mat mudstones. Thrombolites are locally oil stained.

Stratigraphic Occurrence

Arbuckle microbialites were deposited in shallow marine environments, which are grouped into two depositional cycle types. A typical Type 1 cycle includes, from its base, 1) subtidal deposits of wackestones that grade upward to intertidal stromatolites, 2) subtidal channel/beach

sandstones that grade upward to intertidal stromatolites, 3) subtidal oolitic packstones/ grainstones that grade upward to intertidal stromatolites, and 4) subtidal mudstones that grade upward to intertidal wackestones with elongated chert nodules. A typical Type 2 cycle includes, from its base, 1) subtidal mottled wackestones to packstones that grade upward to supratidal deposits containing chert that possibly replaced supratidal evaporites such as chicken-wire anhydrite, 2) subtidal thrombolitic mudstones to wackestones that grade upward to intertidal to supratidal stromatolites.

Reservoir Analogs

The highest quality microbial reservoir facies observed in Missouri are the burrowed peloidal and associated thrombolitic boundstone facies of Type 2 depositional cycles. These are laterally persistent units characterized by high intercrystalline, vuggy porosity and regularly capped by tight, laminated mudstones. Dendritic thrombolites within these cycles had high porosity and high permeability. Examples of burrowed peloidal wackestones and associated thrombolite boundstones can be found in all Lower Ordovician formations in Missouri, but are most abundant in the Gasconade Formation, which represents deeper water deposits. The Jefferson City and Cotter Formations provide thicker beds of tight laminated mudstone facies that may better act to seal smaller thrombolite and peloidal wackestone units. Laminated stromatolites having vuggy "laminar" pores had moderate porosity and low permeability.

References

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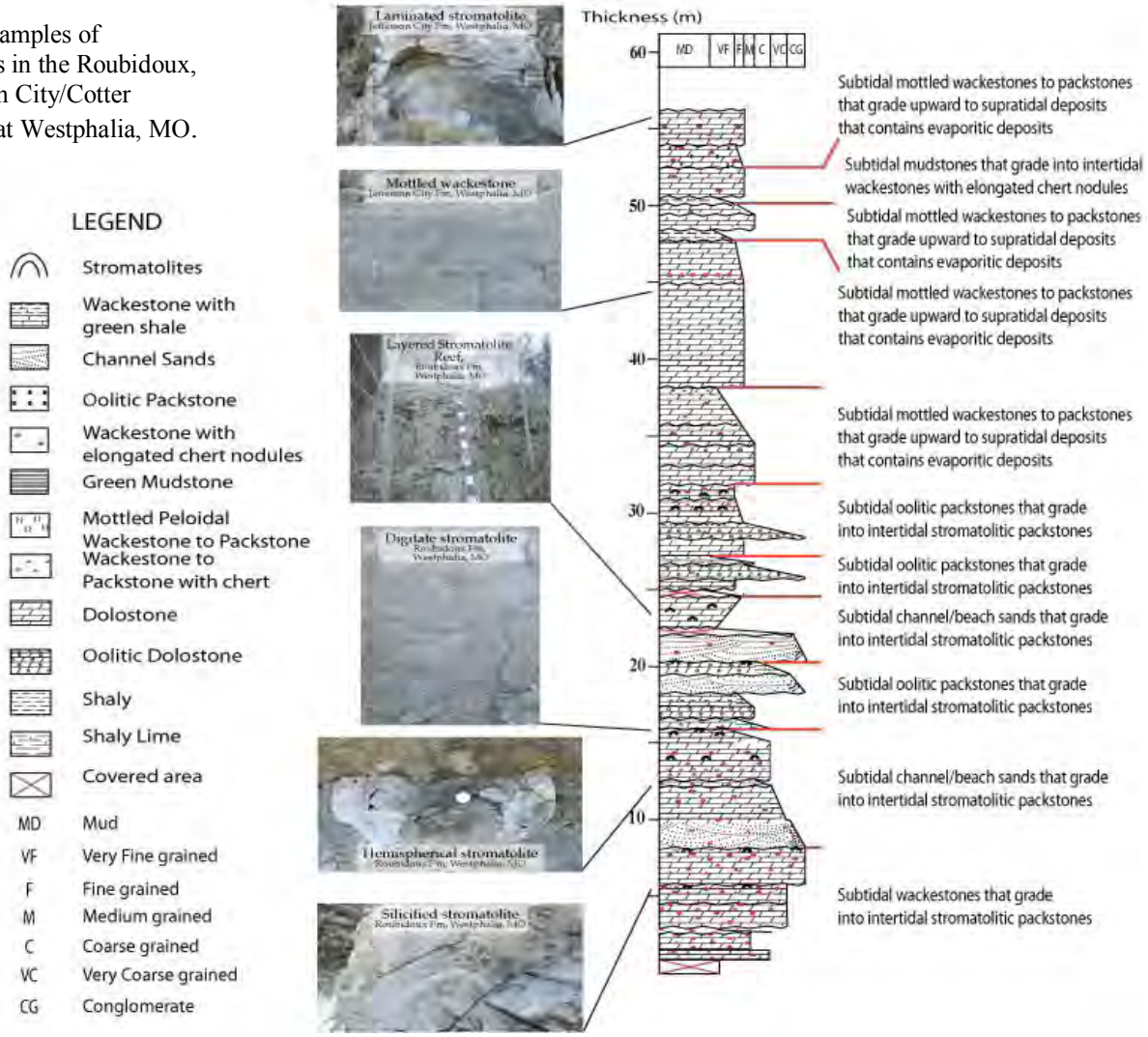
Figure 1. Examples of microbialites in the Roubidoux, and Jefferson City/Cotter Formations at Westphalia, MO.



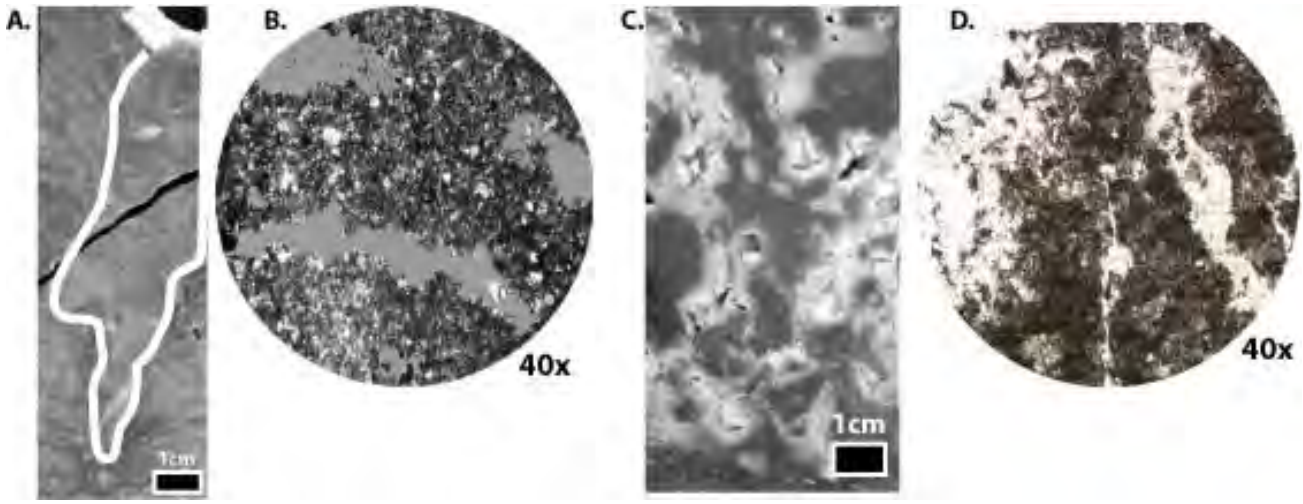


Figure 2. (A) LLH stromatolite with anhydrite from well H-13, MO, 822ft., (B) Photomicrograph of "laminar" vuggy pore of laminated stromatolite. Roubidoux Fm, Westphalia, MO., (C) Dendritic thrombolite from Roubidoux Fm, Well H-13, MO @ 761ft, (D) Photomicrograph of thrombolite showing peloidal clots and vuggy pores.