[PS]A Multi-scale Analysis and Stratigraphy of Microbialites of the Lower Ordovician of Central Missouri and Kansas*

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Abstract

Microbialites are useful paleoenvironment indicators as well as proven hydrocarbon reservoirs. This study focuses on the depositional environments and stratigraphic distribution of Lower Ordovician microbialites in central Missouri as outcrop analogs to subsurface reservoirs in Kansas. The units represented in the vicinity of Westphalia, Missouri include the Roubidoux and Jefferson City Formations. To determine the depositional environments suitable for microbialite development, we are currently examining the micro, meso, and macro-scale features of these structures and their relationship to surrounding lithologies.

These microbialites were deposited in a shallow marine environment and are grouped into two cycle types. Type 1 deposits include 1) subtidal deposits of very coarse crystalline dolomite with green shale grading upward to intertidal stromatolites, 2) subtidal deposits of channel sandstones grading upward to intertidal stromatolites, 3) subtidal deposits of oolitic pack/grainstone grading upward to intertidal stromatolites, and 4) subtidal green mudstones that grade upward to intertidal blocky, very fine crystalline dolomite or intertidal deposits of elongated chert nodules. Type 2 deposits include subtidal sediments of medium to fine crystalline, mottled dolomite that grade upward to supratidal deposits containing cauliflower chert (possibly replacing supratidal evaporite) and brecciated chert.

Most Arbuckle reservoirs drilled in Kansas are located in the upper karsted zones. Outcrop analogs indicate that potential microbialite reservoirs

may exist below this target. Porosity and permeability studies of Missouri and Kansas microbialites are used to investigate this reservoir quality and conduct a comparison study. Porosity within Missouri microbialites includes intercrystalline, fenestrae, and vuggy porosity. Elevated permeabilities are associated with “laminar” vuggy porosity.

A Multi-Scale Analysis and Stratigraphy of Microbialites of the Lower Ordovician Strata of Central Missouri

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ABSTRACT

Microbialites are useful paleoenvironment indicators as well as proven hydrocarbon reservoirs. This study focuses on the depositional environments and stratigraphic distribution of Lower Ordovician microbialites in central Missouri as outcrop analogs to subsurface reservoirs in Kansas. The units represented in the vicinity of Westphalia, Missouri include the Roubidoux and Jefferson City Formations. To determine the depositional environments suitable for microbialite development, we are currently examining the micro, meso, and macro-scale features of these structures and their relationship to surrounding lithologies.

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GEOLOGIC SETTING & EARLY ORDOVICIAN PALEOENVIRONMENT OF WESTERN UNITED STATES

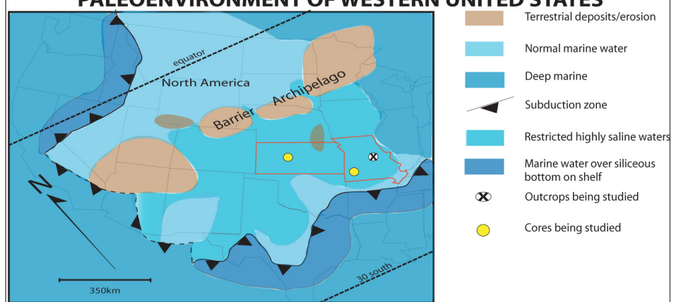


Fig. 1. Interpretation of Early Ordovician paleoenvironment in the western United States. Adapted from Ross (1975).

INTRODUCTION & GEOLOGICAL SETTING

This study focuses on the microbialites in the Roubidoux and Jefferson City Formations of the Arbuckle Group of the Lower Ordovician within Central Missouri.

Deposition of the Arbuckle Group began during the Late Dresbachian of the Late Cambrian and continued until the Late Arenigian of the Early Ordovician. The base and top of the Arbuckle are bounded by major unconformities.

The Lower Ordovician period was a time of elevated temperatures and high levels of CO_2. High sea-levels flooded continents during this period and the Arbuckle Group was laid down during Sauk II & III sequence of Sloss. These were pristine conditions for the growth of microbialites along with the limited reef fauna diversity during this period.

The microbialites in this study were laid down in restricted highly saline waters of a ramp-type subtidal to peritidal environment during the Early Cambrian and Lower Ordovician.

PURPOSE

The purposes of this study are to:
(1) characterize the macro (cm-m) and micro (mm-cm) scale features in microbialites present in the Roubidoux and Jefferson City Formations in central Missouri
(2) determine environments of deposition of the microbialite and surrounding strata
(3) examine microbialite occurrence in a sequence stratigraphic framework.

In addition, reservoir quality of these microbialites are also being studied and is being compared to the microbialites of the Arbuckle Group in Kansas where they are found in the subsurface.

THE MACRO-SCALE (10^{-1} m)

Consists of hemispherical biostromes that are LLH-S type. The LLH-S mounds tend to be about 1.7m to 2m high with each head being about 3m wide. The LLH-S type stromatolites lie on a wavy surface. "Laminar" pores can be found in these biostromes.

Random mottling which maybe of algal nature. This can be seen at the meso and micro scales.

Fig. 2. LLH-S: Laterally-linked stromatolite mounds growing on a base that is spaced between each mound

Laterally linked stromatolites Gasconade Fm, Camdenton, MO

Random mottled thrombolite? Jefferson City Fm, Hollister, MO

Layered stromatolite reef Roubidoux Fm, Westphalia, MO

THE MESO-SCALE (10^{-2} m)

Consists of SH-C and SH-V type stromatolites. The SH-C heads are about 0.1m high and 0.4m wide. The SH-V stromatolites are about 0.2m high and 0.03m wide. The SH-V type stromatolites has a sharp erosional contact with the previous strata and the cycle ends at the top of it. The surrounding strata is a dolomitic packstone and contains fenestral and vuggy porosity. Permeability is excellent within the "laminar" pores.

The SH-C type stromatolites lies on medium crystalline dolomite and has a sharp contact with the previous strata. It also contains vuggy and fenestral porosity.

Fig. 3. SH-C: Stromatolites growing on a constant base

Silicified stromatolite Roubidoux Fm, Westphalia, MO

Digitate stromatolite Roubidoux Fm, Westphalia, MO

Fig. 4. SH-V: Stromatolites growing on a variable base

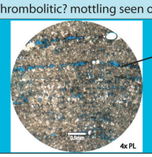
Hemispherical stromatolite Roubidoux Fm, Westphalia, MO

Laminated stromatolite Jefferson City Fm, Westphalia, MO

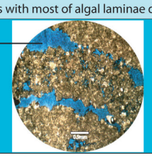
THE MICRO-SCALE (10^{-3} m)

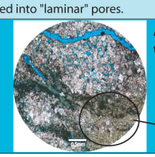
These microbialites usually occur within dolomitic wackestone to packstones. Laminations of the stromatolites can be seen as alternating between dark and light layers or between a micritic layer and coarser dolomite. Some of these layers tend to exhibit "laminar" porosity while others do not. These pores range between very fine silt size to fine sand size, with intercrystalline, fenestral, fracture, and vuggy porosity. Porosity ranges from 7% to 20%. Permeability ranges from 20md to 550md. Very fine silt size, detrital quartz grains are trapped either within laminae or between columns of stromatolites.

Thrombolitic? mottling seen on outcrop is also seen on thin sections with most of algal laminae dissolved into "laminar" pores.



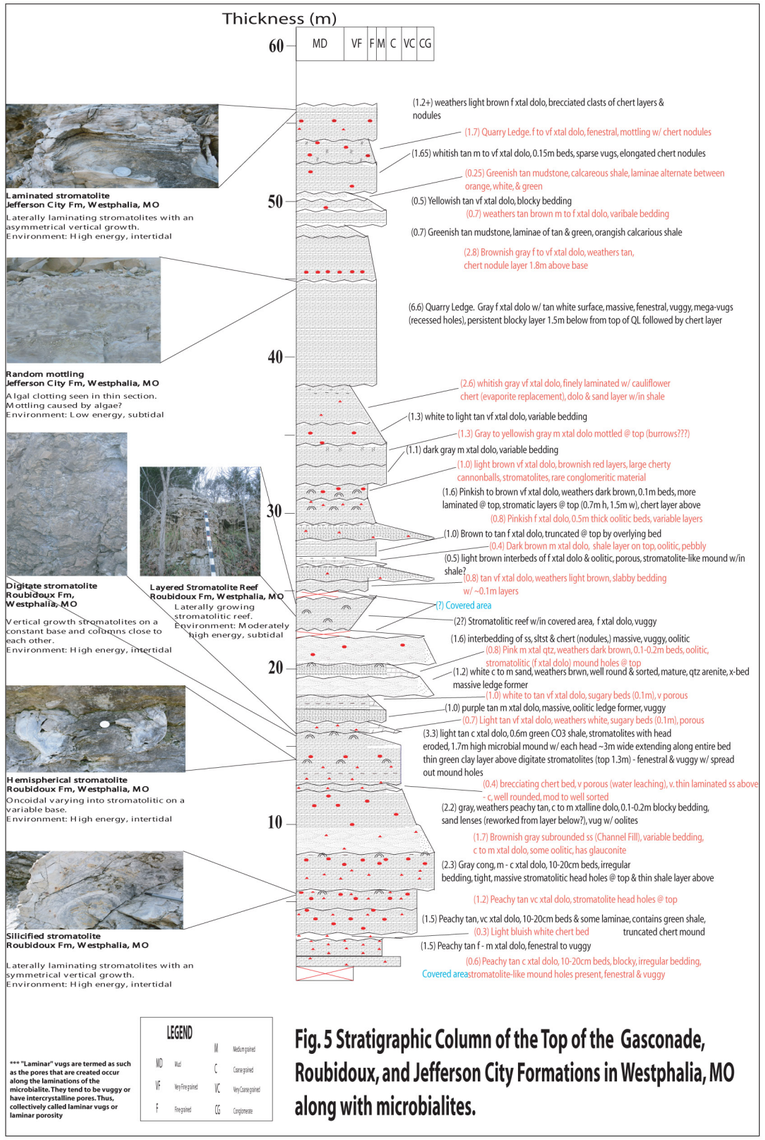
Hemispherical stromatolite Roubidoux Fm, Westphalia, MO





Algal mottling in thrombolitie? Jefferson City Fm, Westphalia, MO

Area of mottling in thrombolitie? with pore



*** "Laminar" vugs are termed as such as the pores that are created occur along the laminations of the microbialite. They tend to be vuggy or have intercrystalline pores. Thus, collectively called laminar vugs or laminar porosity

Fig. 5 Stratigraphic Column of the Top of the Gasconade, Roubidoux, and Jefferson City Formations in Westphalia, MO along with microbialites.

THE MACRO-SCALE (10^{-1} m)

Consists of hemispherical biostromes of stromatolites and thrombolites. According to those microbialites that outcrop in Missouri, these biostromes range from about 1.7m to 2m heigh with a width of each head being about 1m to 3m.

Missouri outcrop

Domical bioherm
Roubidoux Fm, Westphalia, MO

Digitate stromatolites
Roubidoux Fm, Westphalia, MO

Microbialites that outcrop in Missouri range from laterally linked stromatolites, digitate stromatolites to bioherms of stromatolites and thrombolites.

Domical bioherms
Roubidoux Fm, Westphalia, MO

Missouri subsurface

Microbialites from the Missouri well H-13 core, samples' stromatolites that show lateral growth and the thrombolites are usually dendritic structures (vertical clotting).

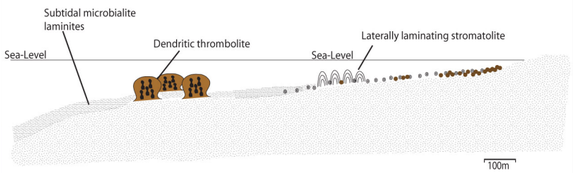


Fig. 6 Schematic diagram of thrombolitic and stromatolitic bioherms growing on a gently sloping ramp-type setting. These thrombolites would have occurred in lower energy subtidal setting where they had enough height to grow into bioherms and lack of disruption for their vertical growth. The laterally laminating bioherms of stromatolite would have formed in the higher to lower energy intertidal to subtidal setting where they have oolites, micro-fossils, and silt trapped between their columns and within their laminae.

Kansas subsurface

Kansas core samples' stromatolites show lateral growth and thrombolites have a more chaotic structure.

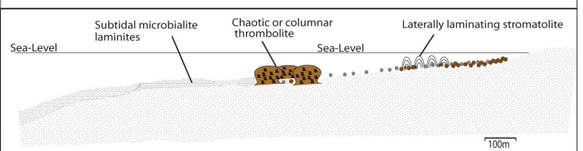


Fig. 7 Schematic diagram of stromatolitic and thrombolitic bioherms growing on a gently sloping ramp-type setting. These laterally linked stromatolites would have occurred in higher energy intertidal setting interpreted by presence of slightly more oolites, silt, and micro-fossils within laminea and the smaller heights of the stromatolites. The thrombolitic bioherms would have formed in higher energy subtidal setting where they have presence of chert fragments as well as the higher energy causing the algal clots to form in a more random structure and preventing continous vertical growth.

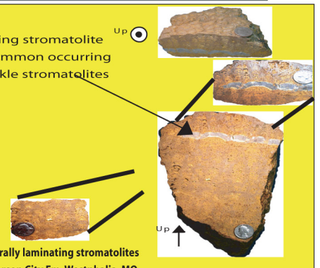
THE MESO-SCALE (10^{-2} m)

Consists of SH-C and SH-V type stromatolites. The constant base stromatolitic heads are about 0.1m high and 0.4m wide, while the variable base stromatolites are about 0.2m high and 0.03m wide. The thrombolitic clots are about 0.02m to 0.03m in height and width.

At this scale level, stromatolites are laterally laminating and thrombolites are dendritic or columnar.

Digitate structured stromatolites
Roubidoux Fm, Westphalia, MO

Laterally laminating stromatolite are silicified. A common occurring within the Arbuckle stromatolites



Laterally laminating stromatolites
Jefferson City Fm, Westphalia, MO

Consists of SH-C type stromatolites. These laterally laminating structures grow on the same base.

These digitate stromatolites have sand trapped between columns.

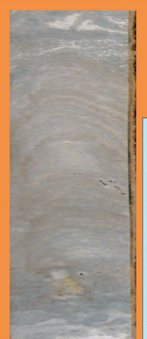
Environment is interpreted to be intertidal.

Laterally laminating stromatolites. Some of these laminae have been dissolved and are now "laminar" pores. Laminae are crenulated at times and grow one on top of the other. Some laminae have grown on top of fossil? structures.

Environment is interpreted to be moderately high energy intertidal.

Dendritic thrombolite
Well H-13 (MO), 761ft

Chaotic algal stromatolite?
986ft
Roubidoux Fm



Laminating stromatolite (in this core, w=4cm, h=11.4cm)
Roubidoux Fm,
Well H-13 (MO), 822ft

Laterally laminating stromatolites with considerable vertical growth.

No "laminar" pores seen in this sample. These were possibly laterally linked stromatolites as witnessed by the core to the right which is found below the core on the left.

Environment is interpreted to be lower energy intertidal.

Dendritic thrombolites are common in this shallow Missouri core samples.

Chaotic stromatolite with laminae turned into "laminar" pores.

Columnar laminating stromatolite
Jefferson City Fm, Well Keja # 1-3 (KS), 3,752ft
stromatolite: w=0.09m, h=0.05m

Columnar stromatolite growing on a constant base.

Environment is interpreted to be moderately high energy intertidal.

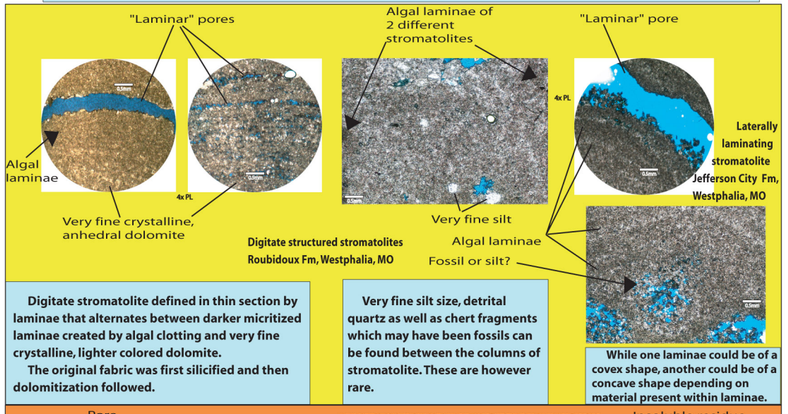
Chaotic or columnar thrombolite
Jefferson City Fm, Well Keja # 1-3 (KS), 3,744ft

Chaotic or columnar thrombolite characterised by the random vertical growth of the algal clots.

Environment is interpreted to be lower energy than the stromatolites. Intertidal to subtidal.

THE MICRO-SCALE (10^{-3} m)

This is the scale at which the algal laminae and clotting of the microbialites can be seen. Most of these structures usually occur within dolomitic wackestone to packstones. Laminations of the stromatolites can be seen as alternating between dark and light layers or between a micritic layer and coarser dolomite. Some of these layers tend to exhibit "laminar" porosity while others do not. Micro-fossils and silt are what usually get trapped within laminae or clots, or between microbialitic structures.



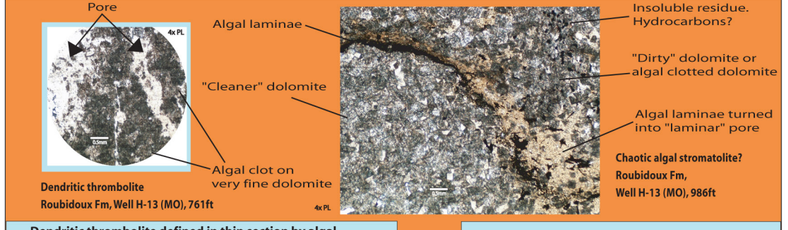
Digitate structured stromatolites
Roubidoux Fm, Westphalia, MO

Digitate stromatolite defined in thin section by laminae that alternates between darker micritized laminae created by algal clotting and very fine crystalline, lighter colored dolomite.

The original fabric was first silicified and then dolomitization followed.

Very fine silt size, detrital quartz as well as chert fragments which may have been fossils can be found between the columns of stromatolite. These are however rare.

While one laminae could be of a covex shape, another could be of a concave shape depending on material present within laminae.



Dendritic thrombolite
Roubidoux Fm, Well H-13 (MO), 761ft

Dendritic thrombolite defined in thin section by algal clotting that is of vertical growth with possible sediment trapped between these clots which have been dissolved into pores that is found between these clots.

The original fabric was first silicified then dolomitized and followed by a second round of silicification filling in some of the pores. Environment is interpreted to be lower energy subtidal.

Chaotic stromatolite? that unlike laminating stromatolites has more randomly arranged algal laminae. Some of these laminae have become "laminar" pores.

Environment is interpreted to be higher energy subtidal to intertidal.

Columnar laminating stromatolite
Jefferson City Fm, Well Keja # 1-3 (KS), 3,752ft

Chaotic or columnar thrombolite
Jefferson City Fm,
Well Keja # 1-3 (KS), 3,744ft

POROSITY vs PERMEABILITY WITHIN MICROBIALITES

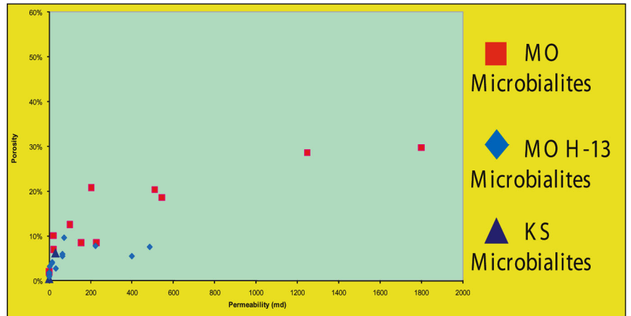


Fig. 8 Porosity vs. Permeability between the microbialites outcropping in Missouri, subsurface Missouri, and subsurface Kansas.

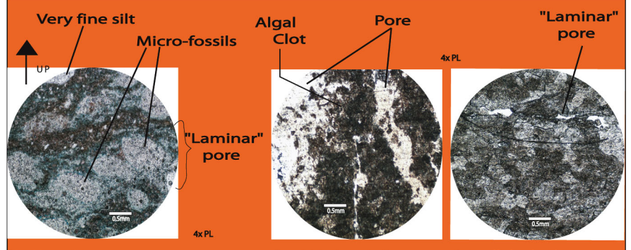
POROSITY & PERMEABILITY

Porosity and permeability analysis was conducted on thin sections using point counting method for porosity and Teodorovich's (1940) method for permeability.

COMPARISON OF OUTCROP AND SUBSURFACE MICROBIALITES

Microbialites found in the Missouri outcrop tend to have higher porosities and permeabilities than those found in the subsurface. The microbialites in the subsurface of Missouri tends to have higher porosities and permeabilities than those of Kansas subsurface. The difference in outcrop and subsurface may be due to exposure of outcrop to more weathering agents.

Tendency of stromatolites compared to thrombolites have greater porosity/permeability due to their "laminar" pores formed along the algal laminae. However, if the material formed alongside the thrombolite clots are less resistant to weathering, they can form pores that are highly porous with high permeabilities.



Algal boundstone
Jefferson City Fm, Westphalia, MO

Dendritic thrombolite
Roubidoux Fm,
Well H-13 (MO), 761ft

Laterally laminating stromatolite
Jefferson City Fm,
Well Keja #1-3 (KS), 3,752ft

Porosity = 29.75% Permeability = 1,800md	Porosity = 26% Permeability = 53,248md	Porosity = 6.22% Permeability = 30md
Pores are mostly "laminar" vugs and intercrystalline	Pores are mostly vuggy and intercrystalline	Pores are mostly "laminar" vugs and intercrystalline

Types of Cycles

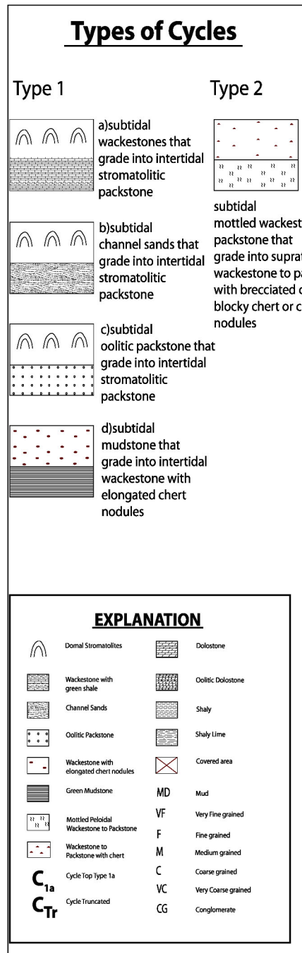


Fig. 9 Cycle types; Type 1 - Subtidal to Intertidal environments, Type 2 - Subtidal to Supratidal environments.

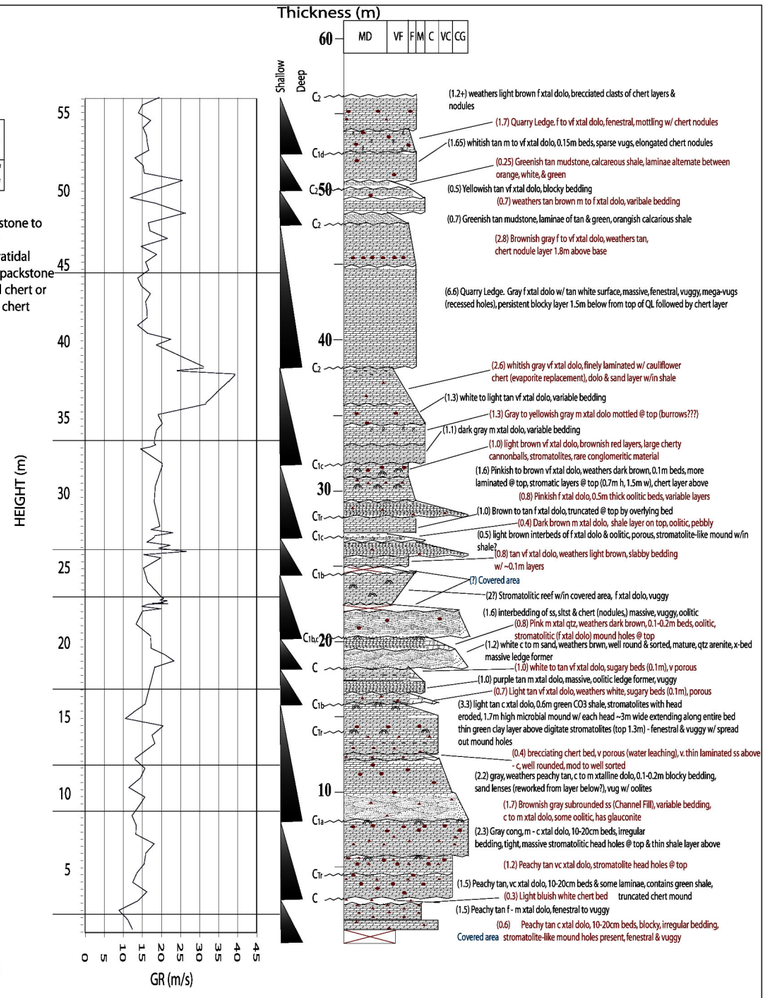


Fig. 10 Gamma Ray Readings, Cyclicity & Stratigraphic Column of the Top of the Gasconade, Roubidoux, and Jefferson City Formations in Westphalia, MO

The stromatolites found at the Westphalia outcrop in Missouri occurs in cycles within the Roubidoux and Jefferson City Formations. They are grouped into two cycle types.

Type 1 deposits include:

1) subtidal wackestone deposits with green shale grading upward to intertidal stromatolites,
2) subtidal deposits of channel sandstones grading upward to intertidal stromatolites,
3) subtidal deposits of oolitic pack/grainstone grading upward to intertidal stromatolites, and
4) subtidal green mudstones that grade upward to intertidal blocky wackestone or intertidal deposits of elongated chert nodules.

Type 2 deposits include:

sediments of mottled wackestones to packstones that grade upward to supratidal deposits containing cauliflower chert (possibly replacing supratidal evaporite) and brecciated chert.

The gamma ray reading is consistent with the cycles except for that one huge which is caused by a more radioactive shale.

DISCUSSION

The goal of this study was to characterize the different scales at which microbialites occur in Missouri in the Roubidoux and Jefferson City Formations. Thus, based on this study, these microbialites have been much more easily recognizable at the meso-scale level unless you are looking at 3m high bioherms. However, the micro-scale level is useful in identifying the work of the bacteria or algae as they create algal clots and algal laminae which at the macro - scale and meso-scale, they just look like laminations. Some of the thin sections show presence of Girvanella sheaths that may have helped in the growth of these microbialites.

Further research is being conducted on the surrounding environments that help to understand why these microbialites grow at varying scales and place these microbialites in a sequence stratigraphic framework.

CONCLUSIONS

Microbialites are abundantly found in the Early Cambrian and Lower Ordovician of the Arbuckle Group in Missouri and Kansas. The Arbuckle outcrops in Central Missouri while found in the subsurface in Kansas. The sizes of these microbialites range on a multi-scale level from micro to macro structures. LLH-S, SH-C, SH-V stromatolites of lateral and vertical growth types, as well as thrombolites of lateral and vertical growth are found within this group.

Porosity within these microbialites vary between vugs that occur between algal clots, intercrystalline, and "laminar" vugs that are found within the algal laminae of stromatolitic facies. Porosities as high as 30% and permeabilities as high as 1,800md were found in laminating stromatolties, while thrombolites had about 26% porosity and 53,000md permeability. In a comparison between porosity and permeability of stromatolites and thrombolites, dendritic thrombolites with less resistant rock forming between the algal clots has the greatest capacity for reservoir rock.

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