PS Micrite, Microporosity and Total Organic Carbon Content: Depositional and Diagenetic Controls Linking Small- and Large-Scale Observations in the Tuwaiq Mountain and Hanifa Formations*

Mustafa A. Al Ibrahim[1,3], Rick Sarg[1], Neil Hurley[2], Dave Cantrell[3], and John D. Humphrey[2]

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Abstract

Micrite texture, porosity development, and total organic carbon (TOC) content are interrelated in carbonate mudrocks, and have been examined in this study, within a sequence stratigraphic framework in the Tuwaiq Mountain and Hanifa formations, Saudi Arabia. Tools used are nuclear magnetic resonance logs, scanning electron microscopy, and confocal microscopy. Nuclear magnetic resonance is suitable for defining pore-size distributions. Confocal microscopy is most suitable for quantifying and examining microporosity, micrite texture, and examining larger-scale heterogeneity (centimeter- to 10s of centimeters-scale). Detection of organic matter is possible, but organic pores are beneath the resolution of the tool. Scanning electron microscopy (SEM) is most suitable for studying micrite texture and organic porosity. Results show that carbonate composition is the dominant control on micrite texture. High-magnesium calcite and aragonite grains recrystallize into low magnesium calcite, which leads to fusing of micrite grains, and porosity reduction. Organic matter, if present, inhibits fusing. The Tuwaiq Mountain Formation wackestones are composed of coalesced micrite whereas the packstones are composed of cemented micritized shelf-derived grains. Both facies contain euhedral pyrite. The Hanifa Formation contains both tight and relatively porous micrite particles. The highest TOC values were recorded in the transgressive system tracts which are mainly composed of dark laminated mudstones. Framboidal pyrite is commonly associated with organic matter. Porosity types found are interparticle, intraparticle in pyrite, organic pores and fractures. SEM images show that coccoliths are the most prominent grain type in the darker-colored intervals of the Hanifa Formation. These darker-colored intervals are more pervasive in the transgressive systems tracts. Coccoliths can bind with fecal pellets to increases settling velocity, thereby helping to preserve organic matter. Lighter-colored intervals, which are dominant in highstand systems tracts, are composed of more euhedral, relatively fused micrite grains. These grains probably formed due to recrystallization of metastable carbonate grains that were deposited as gravity flows derived from the shelf. The sequence stratigraphic framework has provided a framework for micrite texture, porosity, and TOC content prediction.

MICRITE, MICROPOROSITY, AND TOTAL ORGANIC CARBON CONTENT: DEPOSITIONAL AND DIAGENETIC CONTROLS

LINKING SMALL- AND LARGE-SCALE OBSERVATIONS IN THE TUWAIQ MOUNTAIN AND HANIFA FORMATIONS

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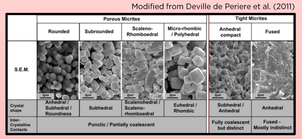
1. ABSTRACT

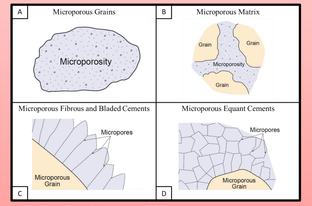
Micrite texture, porosity development, and total organic carbon (TOC) content are interrelated in carbonate mudrocks. These aspects have been examined in this study, in a sequence stratigraphic framework in the Tuwaiq Mountain and Hanifa formations, Saudi Arabia. Tools used are nuclear magnetic resonance logs, scanning electron microscopy, and confocal microscopy. Nuclear magnetic resonance is suitable for defining pore-size distributions. Confocal microscopy is most suitable for quantifying and examining microporosity, micrite texture, and examining larger-scale heterogeneity (centimeter- to 10s of centimeters-scale). Detection of organic matter is possible, but organic pores are beneath the resolution of the tool. Scanning electron microscopy (SEM) is most suitable for studying micrite texture and organic porosity. Results show that carbonate composition is the dominant control on micrite texture. High-magnesium calcite and aragonite grains recrystallize into low magnesium calcite, which leads to fusing of micrite grains, and porosity reduction. Organic matter, if present, inhibits fusing. The Tuwaiq Mountain Formation wackestones are composed of coalesced micrite whereas the packstones are composed of cemented micritized shelf-derived grains. Both facies contain euhedral pyrite. The Hanifa Formation contains both tight and relatively porous micrite particles. The highest TOC values were recorded in the transgressive system tracts which are mainly composed of dark laminated mudstones. Framboidal pyrite is commonly associated with organic matter. Porosity types found are interparticle, intraparticle in pyrite, organic pores and fractures. SEM images show that coccoliths are the most prominent grain type in the darker-colored intervals of the Hanifa Formation. These darker-colored intervals are more pervasive in the transgressive systems tracts. Coccoliths can bind with fecal pellets to increases settling velocity, thereby helping to preserve organic matter. Lighter-colored intervals, which are dominant in highstand systems tracts, are composed of more euhedral, relatively fused micrite grains. These grains probably formed due to recrystallization of metastable carbonate grains that were deposited as gravity flows derived from the shelf. The sequence stratigraphic framework has provided a framework for micrite texture, porosity, and TOC content prediction.

3. BACKGROUND INFORMATION

Micrite texture can vary in carbonate mudrocks. Different textures have different pore-formation potential.

Modified from Deville de Periere et al. (2011)

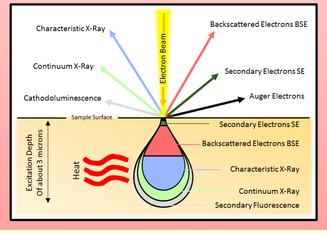




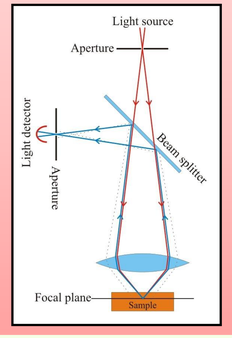
Modified from Cantrell and Hagerty (1999)

Scanning electron microscopes (SEM) can reveal intricate details about rocks in the nano scale. However, it is has very limited areal coverage.

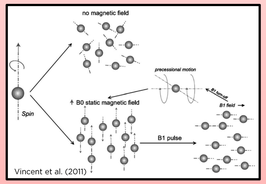
It is used in this study to examine micrite textural variations and pore types.



Confocal scanning laser microscopy measures the excitation of a material to a certain wavelength. It is used to study organic matter and pore distribution in the sample. Imaging area can cover few millimeters to centimeters.

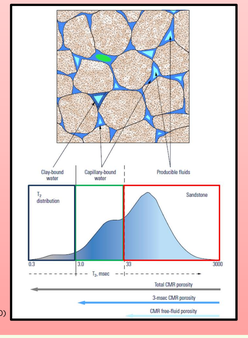


Nuclear magnetic resonance measures the precession of protons to an induced magnetic field. measurements from logs and lab experiments have been used to estimate porosity and pore-size distributions.



Vincent et al. (2011)

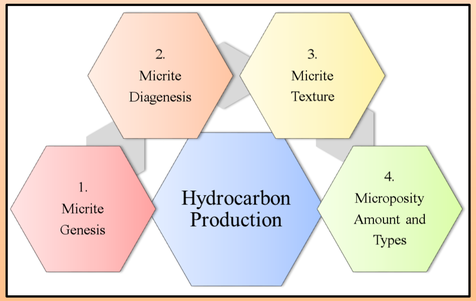
Measurements in this study are correlated to pore size distributions.



Modified from Allen et al. (2000)

2. STUDY OBJECTIVES

The study aims to link observed small-scale heterogeneity to large-scale depositional and diagenetic controls in carbonate mudrocks. This is done by correlating high resolution images to geologic interpretations obtained from other data sources.

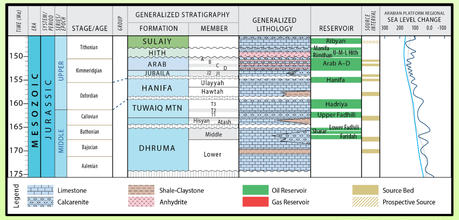


4. GEOLOGIC SETTING AND DESCRIPTION

The Callovian Tuwaiq Mountain and the Oxfordian Hanifa Formations are deposited in a marine carbonate shelf.

These formations are considered the main source for the Mesozoic petroleum hydrocarbon system in Arabia.

The studied interval (red circle) is located in one of the deepest intra-shelf basin in the area.



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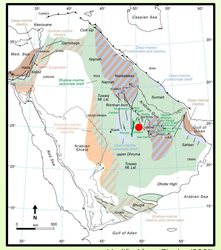

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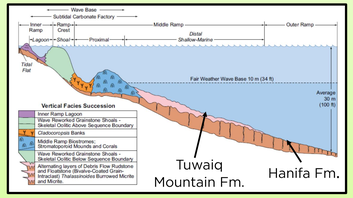
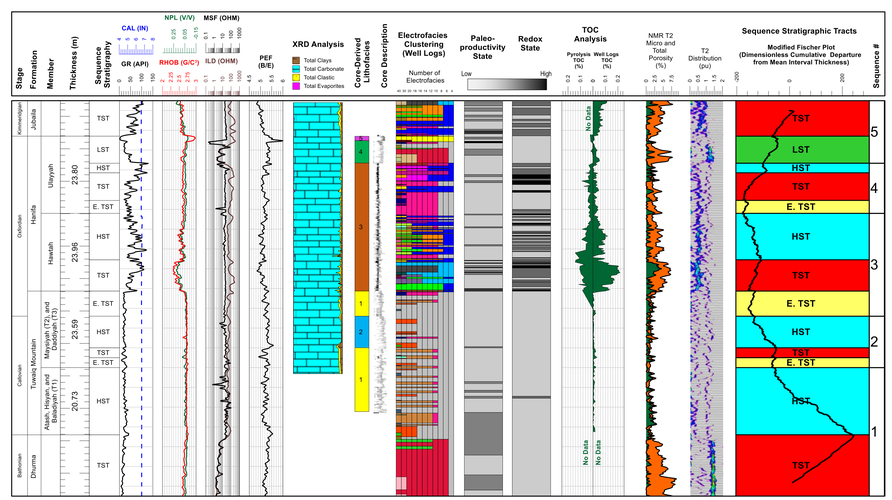


Modified from Lindsay et al (2006)

Five general facies have been identified in the interval (see Section 5). The interval in the study area are interpreted to be deposited in a relatively deep environment in an intra-shelf basin.

Independent sources of information and analysis point to a consistent interpretation, increasing the confidence in the conclusion.

A sequence stratigraphic framework was defined for the Hanifa and Tuwaiq Mountain formations based on core and thin section descriptions, well logs, and geochemical data.



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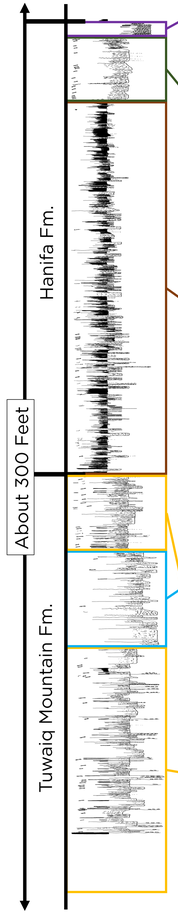
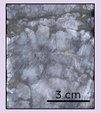
5. FACIES ANALYSIS



5. PALMATE ANHYDRITE

White to light gray anhydrite. Palmate structures with varying length are clearly present. Anhydrite intervals and crystals are separated by carbonate.



4. BIOTURBATED DARK BROWN PACKSTONE

Gray to brown grainy, faintly laminated packstone to wackestone. Moderate to high bioturbation is present.

3. LAMINATED DARK AND LIGHT MUDSTONE

Laminated rhythmic dark brown, dark gray and light brown mudstones and wackestones (to muddy packstones). Lighter intervals have more sparry calcite and darker intervals have more organic matter and muds. Clasts include forams, thin shelled bivalves and peloids. Fractures are calcite healed.

2. CEMENTED PACKSTONES AND GRAINSTONES

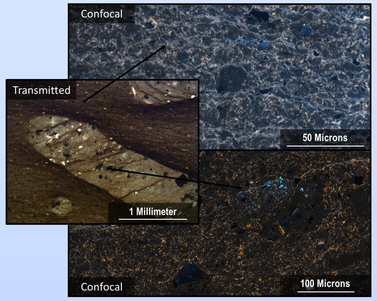
Gray to light gray cemented fine to coarse packstones and grainstones. Grains are composed of forams, bivalve shells, and other unidentified clasts. Bioturbation is more abundant in the muddier sections. Visible porosity in some intervals is generally moldic and inter-granular. Wispy organic lamination, grading to stylolites, are present.

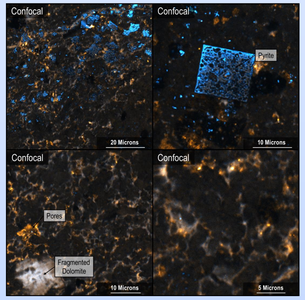
1. WISPY LAMINATED WACKE- TO MUDSTONE

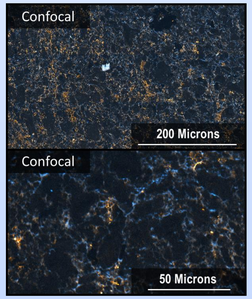
Gray to dark gray fine to very fine wackestones and mudstones (to muddy packstones). Calcite filled fractures are commonly sub-horizontal and rarely bifurcate. Bioturbation is moderate and burrows are horizontal and mud-filled with about 0.5 to 1 cm diameter. *Chondrites* are present in muddier intervals.

6. HIGH-RESOLUTION IMAGING OF LITHOFACIES

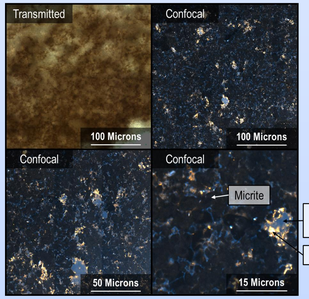
Facies 1 consists of wispy laminated wackestones and mudstones. NMR logs show little porosity. Images show more prominent porosity in the burrows. Rare rhombohedral dolomite crystals are scattered and some are broken. Porosity is mostly interparticle between the micrite grains. The less disturbed intervals, which constitute most of the facies, are more homogeneous. Micrite particles commonly flocculate and porosity is between these clumps. Pyrite is euhedral and is more dominant in burrows.



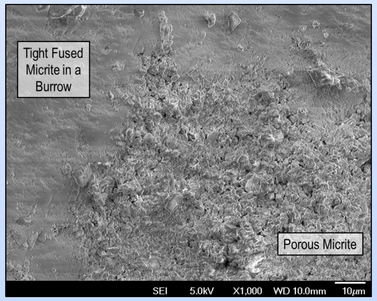




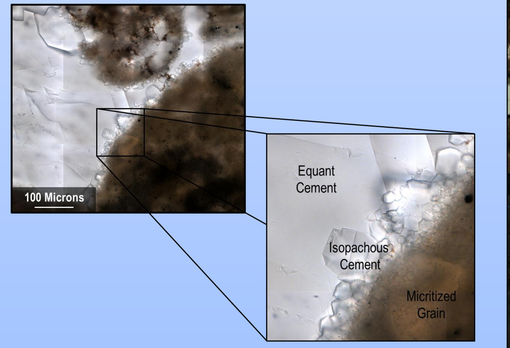
Facies 4 consists of bioturbated packstones to wackestones. NMR data shows relatively larger pores. This is also confirmed by confocal images. SEM and FE-SEM images show subhedral to anhedral micrite grains with varying size. They are generally bigger than micrite particles in other facies. The facies is less compacted than Facies 3, with more organic-rich intervals being the least compacted. The micrite can be classified as porous and subrounded. Interparticle space is filled with organic matter or empty.

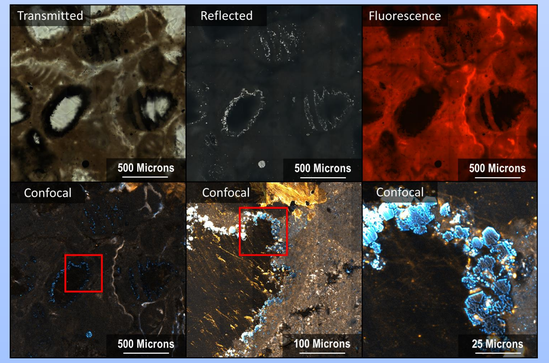


Burrowing and biogenic activity is abundant.

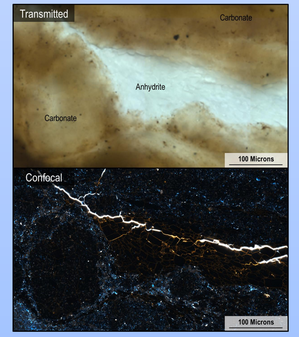


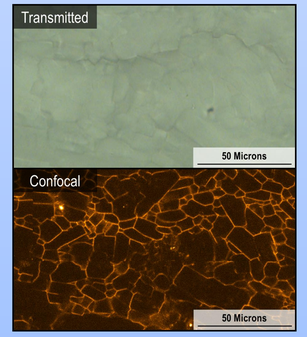
Facies 2 is composed of packstones to grainstones. The NMR log shows very little porosity, comparable to facies Most of the grains are micritized completely, whereas others have moldic porosity that is occluded with cement. The rock contains two distinct phases of calcite cement: (1) isopachous cement coats grains, and (2) equant cements fills the pores. The isopachous cement is subhedral, varying in size, and not ordered. Grains are micritized partially or completely in this facies. Pyrite crystals are euhedral and concentrated in fossil edges.





Facies 5 is palmate anhydrite. Anhydrite is intercalated with carbonates. Confocal images shows that crystal boundaries are the most porous areas in the facies. NMR total porosity in this facies, however, is less than 1 percent. Crystals range in size from a couple to tens of microns with the majority being less than 10 microns in maximum length. Carbonate rich areas contain some organic matter.





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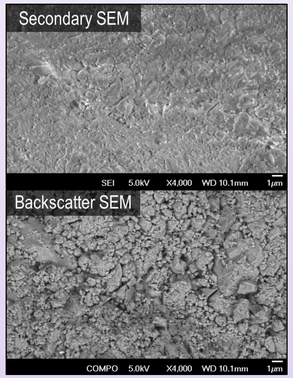
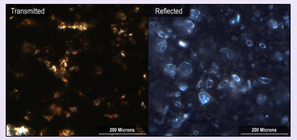
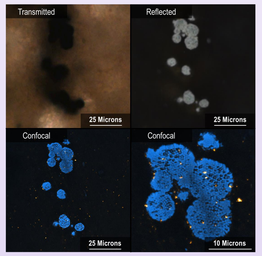
7. VARIATIONS IN LAMINATED CARBONATE MUDROCKS

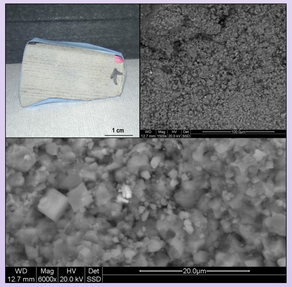


Whereas secondary images show very compacted texture, backscatter images show variations in density. Some of the larger grains are actually composed of smaller micrite particles. The particles can range in size from less than one micron to tens of microns.

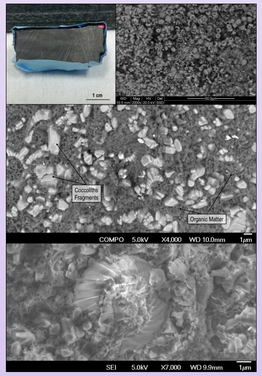


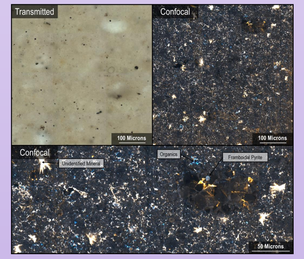
Microquartz grains are interpreted to be detrital. Framboidal pyrite are common in this facies.

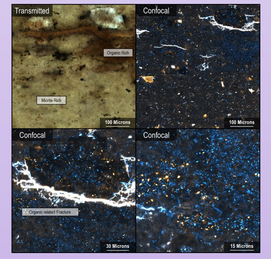


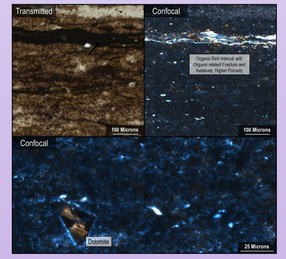


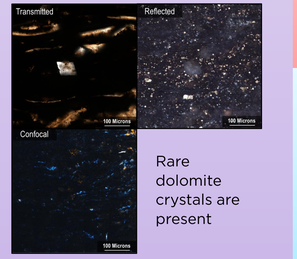
Micrite texture is variable in facies 3. Darker-colored intervals have higher organic carbon content and abundant coccoliths and are interpreted, from elemental analyses to be due to higher productivity and anoxic conditions. Micrite fragments are euhedral. This facies can be classified as a porous subrounded micrite. Organic content is high in these rocks. Micrite particles are generally distinct. Relatively lighter-colored intervals still contain some organic matter. Lighter-colored intervals contain more subhedral to euhedral micrite crystals with fewer coccolith plates. Micrites are generally fused together. This is classified as tight subhedral to anhedral fused micrite.











Rare dolomite crystals are present

Organic Matter Increases

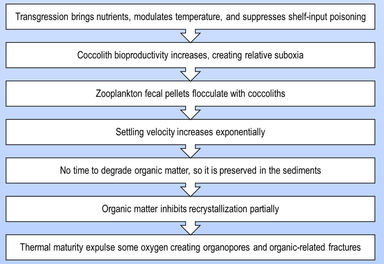
8. SUMMARY OF OBSERVATIONS

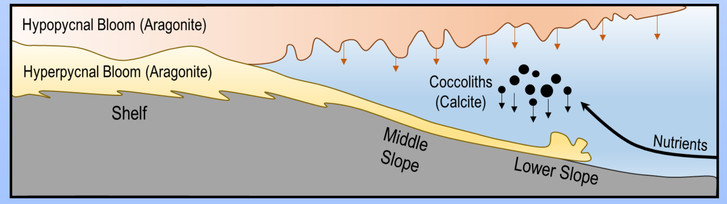
Facies #	Facies	Major Constituents	Major Porosity Types	Pyrite
5	Anhydrite	Anhydrite Micrite	Organic porosity Intercrystalline (anhydrite)	No Pyrite
4	Packstones and Wackstones	Micritized grains Clays Organic Matter	Interparticle	No to little pyrite
3b	Lighter-Colored Laminated Mudstones and Wackstones	Euhedral Micrite Some Coccoliths Pyrite Quartz Clays	Organic porosity Organic-matter-related fractures Intraparticle (pyrite) Interparticle	Framboidal with some euhedral grains
3a	Darker-Colored Laminated Mudstones and Wackstones	Coccoliths Euhedral Micrite Pyrite Quartz Clays	Organic porosity Organic-matter-related fractures Intraparticle (pyrite) Interparticle	Framboidal
2	Packstones and Grainstones	Micritized fossiles Pyrite Qurtz Clays	Interparticle Intracrystalline (anhydrite and pyrite)	Euhedral, concentrated at the edge of the grains and minor framboidal in micrite
1	Wispy Laminated Wackstones and Mudstones	Clumped Micrite Pyrite Rare Dolomite	Interparticle Intraparticle in pyrite	Euhedral, dissiminated and more concentrated in burrows

9. PROPOSED DEPOSITIONAL MODEL

Sediment source composition has a major effect on the ultimate micrite texture. Initial porosity is commonly occluded due to cementation or recrystallization. In carbonate mudrocks, aragonite and high-magnesium calcite particles will ultimately recrystallize to low-magnesium calcite, which leads to the creation of tight micrite texture. Porous micrite can be produced by inhibiting fusing and recrystallization which can be done by coating crystals with organic matter. Transgressive systems tracts have higher potential for the preservation of organic matter. They contain a relatively higher proportion of coccoliths, presumably due to influx of nutrients, temperature modulation, or detrital influx suppression. Coccolith over-population could create local suboxic to anoxic conditions.

Organic matter in these intervals might be preserved due to high settling velocity when bound with coccoliths. This leads to the preservation of organic matter due to high sedimentation rates. Finally, thermal maturity probably controls the amount of organic porosity in the interval.





10. CONCLUSIONS

- A conceptual model is proposed to explain the variations in rock properties including total organic content. The model is related to sequence stratigraphic changes.
- Anoxic to suboxic conditions and relatively high productivity is required for the preservation of organic content.
- Nuclear magnetic resonance, scanning electron microscopy, and confocal microscopy are useful for studying the small scale heterogeneity in mudrocks.
- Integration of data at different scales is essential for understanding mudrock systems.

11. REFERENCES

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