Journal of Scientific Research and Development 3 (3): 30-36, 2016
Available online at www.jsrad.org
ISSN 1115-7569

Microbial mats-induced Microfabric features in Shales from the Chittenango member, Marcellus Subgroup and United States

Shama Balulla *, E. Padmanabhan

Department of Geosciences, Faculty of Geoscience and Petroleum Engineering, University Technology PETRONAS, Seri Iskandar, 31750 Tronoh, Perak, Malaysia

Abstract: The study of microbial mats is of increasing interest for sandstone as well as for shales. Mat-related structures may serve as a facies environment indicators and can be combined with other geochemical data to develop depositional model for shale. Marcellus shale (Middle Devonian) was deposited with a good preservation of the organic matter, in the sediments likely due to anoxic bottom water. Three Core samples were taken from western New York State. The presence of lamination disturbance by bioturbation (isolated cluster feature) occur throughout the shale samples as demonstrated by thin section, Total Organic Content (TOC), Fourier Transform Infrared (FTIR) and Field Emission Scanning Electron Microscopy (FESEM) and may explain the activity of microbial mats. This kind of feature is directly related to cyanobacteria micro-organism. Microfabric features identified included isolated cluster feature, fecal pellet, and random orientation of clay fakes, all indicating bioturbation by cyanobacteria under an anoxic environment. Bacterial activity in anoxic environment is evident by high organic matter content, and the presence of nitrogen organic functional group.

Key words: Marcellus shale; Microbial mats; Microfabric Features; Chittenango Member

1. Introduction

Shale and other fine-grained sedimentary rocks (e.g., claystones, mudstones, siltstones, chalks, porcellanites, diatomites, etc.) consist of approximately 70% by volume of sum of sedimentary rocks (Picard, 1971; Stow, 1981; Wedepohl, 1971). In spite of their abundance, fine-grained sedimentary rocks are not well understood when compared to coarse-clastics and carbonate rocks. Recent interest in shales and mudstones was spurred by the need of the petroleum industry as a source rock and seal facies (Brooks and Fleet, 1986). Due to their fine grain size and lack of obvious physical structure, geochemical approaches have long dominated the study of mudstones. Organic-rich black shales have been interpreted to reflect deep, stagnant, anoxic-euxinic basinal conditions, and are of particular interest due to their economic importance (Ettensohn, 1985; Ettensohn et al., 1988; Morris and Horwitz, 1983; Potter et al., 1980; Stow et al., 2001). (Morris and Horwitz, 1983) used vertical changes in the fossil content of Toarcian (Lower Jurassic) shales to interpret fluctuations in the oxic-anoxic boundary of the water column near the sediment-water interface.

Many researchers have investigated the microstructure preserved in some sedimentary rocks that related to the identifition of specific sedimentary environments and processes. Several studies (Bennett et al., 1991; Morris and Horwitz, 1983; O'Brien, 1987; O'Brien and Slatt, 1990) have investigated the genetic relationships between depositional and diagenetic conditions and the microfabric of shales as observed in thin sections and scanning electron microscope. (Bennett et al., 1991) linked several physicochemical, bioorganic, and burial diagenetic processes with the resulting microstructure observed in shales (O'Brien, 1987) in which they documented the differences between bioturbated and non-bioturbated fabrics in shales. (O'Brien and Slatt, 1990) used differences in the lamination of Toarcian shales from Yorkshire, Great Britain, to make interpretations about water column stratification, sedimentary processes, oxygenation of the water column, and relative distance from the paleo-shoreline of the depositional environments of these shales. Clay fabric defined as the orientation, particle-to-particle relations, and the spatial distribution of the clay particle (Bennett and Hulbert, 1986).

Microbial mats are defined as biofilm, i.e. clusters of micro-organisms attached to a surface and outlines how cyanobacteria, due to their wide inventory of adaptive responses and capacity for biostabilisation of illuminated clastic surfaces. Cyanobacteria and other micro-organisms may leave traces and hints of the previous presence of them in sediments with the chance thus of preservation in the rock record. This activity of such kind of trace fossil can induce sedimentary structure in siliciclastic and it preserved as mats related features

* Corresponding Author.

in these rocks. In that way the details of the contact relationship of successive sediment layers can be used to confirm (or refute) a microbial mat origin (Schieber et al., 2007).

There are many spectrums of structures that may result from the interaction of microbial mats with clastic sediments the study of microbial mat features is rapidly becoming indispensable for modern sedimentological studies; The mat-related sedimentary structures which are based on process-related classification scheme, subdividing features (1) growth, (2) metabolism, (3) physical destruction and (4) decay (Schieber and Riciputi, 2004). By which microbial mats influence physical, chemical and biotic characteristics of shales. Generally, lamination in black shales have been considered by many researchers as rarely disturbed (Wignall, 1994). In cased of lamination disturbed, such disturbance of lamination cannot originate from Bioturbation. It could be originating from other source (physio-chemical, burial-diagenesis processes other than bio-organic processes (Bennett et al., 1991). Consequently, this lamination lack evidence as consistent indicators of anaerobic or anoxic conditions. . Nonetheless, further research into the ways by which microbial mats influence physical, chemical and biological characteristics of shales is need to be investigated. The study provided an understanding on how microbial mats shale might be recognized. The objective(s) of this paper was to characterize this microfabric feature and attempt to utilize microfabric information towards giving the evidence of this a feature as an indicator of anoxic condition.

2. Materials and methods

Given that the black shale of Marcellus subgroup in western New York State is deposited under different sedimentological and geochemical conditions, it is likely that their microfabric would also differ. The Marcellus Shale has been interpreted as deposited in a relatively shallow basin (Schwietering, 1981) where anaerobic conditions were present allowing for large amounts of organic matter to be preserved. Three core samples namely (S1, S2, and S3) were taken from Chittenango Member, Otaka Creek Formation, Marcellus subgroup, Limestone Greek well, western New York State. These three samples were taken from the newly named Chittenango Member (Ver Straeten et al., 2011). In this paper samples from Marcellus subgroup, western New York State (Fig. 1), Chittenango Member (Fig. 2) were carefully examined using thin section, Total Organic Content (TOC) analysis, Field Emission Scanning Electron Microscopy (FESEM), and Fourier Transform Infrared (FTIR).

The thin sections of the samples were examined and imaged at various magnifications under plane polarized and cross-polarized light using petrographic microscope (OLYMPUS BX51TF) equipped with spot digital camera (OLYMPUS DP72). FESEM images of the samples were taken for mineral identification, textural analysis and morphological characterization, according to SEM Petrography Atlas (Welton, 1984) .TOC content was measured using Analytikjena HT 1300 Solids Carbon Analyzer. The organic functional groups present in the shale samples were determined using Fourier-Transform Infra-Red (FTIR) spectroscopy. FTIR spectra of powdered rock sample were collected using (Shimadzu 8400S FTIR Spectrophotometer) with Attenuated Total Reflection (ATR) attachment. The spectra are interpreted according to (Stuart, 2005) (Silverstein et al., 2014).

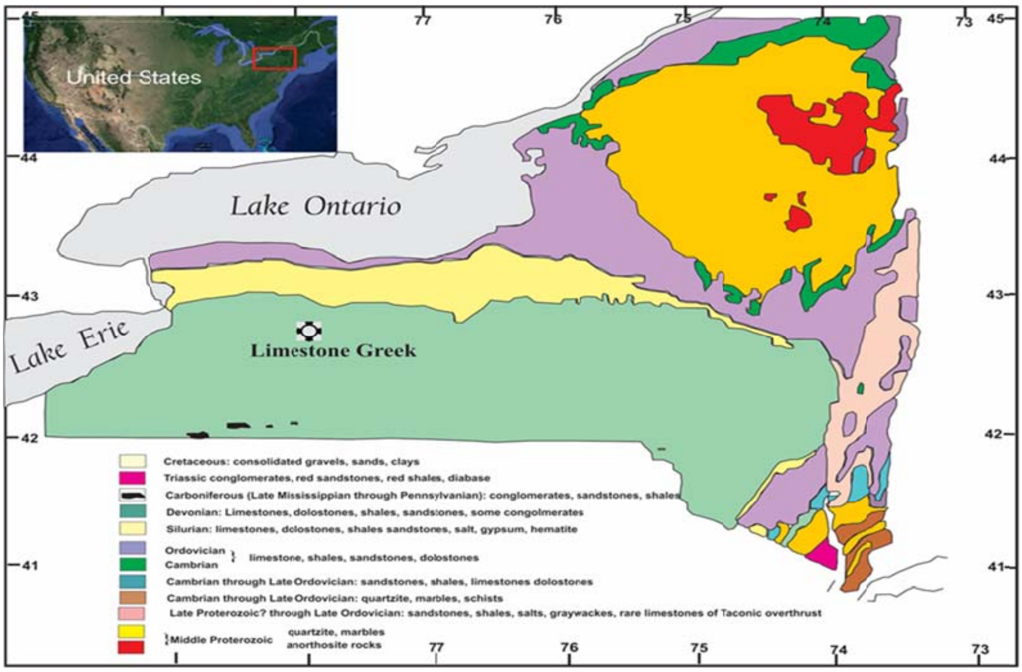

Fig. 1: Location map of the studied core samples modified after http://www.nysm.nysed.gov/nysgs/resources/images/map-bedrock3.jpg and http://maps-for-free.com

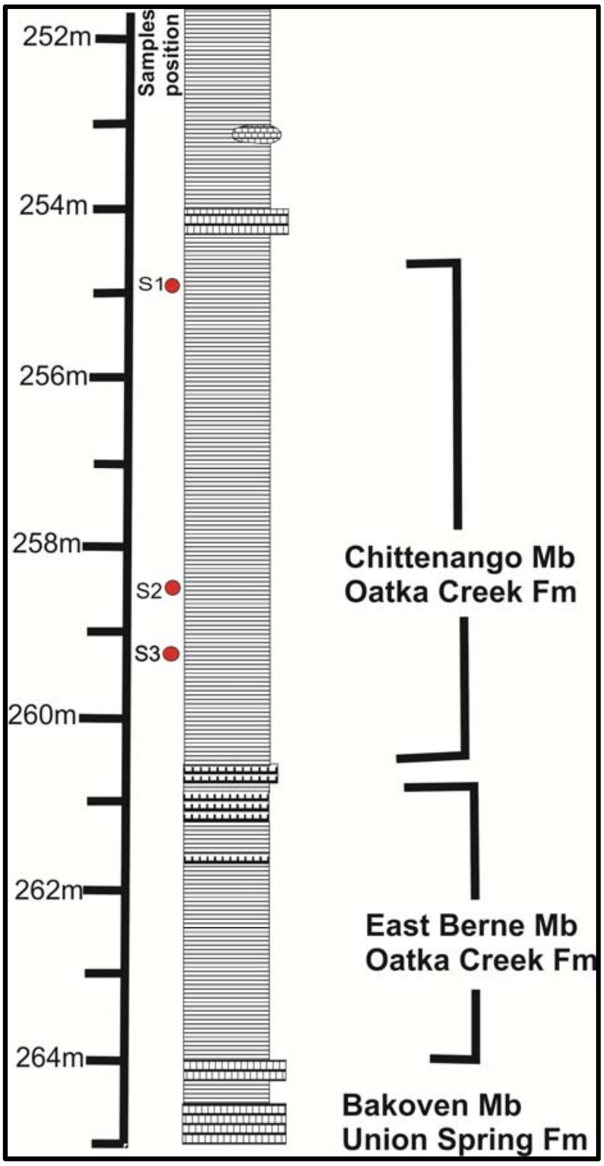

Fig. 2: Litholostratigraphy shows the samples position, modified after (Straeten et al., 2011). Chittenango Member (Mb).

3. Results and discussion

Investigation of thin sections at low magnification showed that Sample S1 consists of discontinuous, lenticular and straight parallel lamination. Sample S2 characterized by irregular wavy crinkly lamination. In contrast the presence of continues thin or finely laminated in S3 as shown in Figs. 3A, B, and C. On initial examination, these thin sections appear to represent laminated shale only with no evidence these lamination are disturbed. However, silt streaks and laminate that were non-parallel and variable orientation were observed as well. The presence of irregular wavy-crinkly lamination suggests microbial mat origin for this shale's (Schieber, 1986).

With increasing the magnification, the three shale samples were observed to be predominance of fine-grained quartz mineral (Fig. 3). They contain abundant silt-size, sub-angular to sub-rounded detrital quartz, carbonate minerals (calcite and dolomite), aggregate of clay minerals, rare alkali feldspar, and abundant pyrite (Fig. 3D, E, and F). The matrix contains a mixture of organic matter and clay minerals. In this magnification, the wavy lamination has a "flaser bedding" appearance with lenses arranged in layers; lenses are composed of light colored (quartz, calcite) minerals encased by dark (clay, organics) matrix. The presence of lenticular laminations indicates that deposition occurred under anoxic bottom water conditions (Demaison and Moore, 1980; Schieber, 2002). Some researchers have attributed lenticular lamination in the shale from Toarcian Posidonia to deposition of fecal pellets from the water column (Röhl et al., 2001). (Schieber et al., 2010) interpreted this lenticular lamination in shales as intermittent erosion and transport of superficial mud by current from water rich mud.

At the micrometer scale, (Fig. 3G, H, and I) shows subangular to subrounded detrital quartz, carbonate minerals (calcite and dolomite), aggregate of clay minerals, rare alkali feldspar, and abundant pyrite. The most important thing in these thin sections is the isolated cluster (marked by arrows) of silt sized grains of quartz in much finer mudstone matrix. Thus, the bioturbation produced within this fabric which it might be called a "bioturbation-laminated" fabric or grain isolation (isolated cluster). This feature is interpreted as a feature related to microbial mat decay (Schieber et al., 2007). During decay submerged mats could produce sufficient buoyancy to allow portion of decaying mats float to the surface and become an agent of grain rifting. The result of this would be clustered of coarse grains in a much finer matrix (Fig. 3). He stated that typically this decay of microbial mats occurs in an anaerobic environment. Lenticular and wavy-crinkly laminations are the most indication of a cyanobacterial mat origin (Bouougri and Porada, 2002).

From the thin section characteristic of this kind of sedimentary feature sometimes is accompanied by random orientation of mica flakes (Schieber et al., 2007). Some large and random mica flakes are pointed in the figures in red arrows.

Pyrite in black shale can evoke image of anoxic condition (Schieber, 2003) and when it associated with lamination, their appearance are often thought an indication of anoxic condition. Fig. 4 shows pyrite mineral as disseminated mineral (are pointed in black arrows) in the fine. In marine sediment setting sulphate reducing bacteria thrive in the sub-mat environment, produce hydrogen sulphide, and induce pyrite formation (Berner, 1984). Framboidal pyrites (Berner, 1969) considered an indicator of early diagenetic pyrite formation at shallow burial depth (Berner, 1969; Love, 1967).

Lamination, if originally present in the sediment, it is partially or completely reworked by bioturbation (O'Brien, 1987). Resulting in interrupted laminae or absence of laminae, swirled fabric, and/or particles (such as fossil fragments) oriented at angles other than parallel to the bedding.

Scanning electron microscope micrographs of these shale sample showing the lamination disturbance. Fig. 4A shows the presence of fecal pellet, which is defined as; a microfabric characterized by thick packing of random orientenation of nonplaty material, this in contrast to the preferred orientation of platy minerals of the surrounding shale components (Bennett et al., 1991). This pelletization may be important indicator depositing argillaceous sediments in marine inter-deltaic environments (Pryor, 1975).

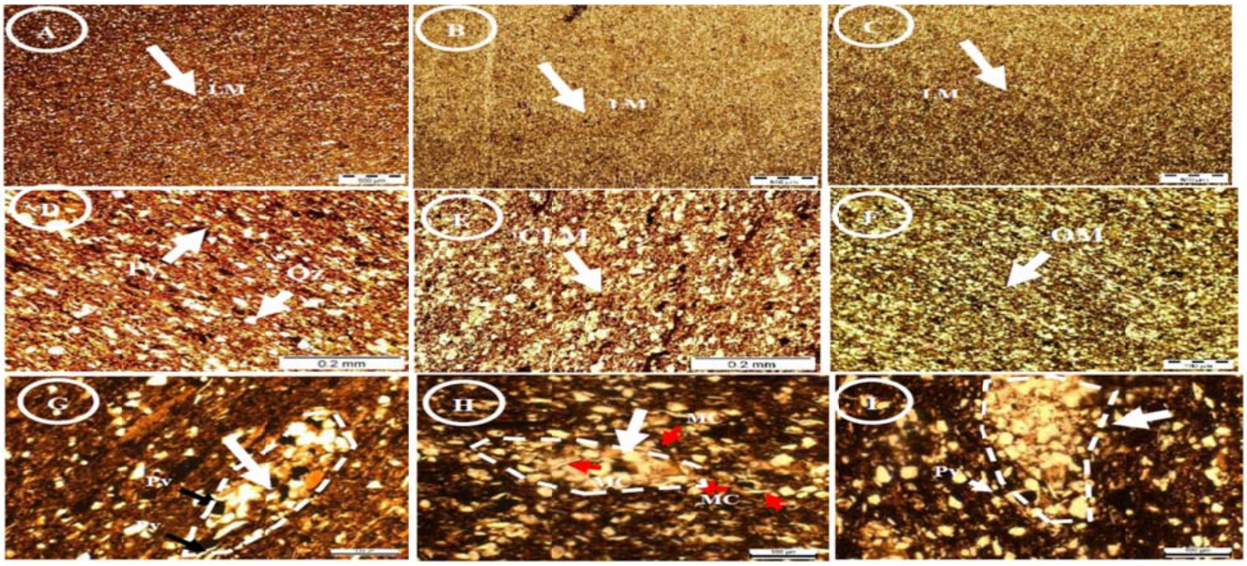

Fig. 3: Photomicrograph of thin section for three shale samples from Chittenango Member from Limestone Greek well, Western New York State. A), B), and C) show faint lamination in low magnification D) Lenticular lamination E) irregular wavy-crinkly lamination F) Finely laminated shale. G), H), and I) show the isolated cluster sedimentary feature (silt sized grains of quartz inwith other grains like pyrite py and muscovite MC in much finer matrix) Quartz Qz Clay mineral CLM organic matter OM.

In clay-rich sediment and rock, clay microfabric and particles orientation provide a useful clue to the condition of deposition of sedimentary rock (O'Brien, 1980, 1987). The SEM micrograph of the samples shows random particle orientation of illite clay mineral. This particular arrangement of clay particles has two origin; produce by primary preservation of primary fabric from flocculated clay or secondary by bioturbation (O'Brien and Slatt, 1990). The one in this sample is bioturbated clay fabric meanwhile it characterized by the dominance of randomly oriented individual clay particles rather than domain or cluster in (Fig. 4B).

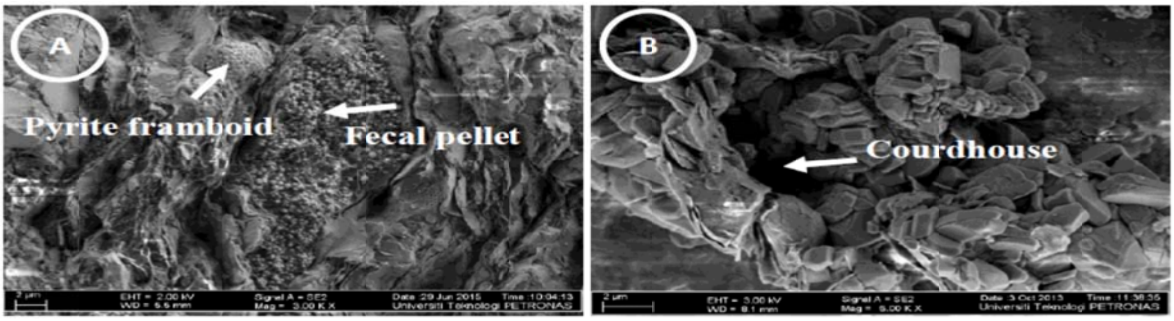

Fig. 4: A) Fecal pellet making random fabric contrasts to that of the enclosing shale. B) Random orientation of clay individual clay flakes (individual clay platelets which is typical of bioturbated fabric)

Total organic content for these samples is relatively high 9.8 %, 3.27 %, and 2.84%) for S1, S2, and S3 respectively (Table. 1) .The high organic content of these samples may indicate anoxic condition.

Table 1: Total Organic Content (TOC) results for shale samples.

Sample No	Sample depth	Member	TOC %
S1	254.9m	Chittenango	9.80
S2	259.2m	Chittenango	3.27
S3	261.5m	Chittenango	2.84

The presence of Cyanobacteria in these samples, which is suggestive of lamination disturbance, is made by its activity, and can be confirm from the FTIR analysis. The FTIR spectrum show the (Fig. 5) peak of 3535 cm-1 detected is typical for N-H stretching bond, which could be assigned for amine group. The existence of this type of the functional group is expected to be from the cyanobacteria and could be confirmation of the activity of microbial mats.

Accordingly, the features with the evidence that are from the shales deposited under anoxic environment is consistent with (Butterfield, 2009; Butterfield, 2011) in which he suggested that phytoplankton communities during Phanerozoic oceanic anoxia events may related to cyanbacterial dominat communities at that time. (Werne et al., 2002) also suggested that the Otaka Creek Formation (the formation from which samples of this study were obtained) was deposited under euxinic condition (anoxic, sulfidic) bottom waters.

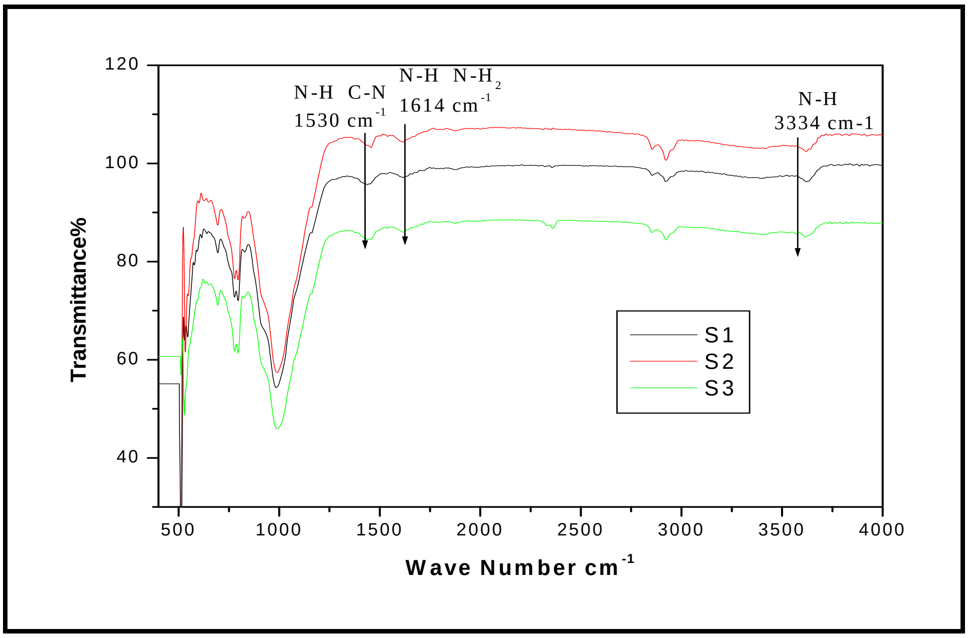

Fig. 5: Fourier Transform Infrared (FTIR) spectrum of the shale samples

4. Conclusion

Initially these shale samples may seem to be feature less, but with careful examination reveal some sedimentary feature, which it can greatly advance the understanding of these rocks.

The presence of isolated cluster feature indicates lamination disturbance by bioturbation could be an indication for microbial mats feature. This kind sedimentary feature is mainly from the activity of micro-organism (cyanobacteria). Careful examination of these shales can help to extract information about paleo-anoxic condition and later it might be combined with the geochemical data to develop depositional model for these shales. Careful study of microfabric could play significance role in determining the physical and mechanical properties of sediment and rock and their behavior. Re-assessment of the sedimentary fabric or features of many shale units are important in the oil and gas industry since gas-shales systems such as Marcellus shales considered as one of the important shale gas plays in the United State of America. This could help in the exploration and exploitation of the gas shale resources.

Acknowledgment

The senior author would like to thank UTP graduate assistantship for supporting this study. The authors would like to express their gratitude to Prof. Dr. Jeffery Over from the Department of Geological Sciences, Geneseo, NY, USA for his support and providing the samples for this study. This research was partially supported by Petroleum Research Fund (PRF) awarded to E. Padmanabhan.

References

Bennett, R. H., O'Brien, N. R., and Hulbert, M. H (1991). Determinants of clay and shale microfabric signatures: processes and mechanisms, Springer.

Bennett, R., and Hulbert, M (1986). Clay Microstructure. International Human Resources Development Corporation Press: Boston, MA.

Berner, R.A (1969). The synthesis of framboidal pyrite: Economic Geology, 64(4): 383-384.

Berner, R.A (1984). Sedimentary pyrite formation: an update: Geochimica et Cosmochimica Acta,v. 48, no. 4, p. 605-615.

Bouougri, E., and Porada, H., Mat-related (2002). Sedimentary structures in Neoproterozoic peritidal passive margin deposits of the West African Craton (Anti-Atlas, Morocco): Sedimentary Geology, 153(3): 85-106.

Brooks, J., and Fleet, A (1986). Marine petroleum source rocks.

Butterfield, N. J (2011). Animals and the invention of the Phanerozoic Earth system: Trends in ecology & evolution, 26(2): 81-87.

Butterfield, N (2009). Oxygen, animals and oceanic ventilation: an alternative view: Geobiology, 7(1): 1-7.

Demaison, G., and Moore, G. T (1980). Anoxic environments and oil source bed genesis: AAPG Bulletin, 64(8): 1179-1209.

Ettensohn, F. R (1985). Controls on development of Catskill Delta complex basin-facies: Geological Society of America Special Papers, 201: 65-78.

Ettensohn, F. R., Miller, M., Dillman, S., Elam, T., Geller, K., Swager, D., Markowitz, G., Woock, R., and Barron, L (1988). Characterization and implications of the Devonian-Mississippian black shale sequence, eastern and central Kentucky, USA: Pycnoclines, transgression, regression, and tectonism.

Love, L (1967). Early diagenetic iron sulphide in recent sediments of the Wash (England): Sedimentology, 9(4): 327-352.

Morris, R., and Horwitz, R (1983). The origin of the iron-formation-rich Hamersley Group of Western Australia—deposition on a platform: Precambrian Research, 21(3): 273-297.

O'Brien, N. R., and Slatt, R. M (1990). Argillaceous rock atlas, Springer Science & Business Media.

O'Brien, N. R (1980). Use of clay fabric to distinguish turbiditic and hemipelagic siltstones and silts: Sedimentology, 27(1): 47-61.

O'Brien, N (1987). The effects of bioturbation on the fabric of shale: Journal of Sedimentary Research, 57(3).

Picard, M. D (1971). Classification of fine-grained sedimentary rocks: Journal of Sedimentary Research, 41(1).

Potter, P. E., Maynard, J. B., and Pryor, W. A (1980). Sedimentology of shale, Springer Science & Business Media.

Pryor, W. A (1975). Biogenic sedimentation and alteration of argillaceous sediments in shallow marine environments: Geological Society of America Bulletin, 86(9): 1244-1254.

Röhl, H.-J., Schmid-Röhl, A., Oschmann, W., Frimmel, A., and Schwark, L (2001). Erratum to "The Posidonia Shale (Lower Toarcian) of SW-Germany: an oxygen-depleted ecosystem controlled by sea level and palaeoclimate":[Palaeogeogr., Palaeoclimatol., Palaeocol. 165 (2001) 27–52]: Palaeogeography, Palaeoclimatology, Palaeoecology, 169(3): 273-299.

Schieber, J., and Riciputi, L (2004). Pyrite ooids in Devonian black shales record intermittent sea-level drop and shallow-water conditions: Geology, 32(4): 305.

Schieber, J., Bose, P. K., Eriksson, P., Banerjee, S., Sarkar, S., Altermann, W., and Catuneanu, O (2007). Atlas of microbial mat features preserved within the siliciclastic rock record, Elsevier.

Schieber, J (2003). Simple gifts and buried treasures—implications of finding bioturbation and erosion surfaces in black shales: The Sedimentary Record, 1(2): 4-8.

Schieber, J., Southard, J. B., and Schimmelmann, A (2010). Lenticular Shale Fabrics Resulting from Intermittent Erosion of Water-Rich Muds--Interpreting the Rock Record in the Light of Recent Flume Experiments: Journal of Sedimentary Research, 80(1): 119-128.

Schieber, J (1986). The possible role of benthic microbial mats during the formation of carbonaceous shales in shallow Mid-Proterozoic basins: Sedimentology, 33(4): 521-536.

Schieber, J., The role of an organic slime matrix in the formation of pyritized burrow trails and pyrite concretions: Palaios, 2002,v. 17, no. 1, p. 104-109.

Schwietering, J (1981). Occurrence of oil and gas in Devonian shales and equivalents in West Virginia: Department of Energy, Washington, DC (USA).

Silverstein, R. M., Webster, F. X., Kiemle, D., and Bryce, D. L (2014). Spectrometric identification of organic compounds, John Wiley & Sons.

Stow, D. A (1981). Fine-grained sediments: terminology: Quarterly Journal of Engineering Geology and Hydrogeology, 14(4): 243-244.

Stow, D., Huc, A.-Y., and Bertrand, P (2001). Depositional processes of black shales in deep water: Marine and Petroleum Geology, 18(4): 491-498.

Straeten, C., Baird, G., Brett, C. E., Lash, G. G., Over, J., Karaca, C., Jordan, T., and Blood, R (2011). The Marcellus Subgroup Type Area, Finger lakes Area of New York, And Beyond.

Stuart, B (2005). Infrared spectroscopy, Wiley Online Library.

Ver Straeten, C. A., Brett, C. E., and Sageman, B. B (2011). Mudrock sequence stratigraphy: A multi-proxy (sedimentological, paleobiological and geochemical) approach, Devonian Appalachian Basin: Palaeogeography, Palaeoclimatology, Palaeoecology, 304(1-2): 54-73.

Wedepohl, K. (1971). Environmental influences on the chemical composition of shales and clays: Physics and Chemistry of the Earth, 8: 305-333.

Welton, J. E (1984). SEM petrology atlas, American Association of Petroleum Geologists Tulsa^ eOklahoma Oklahoma.

Werne, J. P., Sageman, B. B., Lyons, T. W., and Hollander, D. J (2002). An integrated assessment of a "type euxinic" deposit: evidence for multiple controls on black shale deposition in the Middle Devonian Oatka Creek Formation: American Journal of Science, 302(2): 110-143.

Wignall, P (1994). Black shales. Geology and Geophysics Monographs, 30, Oxford University Press, Oxford.