DEPOSITIONAL ENVIRONMENT AND DIAGENESIS OF THE MIDDLE JURASSIC BLACK SHALES AND ASSOCIATED IRON SULFIDS, CENTRAL SINAI, EGYPT

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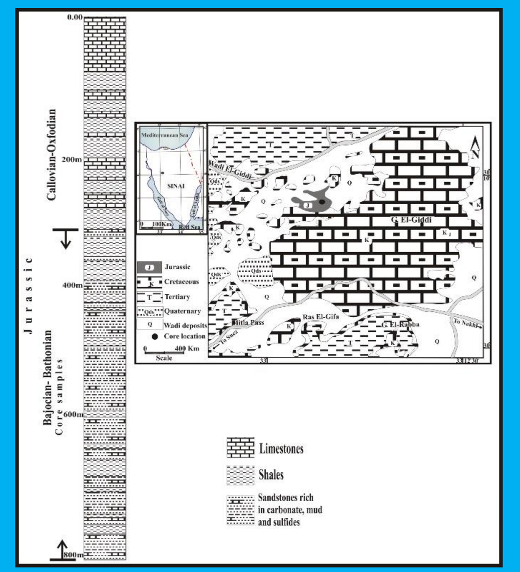
ABSTRACT

Petrographic studies of selected core samples from the subsurface Middle Jurassic sequence (Bajocian- Bathonian strata) in Central Sinai, Egypt depicts different lithofacies that were deposited in complex environmental conditions. Variations in the depositional settings have resulted in formation of different lithologies that range from strata that were formed in oxic condition (highly bioturbated with depleted pyrite), to euxinic strata (fine lamination, coal layers, and sulphide-rich sediments). The deposition of these Bajocian- Bathonian strata (Middle Jurassic) were controlled by major cycles of rapid sea level changes and sequence of uplift movements. Three major lithofacies were recorded as follows: (1) lagoon and shoreline deposits (highstand system tract); (2) estuarine with tidal flat deposits (transgressive system tract); and (3) deltaic deposits (lowstand system tract).Inductively Coupled Plasma (ICP-MS), X-ray, and Sulfur isotope analyses of the anoxic organic-rich black shale indicate that it mainly consists of Kaolinite, montmorillonite, chlorite, and iron/sulfur mixed layers. The high TOC (13.8%), Vanadium (370 ppm), high Ba content, low Th/U ratio, the high degree of pyritization (up to 0.86), and the close positive relationships between total sulfur and Cr, Ni, Cu, Mo indicate pervasive euxinic- depositional environment of the black shales. SEM studies reveal the presence of pyrite as cubes and framboids of different shapes and sizes. Framboidal pyrite is made up of spherical aggregates of submicron-sized pyrite crystals densely packed together. The δ ^{34}S value of the framboidal pyrite ranges from -7.4 to -5.8 ‰ V-CDT and indicates their formation through bacterial reduction in euxinic conditions just below the sediment/water interface in an open system.



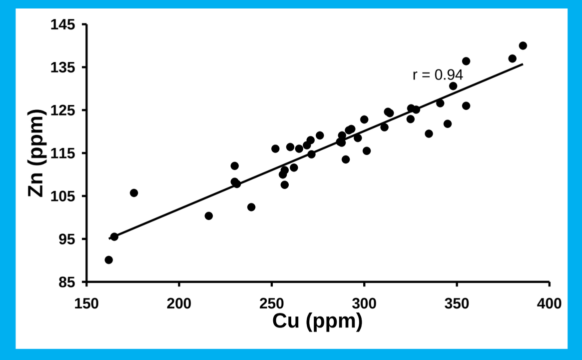
Location and geologic maps and schematic stratigraphic sequence of Wadi El-Giddi borehole (G.R-2)

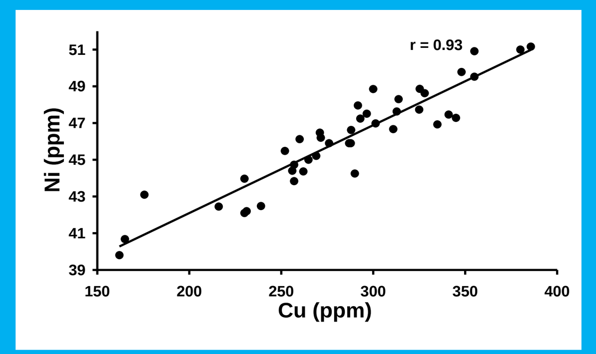
Stratigraphy and Sedimentology

The surface and subsurface rocks at Wadi El Giddi in central Sinai are of Middle to Late Jurassic. The surface succession (~70m thick) is composed of coralline limestone that belongs to the Arousyia Member of the Masajid Formation (Oxfordian, Upper Jurassic). The subsurface sequence is ~ 800m thick. The upper 300m belong to the Callovian; Masajid Formation (Late Jurassic). The lower 500m are of Bajocian-Bathonian; Safa and Bir El-Maghara formations (Middle Jurassic age). This study focuses on the thinly laminated, dark gray pyritic, black shales of the latter part of the succession. The studied sequence consists of a range of facies from oxic strata, highly bioturbated and lacking pyrite, to euxinic strata characterized by fine lamination, coal layers and sulphide-rich sediments. The deposition of the Bajocian- Bathonian strata appears to have been controlled by major cycles of rapid sea level changes and sequence of uplift movements. Rifai et al. 2007 divided the succession into three system tracts: (1) a high stand systems tract (HST) with lagoonal and beach/bar shoreline complex; (2) a transgressive systems tract (TST) with estuarine, tidal sand bars and tidal flat deposits and (3) a lowstand systems tract (LST) with deltaic deposits. Within the transgressive systems tracts (TST), estuarine deposits have prevailed. Marshes and swamp deposits are well developed and represented by coal seams, and coal bearing mudstone. Estuarine lagoon and tidal flat are represented mainly by sulfide-rich sandstones alternating with laminated organic-rich shales. These formations are underlain and overlain by coal rich mudstone and laminated green mudstone; respectively.

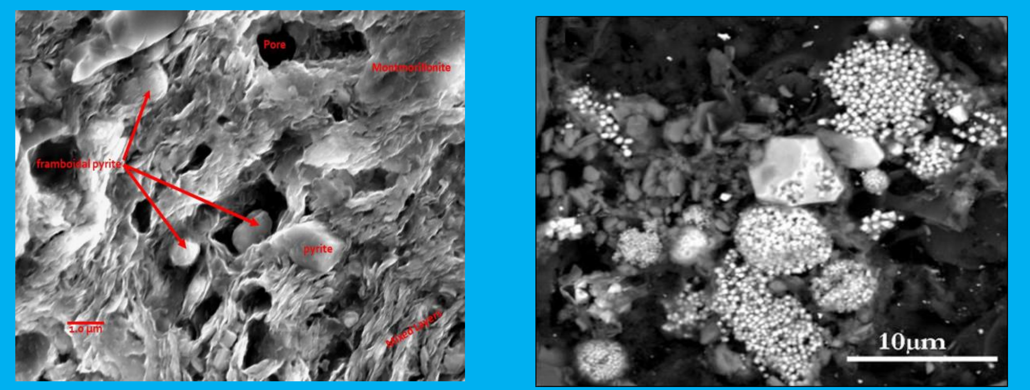
PETROGRAPHY

well-laminated beds, 15–560 cm thick , Rich with organic content (TOC varies from 8.6 to 13.8%). Banding due to variations in organic, clay, and silt concentration and commonly possess a pinch-and-swell arrangement, rich with pyrite . Differential compaction around pyrite concretions indicates growth before the compaction of shale was completed. Morphology of framboids may inherited from the chemotrophic bacteria, which accelerate formation of pyrite .





Relationships between Cupper vs. zinc and nickel for the studied Wadi El-Giddi black shales



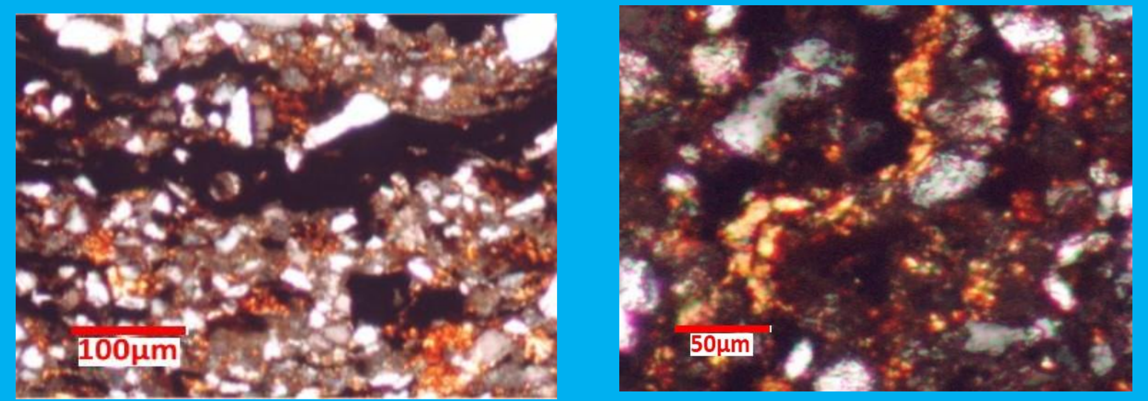
Backscatter SEM Image of framboidal pyrite, showing (A) oriented fabric of pressure shadow sample revealing a porous microfabric composed of arranged clay flake with <1.0μm pyrite microcrysts (P); and of microcrysts and evidence of compaction through kaolinitic black shale. (B) tight packing

MAJOR AND TRACE ELEMENTS ENRICHMENT

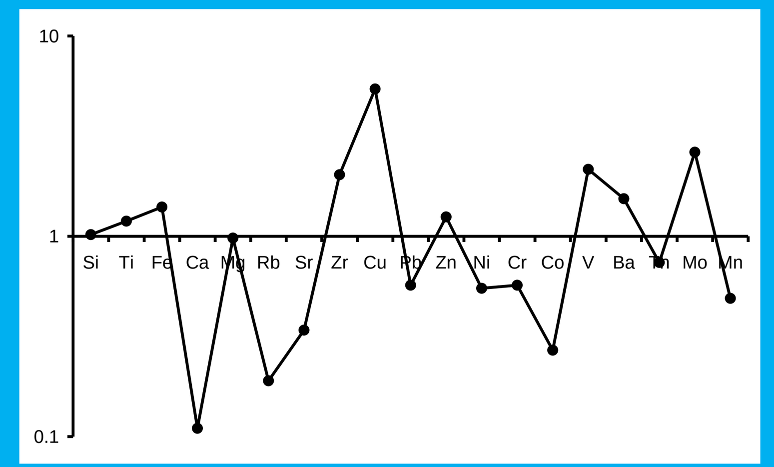
The calculated DOP for Wadi El-Giddi black shales ranging between 0.77 and 0.86.

The approximate order of EF relative to the WSC is Cu> Mo> V >Ba > Zn > Pb > Cr =Ni.

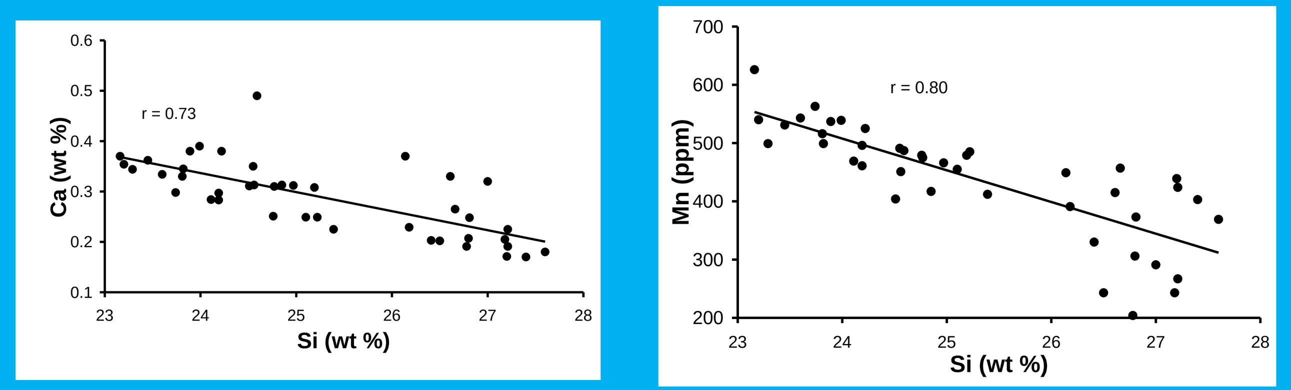
The Wadi El-Giddi black shales reflect high values for the ratios of Ni/Co (8.36), V/Cr (5.98), V/(V+Ni) (0.864). The δ ^{34}S value for the Wadi El-Giddi pyrite framboids ranges between -7.4 and -5.8 ‰ indicates their formation via bacterial reduction in euxinic conditions just below sediment/water interface in an open system.



Photomicrographs of the black shales showing (A) oriented, pressured and laminated shale with high contents of organic materials and silt ; (b) arrangement of the organic matter and pyrite (dark) in pinch forms.



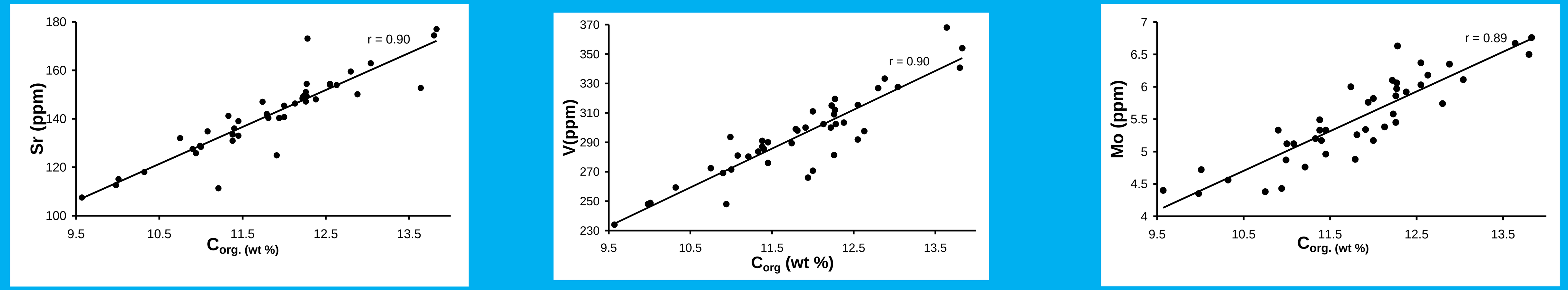
The enrichment factor values for major and trace elements in the Wadi El-Giddi black shales



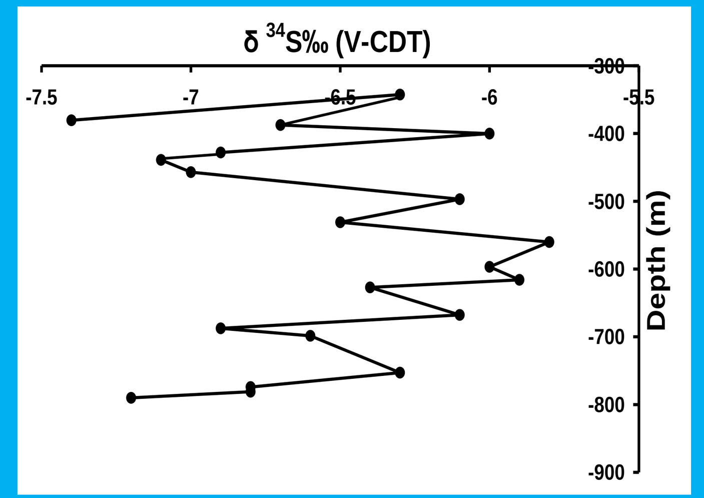
Binary plots of Silicon content vs. calcium and manganese for the studied black shales.

CONCLUSIONS

- Semi closed basin (lagoon) with euxinic bottom water were the predominant accumulation conditions during the sedimentation of Wadi El-Giddi laminated and banding black shales.
- Pyrite framboids were formed under conditions favorable for rapid nucleation and slow crystal growth. Their narrow size distribution range with their nearly uniform and small size (<10 μm) may reflect relatively short growth times.
- The involvement of sulphate-reducing chemotrophic bacteria accelerated the formation of pyrite, via oxidation of FeS by H2S near the sediment/ water interface.
- The high contents of organic carbon, molybdenum, vanadium, copper and high ratios of Ni/Co, V/Cr and V/(V+Ni), indicate that the studied black shales and their associated framboids were formed in euxinic environment. Their formation is related mainly to the presence of sulfate- reduction zone under the prevalence of reducing conditions in the basin of deposition.
- The higher values of barium suggest the studied black shales were formed under conditions of high fertility. Thus, the formation of the well-laminated shales appears to have deposited under high flux of organic matter at the lagoonal floor, which caused a dramatic decrease in bottom-water oxygen levels.
- The narrow range δ 34S (–7.4 to -5.8 ‰) is consistent with the interpretation of the biogenic signature derived from open system bacterial reduction of lagoonal water sulfate.



Relationship between total organic carbon vs. vanadium, molybdenum and strontium throughout the studied Wadi El-Giddi black shale.



Variation of sulfur isotope with depth throughout the studied black shales sequence

Elements	Mean (ppm)	$(Element / Al)_{W.G}$*	$(Element / Al)_{WSC}$**	EF
Si	25.26	2.63	2.59	1.02
Ti	0.56	0.06	0.05	1.19
Fe	6.89	0.72	0.51	1.4
Ca	0.29	0.03	0.27	0.11
Mg	1.43	0.15	0.15	0.98
Rb	28.2	2.9	15.2	0.19
Sr	141.5	14.7	43.5	0.34
Zr	381.3	39.6	19.6	2.03
Cu	284.3	29.6	5.4	5.44
Pb	12.0	1.2	2.2	0.57
Zn	117.3	12.2	9.8	1.25
Ni	46.1	4.8	8.7	0.55
Cr	60.1	6.2	10.9	0.57
Co	5.5	0.6	2.2	0.27
V	294.1	30.6	14.1	2.16
Ba	968.0	100.6	65.2	1.54
Th	9.3	1.0	1.3	0.74
Mo	5.5	0.6	0.2	2.63
Mn	439.3	45.7	92.4	0.49

Enrichment factors (EF) of the studied major and trace elements of Wadi El-Giddi black shales.

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