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Sedimentological Studies of Early Carboniferous Um Bogma Formation, Southwestern Sinai, Egypt

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Abstract:
The Lower Carboniferous carbonates Um Bogma Formation exhibits a significant rock unit of the Paleozoic rocks in southwestern Sinai, Egypt. The formation is subdivided into Lower, Middle and Upper Members with well-displayed paleokarst profile, that resulted from sea regression with uplifting of Lower member. Field observations with microscopic examination for the study of the microfacies associations and elucidation of the environment and the diagenetic processes shows that the rocks are texturally classified as carbonate and argillaceous rocks.
The carbonate rocks are texturally classified as crystalline dolostone, Sandy Oo-sparite, Bio-micrite-pseudo-sparite, Bio-Oo-sparite, silty Bio-Sparie, and Bio-dolosparite. The clastic rocks are texturally classified as Mudstone/Ferruginated Shale, Quartz arenite, and Quartz wacke.The sediments of the Um Bogma Formation were subjected to various diagenetic processes which belong to both isochemical and allochemical processes.
The Lower member give indication of intertidal to subtidal marine environment. The Middle member starts with the open sea shelf environment then followed by shallow subtidal marine environment. The Upper member shows shallow subtidal to lower intertidal that followed by clastic rocks that reflect the regressive sea within tidal flat.

Key Word: *Um Bogma, Southwestern Sinai, Lithostratigraphy, Microfacies, Carbonate Rocks, Diagenesis, Depositional Environment.*

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I. Introduction

The Um Bogma Formation exhibits the oldest marine transgression during the Paleozoic age in Sinai. The marine carbonates of the Fm. are rich in fossils which assigned it to Early Carboniferous age, that was accepted by many researchers. It is of limited distribution within Um Bogma area, Southwestern Sinai. In the last decades, several important papers have published on the Geology and tectonics of Southern Sinai (e.g., Saada et al., 2020, Kharbish & EL Awady, 2019).

The Um Bogma Fm. consists majorly of dolostone, marl, sandstone, and mudstone. Dolostone is considered as the main rock type in the lower and upper members, while the middle member consists of intercalations of shale, marl and dolostone with well-preserved fossil remains. It is also characterized by the presence of polymetallic mineralizations, and ores associated within it, including manganese and iron ores, secondary copper minerals, gibbsite and bauxite bearing sediments and Uranium mineralizations (PL. 1, A).

Aim and scope of study:

The main objective of this study is to develop a vision for reconstructing and understanding of depositional paleo-environment of Um Bogma Fm. in the Um Bogma area based on sedimentological and mineralogical studies with lithofacies and microfacies analysis.

II. Materials And Methods:

Study area

Um Bogma area is located in Southwestern Sinai, Egypt and is bounded between latitudes 28° 52̀ and 29° 09̀ N and longitudes 33° 14̉ and 33° 31̀ E. The area is covered by Precambrian basement, Paleozoic succession, Triassic basaltic sheet, Mesozoic-Tertiary carbonates, and Quaternary deposits. The Paleozoic succession is subdivided into lower sandstone unit (Sarabit El Khadim, Hamata, and Adedia Formation, middle carbonate unit (Um Bogma Formation) (PL. 1, B), and Upper Sandstone unit (Abu Thora Formation) (Fig. 1).

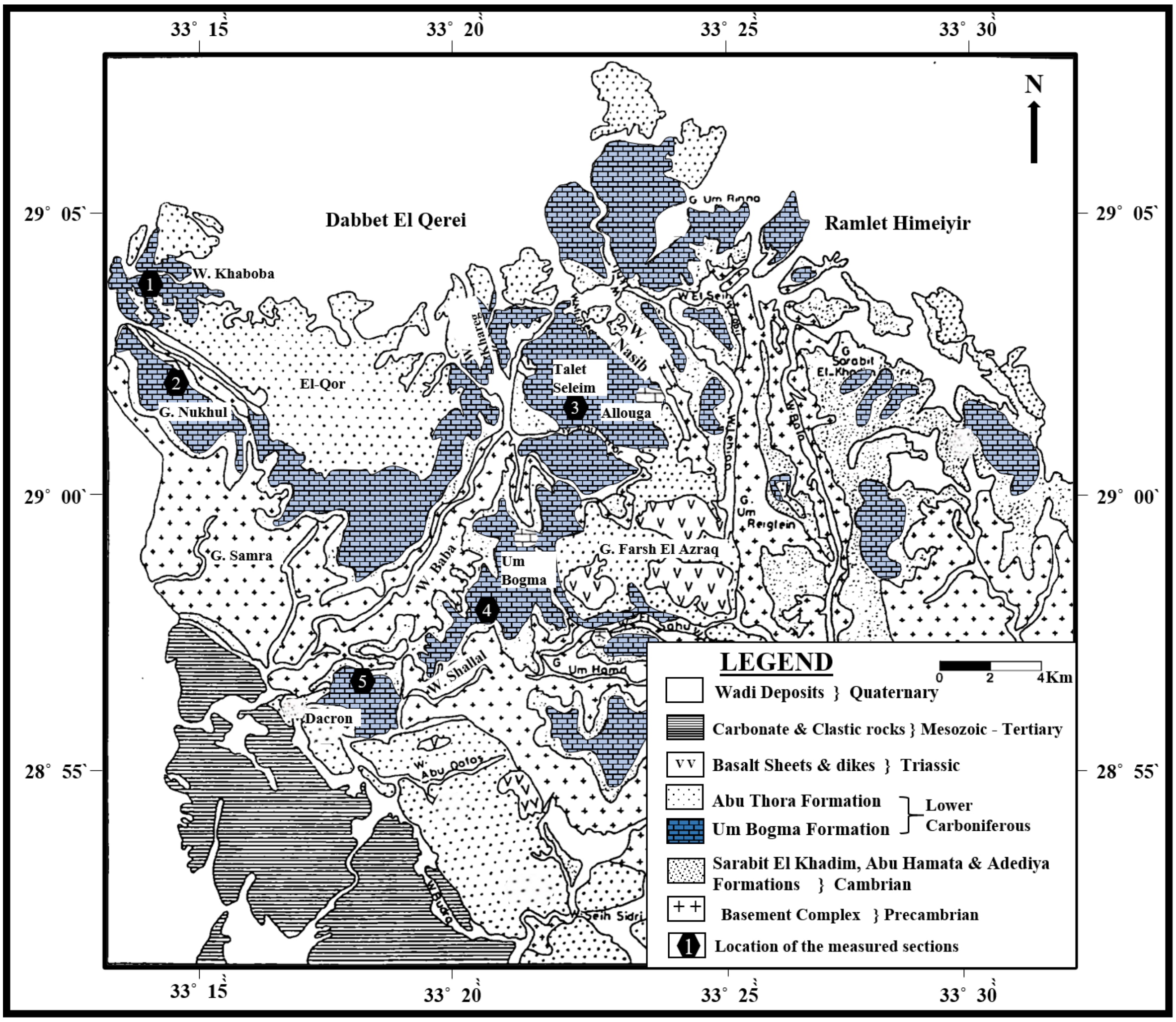

Fig. 1. Modified Geological map of Um Bogma area in Southwestern Sinai showing the lateral distribution of the Paleozoic rocks and location of the measured lithostratigraphic sections (after Aita, 1996).

Methods of study:

The present study gathers between the outcrop description, XRD and petrographic examination on the 30μm thick standard thin section (Flügel, 2010) to identify the carbonate and noncarbonate facies and the mineralogy assemblages of the Lower Carboniferous Um Bogma Formation.

The Um Bogma Formation were measured, studied, and described in detail within five different localities (G. Nukhul, W. Khaboba, Talet Seleim, W. Shallal, and W. Baba) in Um Bogma area, with sampling and field observation about sedimentological and mineralogical distribution of Um Bogma Fm. In addition to, Identifing the three members and constructing of isolith map of different members of Um Bogma Fm.

Microscopic examination for the study of the microfacies associations and elucidation of the environment and the diagenetic processes.

III. Results And Discussion:

I. Lithology and Stratigraphy

Based on the primary observation and detailed study of the gathered samples, a nomenclature was given to each of three members. Based on nomenclature of El-Sharkawi (1990) and Aita (1996), Um Bogma Fm. is subdivded as; **Lower Dolostone-Ore, Middle Marly Dolostone-Siltstone**, and **Upper Dolostone-Sandstone Members** (Fig. 2) (PL. 1, C).

Lower Dolostone-Ore Member

In the Northwestern localities, at G. Nukhul, the sandstone basal parts start with pink-colored sandstone, which is mainly dolomitic sandstone which change into hard, pink-colored, porous, and fossiliferous dolostones intercalated with sandy dolostone and thin laminae of mudstone. It reaches up to 14 m in thickness from a maximum 14 m thick at W. Khaboba, to the northwest, to a minimum of 0.5 m to the east at G. Um Rinna.

Toward the central, Eastern and Southeastern localities of the Um Bogma area, the paleokarst profile is well-displayed.

The paleokarst profile is subdivided into three horizons: lower karstified parent rocks, middle subsoil horizon (B), and upper topsoil horizon (A1, A2 and A3). The paleokarst profile includes remains of parent rocks that formed of stylolitic dolostone mixed with cavernous, gypsiferous, brittle and manganiferous sets. Caves and cavities of the paleokarst system form by the dissolution of the soluble rocks and occur as patterns of interconnected channels, those caves are filled with intrakrastic earthy materials and manganese deposits (PL. 1, D & E).

Middle Marly Dolostone-Siltstone Member

. It is marked by yellowish color of alternating beds of carbonates, clastics & carbonate-clastic mixtures and composed of cycles of fine to medium grained, poorly sorted, sandy dolostone, siltstone, shale and highly fossiliferous marl with corals, brachiopods, echinoderms, molluscs, gastropods, and bryozoan (PL. 1, F). It reaches up to 14 m at W. Khaboba and reduces in thicknesfrom NW to SE.

Upper Dolostone-Sandstone Member

It is composed of thinly bedded, cliff- and step- forming, massive and yellowish-brown to grey, hard compacted, crystalline dolostones, similar to those of the lower member but with remarkable increasing in the clastic content, especially of sand beds, towards its top. It ranges in thickness from 13m at the northwestern part of the study area to 2 m at W. Allouga.

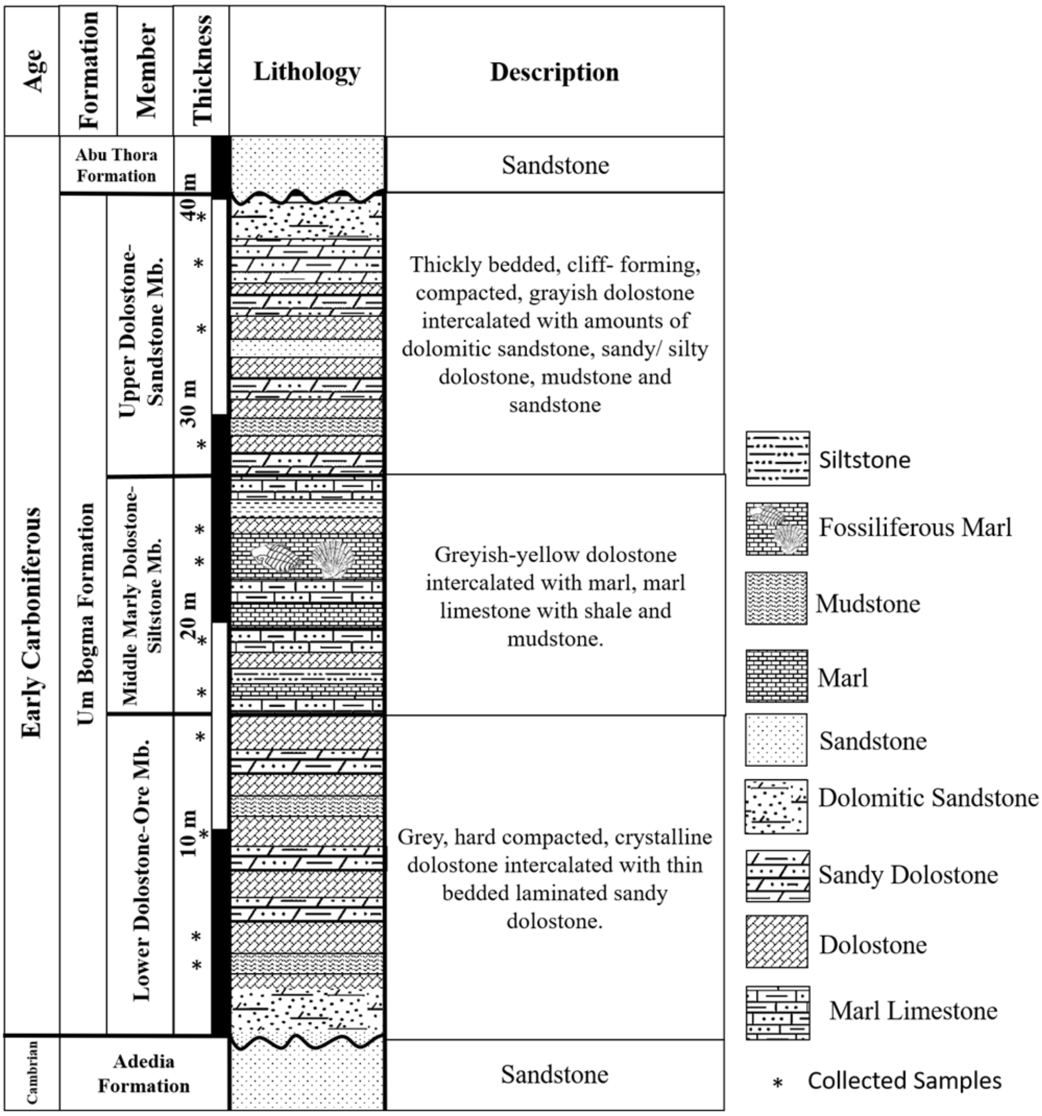

Fig. 2. Lithostratigraphic section of Um Bogma Formation in the Type Locality G. Nukhul.

II. Microfacies Analysis

The types and nomenclature of the carbonate microfacies were described according to most common classification of Dunham (1962), that was modified by Embry & Klovan (1971) with Folk (1959, 1962). The Standard Microfacies Types (SMF) and the Standard Facies Zones (FZ) of Wilson (1975) and Flügel (2004) were applied to the present samples and microfacies.

Carbonate Microfacies

The carbonate rocks are texturally classified as **crystalline dolostone, Sandy Oo-sparite, Bio-micrite-pseudo-sparite, Bio-Oo-sparite, silty Bio-Sparie,** and **Bio-dolosparite**.

1. **Crystalline Dolostone**: This microfacies indicates intermediate to late-diagenetic replacement dolomite. It was recorded within the three different members and consists of compact, hard crystalline Dolostones with less amounts of microsparite and sparite patches (Lower Member), and non-Ferron calcite sparite patches (Middle and Upper Members). Baroque or Saddle dolomite were also recognized within G. Nukhul PL. 2, A). The micrite of lower member suggests deposition within ineffective winnowing and calm currents, at inner shelf below the normal wave base. While the middle and upper microfacies reflects agitated, shallow subtidal to lower intertidal depositional environment.
2. **Sandy Oo-sparite:** It was recorded within the lower and upper members of G. Nukhul and W. Khaboba, Upper mb. of W. Baba, G. Um Rinna. Ooids are of elliptical shape, 0.3-0.5 mm, and showing poor preservation of concentric laminae structure with presence of micritic envelopes PL. 2, B). The presence of less abundant ooids suggests increasing in the water depth to reach from 10 to 15 m. It is correlated to the SMF-15 and FZ-6 of Wilson (1975) and Flügel (2004).
3. **Bio-Oo-Dolosparite:** It was recorded within the upper part of most localities of the middle member There are 2 types of ooids: superficial ooids and normal ooids. The bioclasts of microfossils and shell fragments include fragments of corals, foraminiferal tests and algae with worm track cut across the dolomite cement. The shell fragments are filled with phosphatic material, mainly of recrystallized dolomite PL. 2, C). This microfacies suggests precipitation within water depth of 2-15 m; according to the biological content and ooids' size and amount (Newell et al., 1960). It is correlated to the SMF-11 and FZ-6 of Wilson (1975) and Flügel (1982).
4. **Bio-micrite-pseudo-sparite:** It was recorded within middle mb. of W. Khaboba, G. Nukhul and G. Um Bogma. Folk (1980) stated that "pseudo-sparite" results from the removal of Mg from the rock upon weathering process with surface waters of very low Mg/Ca ratio, that allows recrystallization of micrite to microspar or pseudospar. The bioclasts include echinoderms, corals, brachiopods, and others, some are poorly preserved, but others are pseudomorphically replaced into pseudo-sparite PL. 2, D). This microfacies shows deposition within open sea shelf environment with an open circulation. It is correlated with the SMF-8 and FZ-2 Wilson (1975) and Flügel (2004).
5. **Silty Bio-sparite:** It was recorded within the middle mb. G. Nukhul and could be defined as limestone consists mainly of skeletal grains embedded within sparry cement as groundmass (Folk, 1959, 1962). It is composed of considerable amounts of very fine to fine-sized microfossils and shell fragments that are filled with recrystallized dolomite with minor amounts of iron oxides. This microfacies shows deposition within the slope of open platform while the silty Quartz grains may give an indication of near-shore depositional environment with alteration in sediment supply and sea level changes. It is correlated with the SMF-12-S (coquina composed of shells without specific identification) and FZ-7 Wilson (1975) and Flügel (2004).
6. **Bio-Dolosparite:** It was recorded within the middle part of the Upper mb. of W. Khaboba. The bioclasts/fossil fragments occur in different sizes from fine- to coarse-size, that are randomly distributed in dolomite cement. Those bioclasts include shell fragments of Pelecypods with echinoderms. The shell fragment walls show replacement by recrystallized dolomite, and/or Iron Oxyhydroxides. This microfacies shows deposition within agitated marine depositional environment with good water circulation. It is correlated to SMF-11 and FZ-6 (Winnowed edge platform) of Wilson (1975) and Flügel (2004).

Clastic Microfacies

The argillaceous rocks, on the other hand, are texturally classified as **Mudstone/Ferruginated Shale, Quartz arenite,** and **Quartz wacke**.

7. **Mudstone/ Ferruginated Shale:** It is associated mainly with the Iron-Manganese oxide ores within W. Shallal and Abu Thora mines at the lower mb. It shows parallel beddings. Iron oxides, as cement, are admixed with other constituents and rim some crystals of the rock, as well as distributing heterogeneously from band to band (PL. 2, E). The presence of mudstone and shales within the stratigraphic succession suggests deposition within quiet-water environment, while fissility suggested deposition within anoxic environment (Boggs, 2009).
8. **Quartz arenite:** It was recorded within the Upper mb. of W. Khaboba with wide distribution up to 3 km. Quartz grains are compacted as diagenetic quartz arenites; granulated that show Undulatory extinction and concavo-convex and welded contacts. Margins of some grains are embayed and dissolved due to corrosion during diagenesis (PL. 2, F). The microfacies is correlated with tidal flat cycles, based on the fining-upward

cycle (Klein, 1971 & 1977). Pettijohn (1975) stated that the tidal sand bodies show decreasing upward, from basal lag gravel.

9. Quartz Wacke: It was recorded within the Upper mb. of W. Khaboba as limited distribution and extensions with uniform thickness. The detrital Quartz grains occur as monocrystalline with even extinction with rare undulose extinction (PL. 3, A). The microfacies is correlated with longitudinal sand bars in upper- to lower- shoreface depositional environment.

Paleokarst Profile and Paleosol formation (Lateritization)

Towards the central localities including the studied sections; Talet Seleim, Wadi Baba and Wadi Shallal, paleokarst profile is well displayed. Epigenetic metoric water of weathered crust karstification occurs during uplift of original exposed carbonate rocks and are related to structural unconformities and paleo-structures. Based on different lithology, texture and mineral composition, horizons are subdivided into:

a) The Lower parent rocks: It is composed of blocky mosaic calcite with some zoned dolomite rhombs and Quartz grains floating in calcite cement. The stylolite seams are filled with Fe-Mn oxyhydroxides (PL. 3, B).

b) The Subsoil Horizon (B Horizon): It is composed of karstified dolostone and mudstone intermixed with loose earthy precipitates, of Iron and Manganese oxyhydroxides and Kaolinite (PL. 3, C). It coincides with the supergene concentration horizon of the deep weathering/ laterite profile.

c) The Topsoil Horizon (A Horizon): This horizon is subdivided into three latosol sub-horizons described as follows:

Lower Laminated Ochreous Siltstone Sub-Horizon (A_3): It is composed of very fine to fine, poorly sorted, subangular to angular quartz grains, floating in very-fine grained matrix of kaolinite and Iron-Manganese oxyhydroxides. The Quartz are distributed in stratiform, parallel to rock lamination or shows random distribution with kaolinite matrix (PL. 3, D).

Middle Nodular Kaolinite and Alunite Sub-Horizon (A_2): It is composed of nodules of kaolinite and alunite with ochres mudstone. The Quartz grains occur in sand-size grained, embedded within very fine-grained matrix. Alunite crystals are concentrated around kaolinite that occur as vermicular authigenic overgrowths (PL. 3, E).

Upper Organic-rich Sub-Horizon (A_1): It is composed mainly of organic rich matters. Small quantity of Quartz grains embedded within very fine-grained matrix of kaolinite, gibbsite, alunite intermixed with dark brown to black organic matter with Iron-Manganese oxyhydroxides.

III. Diagenetic Processes

The diagenetic processes were discussed including those affected the carbonate and the clastic rocks of the Um Bogma Formation. The diagenesis of the carbonate rocks shows isochemical and allochemical processes.

The isochemical processes include compaction, cementation, neomorphism and dissolution. Compaction occurs as cracking, fracturing, interpenetration, and close packing of grains. Cementation is shown as blocky, mosaic, and rims. Neomorphism occurs as micritization and Recrystallization. Micritization occurs within shallow marine environments. Recrystallization occurs as grumouse texture of microsparite and pseudo-sparite. Dissolution is shown by the presence of Stylolites (PL. 3, F) and secondary porosity of inter-crystalline and fracture porosities.

The allochemical processes include dolomitization, de-dolomitization and silicification. Dolomitization occurs as dolomitized allochems including fossils and ooids, and euhedral dolomite rhombs, and results of sea water and fresh water “Dorag Dolomitization”, and as result of burial of deep surfaces “Burial Dolomitization”. De-dolomitization is shown as grumouse texture; occurs through contact with meteoric water and porewater of different compositions. Silicification occurs as replacement process of Quartz replacing dolomite rhombs as scattered within matrix of rocks.

The diagenesis processes of the clastic rocks include cementation of silica and iron-oxides, compaction, and pressure solutions.

IV. Depositional Environment

During the Early Carboniferous, there was a rise in the global sea level and warm temperature, Egypt northernmost margins were invaded by the Paleotethys Ocean, which resulted in the mixed Siliciclastic-Carbonate platform, this resulted in the deposition of the shallow marine fossiliferous carbonates of the Um Bogma Fm in the Um Bogma area (Guiraud et al., 2001 & 2005). The paleomagnetic direction of the Lower Carboniferous Mn-Fe ore of Um Bogma Fm was situated at latitude 10° south the equator, in which the climate is of tropical conditions (El Agami et al., 2000).

The clastic sediments of Lower member of Um Bogma Formation are mainly found within the lower part of this member and gives an indication of the first marine transgression throughout the Um Bogma area.

While the carbonate facies give an indication that deposition may be occurred in high-energy tidal bars and moderately agitated, warm well- oxygenated marine depositional environment. Those depositional environments at the northern and western parts reflect that they were topographically low localities. But towards the central localities, the paleokarst profile and formation of typical lateritic soil profile gives an indication that those areas were subjected to uplifting and deep weathering that results in parent carbonate rocks, subsoil latosol horizon and topsoil horizon and led to the concentration in the high mineralogical content within these horizons, such as Fe, Mn, Cu, Al, U mineralizations.

The Middle member starts as Bio-micrite-pseudo-sparite microfacies association, which indicates the deposition within the open sea shelf environment with an open circulation and shallowing marine agitated environment where the deepest part in the depositional basin. The diverse biological content indicates sea water at normal salinity and oxygenation, while changes in the cortex thickness of ooids reflects the variations in water depth, concentration of $CaCO3$ with temperature. The microfacies reflect deposition within moderately agitated warm water of shoal environment, in winnowed platform edge under wave action at or above wave base.

The Upper member is overlain unconformably by the clastic rocks of Abu Thora Formation, deposited under shallow marine to beach environments (Morsy et al., 1992), and reflect marine regression with high rates of relative sea fall (Kordi et al., 2016). The carbonate microfacies reflected deposition within agitated, shallow subtidal to lower intertidal and of winnowed platform edge. The clastic microfacies reflect the regressive sea within tidal flat of fining-upward cycle.

V. Summary and Conclusion

The study is concerned with the Lower Carboniferous carbonates Um Bogma Formation at Um Bogma area and concludes the Lithology, Microfacies association, Paragenetic Sequence, Mineralogical content, and Depositional Environment (Fig. 3). The Um Bogma Formation is subdivided into three members: Lower Dolostone-Ore Member, Middle Marly Dolostone-Siltstone Member, and Upper Dolostone-Sandstone Member, with well-displayed paleokarst profile and Paleosol formation.

The Lower member within the northwestern parts consists of oo-dolosparite, sandy oo-sparite, medium crystalline dolostone, and mudstone/shale associations. Those associations reflect high energy tidal bars and moderately agitated, warm, and well-oxygenated marine depositional environments.

The paleokarst profile is subdivided into three horizons: the lower karstified parent rocks, the middle subsoil latosol horizon (B), and upper topsoil horizon (A1, A2 and A3). It shows uplifting and deep weathering at central parts of Um Bogma area that led to the unique mineralogical enrichment within paleokarst horizons.

The Middle member is composed of bio-oo-dolosparite, Bio-micrite-pseudo-sparite, silty bio-sparite and Crystalline Dolostones associations. The microfacies reflect deposition within moderately agitated warm water of shoal environment, in winnowed platform edge under wave action at or above wave base.

The Upper member is composed of medium/coarse crystalline dolostone, Bio-dolosparite, sandy oo-dolosparite, Quartz wacke and Quartz arenite. The carbonate microfacies reflected deposition within agitated, shallow subtidal to lower intertidal and of winnowed platform edge. The clastic microfacies reflect the regressive sea within tidal flat of fining-upward cycle.

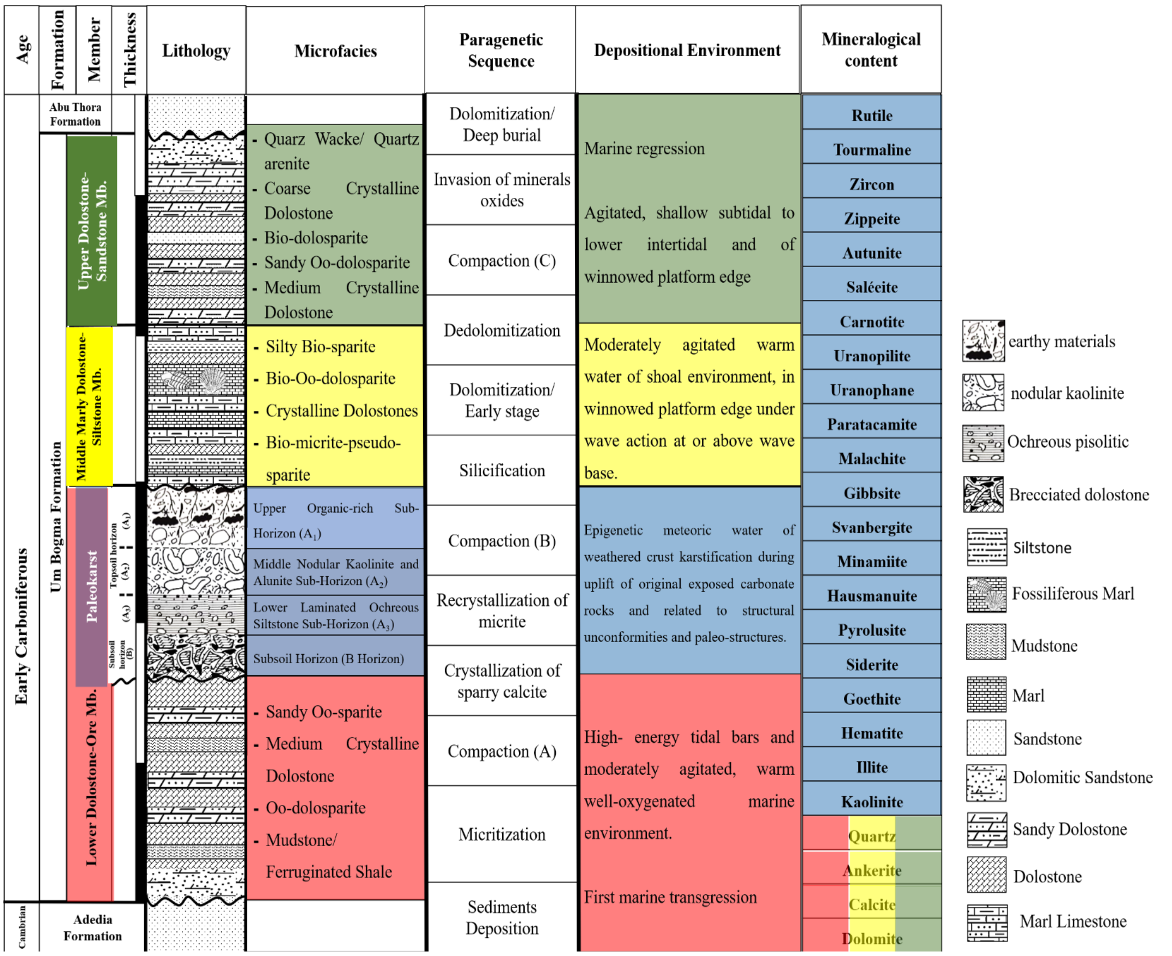

Fig. 3. Shows conclusion of Lithology, Microfacies association, Paragenetic Sequence, Mineralogical content, and Depositional Environment.

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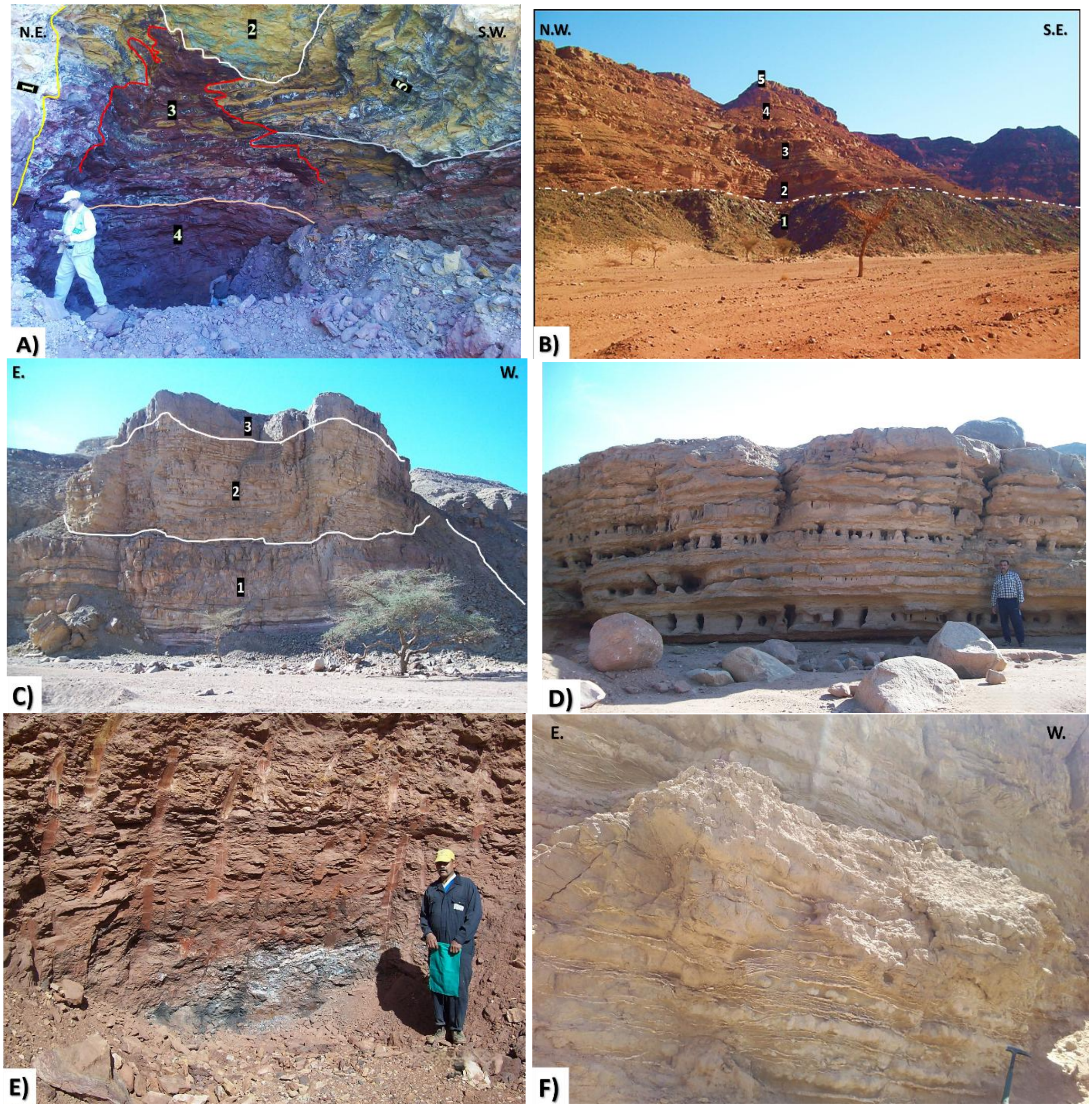
PLATE 1



A) Large mine of different mineralizations including alunite (1), Copper (2), Iron oxyhydroxides (3) and Manganese lenses (4). Mn Lenses (4) are seen within Abu Thor, Abu Hamata, and Talet Seleim areas. Copper minerals (2) are embedded within marl channels (5), while the Fe-Mn minerals are embedded within mudstone.

B) Panoramic View and field photograph showing the unconformity between basement complex (1) and Cambrian rocks (Sarabit El Khadim (2), Abu Hamata (3), Adedia (4) formations) and the Lower member of Um Bogma Formation (5).

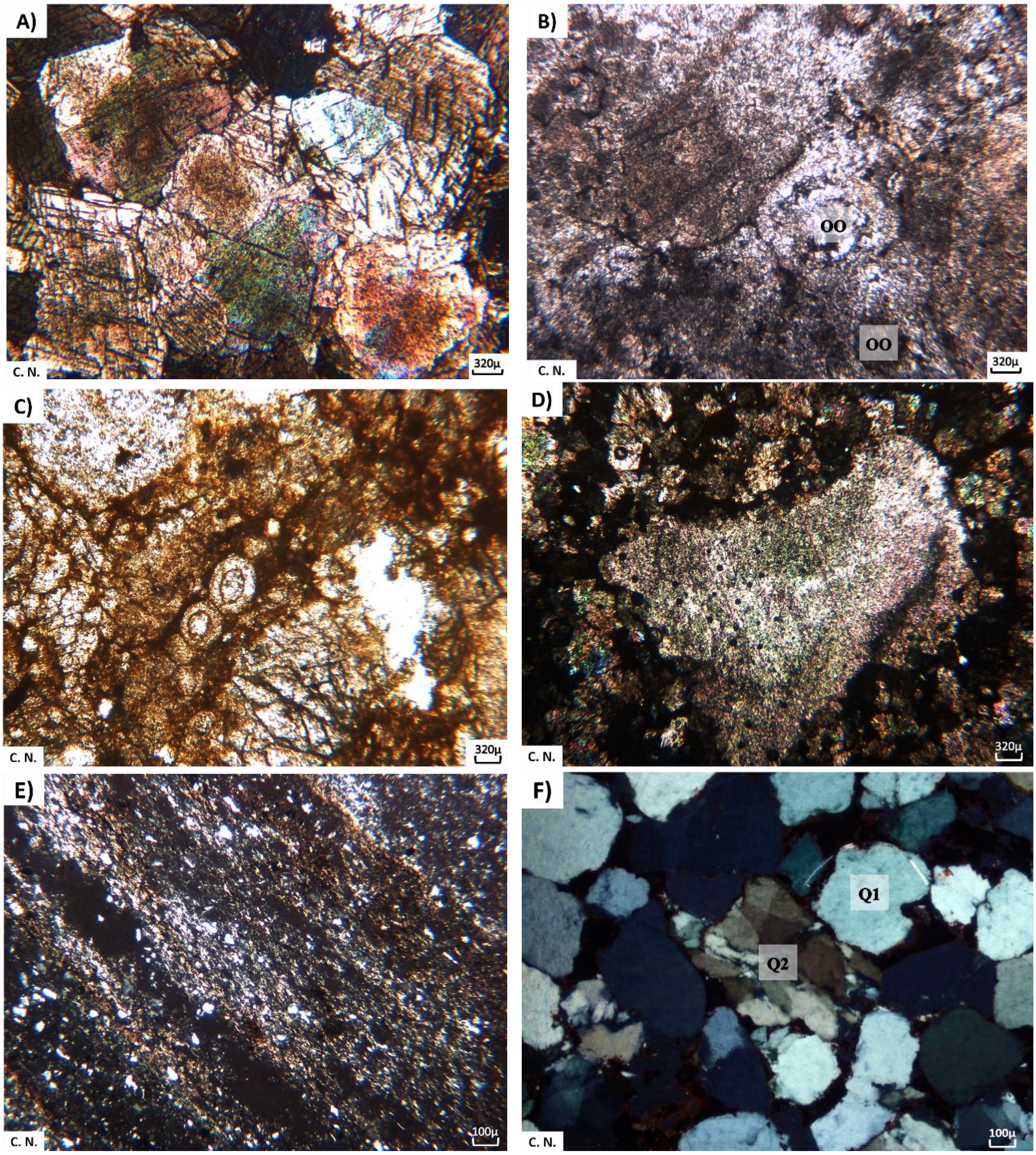
C) Um Bogma Foramtion classified into three members (Lower dolostone Ore (1), Middle Marly dolostone-siltstone (2), and the upper dolostone-sandstone (3) members) W. Shallal locality.

D) The karstified and cavernous of the Lower dolostone member of UB Fm. at W. Baba.

E) Subsoil horizon (contains black Manganese oxyhydroxides) and topsoil horizon of mudstone (contain brown clay of iron oxyhydroxides) at Talet Seleim area.

F) Fossils of Middle Member of Um Bogma Formation.

PLATE 2



a) Compacted and fractured dolostone of anhedral to subhedral interlocked crystals, Lower Member, Um Bogma Formation

b) Ooids embedded within microsparry dolomite cement, Lower Member, Um Bogma Formation

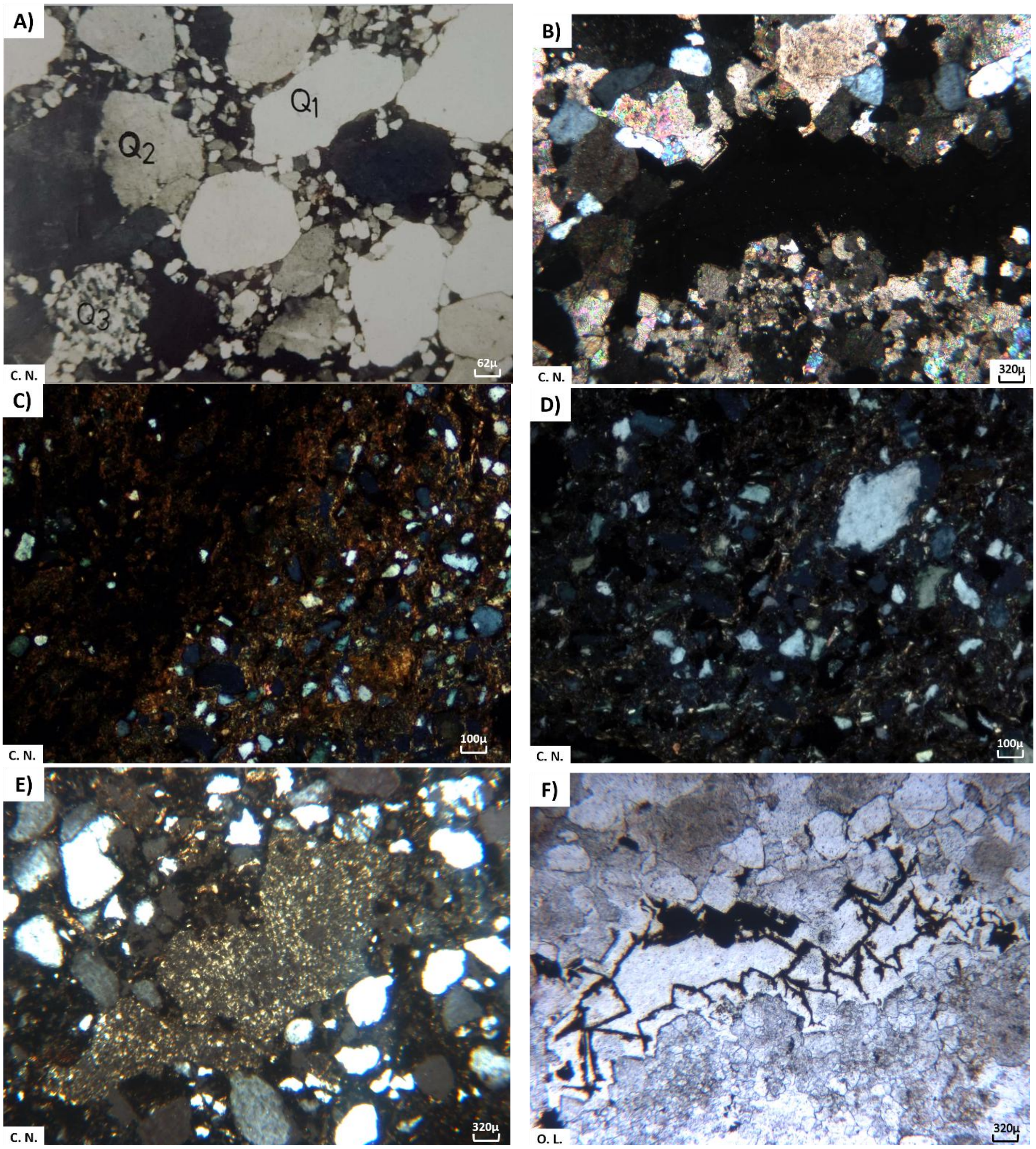
c) Ooids that are well rounded elliptical in shape embedded within sparry dolomite cement, Middle Member, Um Bogma Formation

d) Bioclasts embedded within micrite and pseudo-sparite cement, Middle Member, Um Bogma Formation

e) Thin diagonal parallel bands mainly of clay and silt size with some fine sand size particles, Lower Member, Um Bogma Formation.

f) Compacted quartz grains of monocrystalline (Q1) and polycrystalline (Q2) crystals. Some grains are cracked and sutured at its edges due to weathering processes, Upper Member, Um Bogma Fm.

PLATE 3



A) Different types of Quartz grains; Q1: monocrystalline Quartz, Q2: Polycrystalline, and Q3: stretched Quartz, Upper Member, Um Bogma Formation

B) Dolomite rhombs, calcite crystals with less amounts of Quartz grains, parent rock, Paleokarst Profile, Lower Member, Um Bogma Formation

C) Subsoil horizon (B) showing gradual precipitation with increasing in the cement to crystal ratio from SE to NW., Paleokarst Profile, Lower Member, Um Bogma Formation

D) Very fine to fine, poorly sorted, subangular to angular quartz grains, floating in very-fine grained matrix of kaolinite and Iron-Manganese oxyhydroxides; Lower Laminated Ochreous siltstone (A3 Sub-Horizon), Topsoil horizon (A), Lower Member, Um Bogma Formation

E) The vermicular authigenic kaolinite surrounded by alunite crystals within Middle Nodular Kaolinite and Alunite (A2 Sub-Horizon), Topsoil horizon (A), Lower Member, Um Bogma Formation

F) Stylolite where the suture is filled with iron oxides, Lower Member, Um Bogma Formation