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Integrated Quantitative and Qualitative Petrographic and Diagenetic Methods to define Carbonate Outcrop and Reservoir Rocks Characterization: A Case study of the Cyrenaican Miocene Ar-Rajmah Group, NE Libya

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Abstract

The petrographic and diagenetic lab work of the Cyrenaican Miocene carbonate rocks northeast Libya involves an intensive study of 503 hand samples and their thin sections. 148 samples of the measured field section A1 of 74m thick were selected at 0.5 m intervals and then prepared to be studied.

Proper thin sections preparation required insertion of some dyes and chemical treatments. Blue dye was inserted into the epoxy of all thin sections to enhance porosity identification. Alizarin Red-S stain was used to distinguish between calcite and dolomite minerals, and potassium ferricyanide stain was used to differentiate ferroan from non-ferroan carbonate minerals.

For the petrographic work, a three part thin section description scheme was established and followed. It includes: 1) quantitative analysis, 2) qualitative analysis, and 3) diagenetic process and their paragenetic sequence. The quantitative part involved determining the type and percentage of grains/fossils, matrix, cement, and pores. The qualitative studies rock textures (fabrics and grain size), sedimentary structures (primary and secondary), and trace fossils. Diagenetic processes includes micritization, dissolution/leaching (pore creations), cementation (pore destruction), compaction (mechanical and chemical), and neomorphism (recrystallization, inversion, and replacement). Through the cross cutting relationship the paragenetic sequence were defined by putting each diagenetic event in its proper relative time order of occurrence.

The most important final products of these integrated petrographic and diagenetic methods are curves that define vital reservoir rocks characterizations such as high/low porosity zones and their types, high/low cement zones and their types, grain dominated versus mud dominated zones, high/low diagenetically affected zones and type of diagenesis, bio-zones, dolomite versus calcite zones, carbonate texture curves, dolomite types and zones, and a chart of the paragenetic sequence of the diagenetic events and their processes. In addition, the depositional and diagenetic reservoir properties are interpreted in the sedimentological and sequence stratigraphic context of the studied Cyrenaican Miocene sequence to determine the extent at which the relative sea level changes and tectonics could control the carbonate reservoir properties.

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Introduction

The Cyrenaica Platform (Fig. 1) is located in northeastern Libya and includes the Al-Jabal Al-Khdar and the Soluq Trough, between 31°-33° N Latitude and 19°-30'-21° E Longitude. The study area comprises both the IRC Benghazi (NI 34-14) and Soluq (NH 34-2) map sheets (Klen, 1974; Francis et al, 1977). The high-quality outcrops are exposed nearly continuously for greater than 130 km along the coastal escarpment. This work documents the detailed petrographic and diagenetic characteristics of the Miocene carbonate sequence of Ar-Rajmah Group. In this work we will define the Ar-Rajmah Group depositional facies and their petrography, depositional and diagenetic characterizations through time. In addition to defining the diagenetic processes and their diagenetic sequences, these reservoir analogue facies will be evaluated quantitatively and qualitatively based on our invented tri-part scheme of thin sections description.

Geological Setting

Cyrenaican, northeast Libya is a part of stable foreland basin in the Central Mediterranean region (Ziegler , 1988 and Esteban, 1996 edited by Franseen et.al. 1996). The Cyrenaica area of northeast Libya includes two major tectonic provinces, the Al-Jabal Al -Khdar Uplift to the north and the Cyrenaica Platform in the south, and two troughs, the Soluq and Marmarica Troughs (Hallett, 2002). The exposed surface rocks of the Cyrenaican platform range from Cretaceous to Late Miocene (El-Hawat and Abdulsamad, 2004). The Miocene Ar-Rajmah Group includes the Benghazi Formation, and Wadi Al-Qattarah in Al-Jabal Al-Khdar Uplift, and the Benghazi Formation, Al-Sceleidima Formation and Msus Formation in Soluq Trough area. The Wadi Al-Qattarah Formation lateral equivalents are the Al-Sceleidima Formation and Msus Formation.

Methods

The field measured vertical logs have been sampled, and to be later used in constructing the stratigraphic cross-sections. Detailed laboratory work for petrographic analysis and diagenesis of the limestone facies has been conducted on 503 representative sample thin sections. Blue dye was used, the epoxy to show porosity, potassium ferricyanide was used to differentiate ferroan and nonferroan minerals, and Alizarine Red S. staining was used to differentiate between dolomite and calcite (Dickson, 1965, 1966). The limestone textures were classified using Dunham (1962) that later modified by Embry and Klovan (1971). Cement morphologies were classified following Tucker (1988). The components percentages have been accounted by using the estimation comparison chart of Folk et. al. (1970). The crystalline dolomitized limestone textures were described using Randazzo and Zachos classification (1983), Amthor et al. (1993), Sibley & Gregg (1987), and Tucker (1996). Cements types and fabrics were identified and described using schemes provided by Flügel (2004). The grain contacts and compaction were described in accordance with Taylor (1950). Porosity was described as in (Choquette and Pray, 1970) and using the genetic porosity classification (Ahr, 2011; Humbolt and Ahr, 2008; and Ahr et al., 2005).

In this study we seek to understand the diagenetic history of the Cyrenaican Miocene rocks of Ar-Rajmah group, as a reservoir-analogue rock unit. This would shed much more insight into the paragenetic sequences and characterizations of this reservoir-analogue carbonate rock unit. 148 prepared thin sections of 0.5 m sampling interval from the measured field section A1 have been described in detail petrographically and diagenetically. A specifically designed tri-part scheme of description has been followed to obtain data that can be used to evaluate these reservoir-analogue rocks quantitatively and qualitatively, the data was plotted against the vertical thickness of the stratigraphic section A1.

The thin sections description scheme consists of three parts (Fig. 1.3). The first and second parts are concerned with the quantitative and qualitative petrographic attributes, whereas the third part focuses on the diagenetic processes.

The **petrographic description** obtained data can be analyzed both quantitatively and qualitatively. The quantitative analysis accounts for grains, matrices, cements and pores types and percentages. The qualitative analysis accounts for types of textures, sedimentary structures and trace fossils. The textural study concentrated mainly on fabrics and grains, while the sedimentary structures study made to distinguish, describe and classify erosional, depositional and deformational structures.

The **diagenetic processes** include five main groups that to be used to unravel the paragenetic history of the Cyrenaican Miocene rocks of Ar-Rajmah group. These diagenetic groups include micritization, dissolution/leaching (pore creations), cementation (pore destruction), compaction (mechanical and chemical), and neomorphism (recrystallization, inversion, and replacement).

Results and Discussion

The Cyrenaican Miocene carbonate platform of the Ar-Rajmah Group, NE Libya was deposited in a carbonate ramp setting as indicated by the field and petrographic work. The carbonate platform consists of eleven depositional facies were subjected to eighteen diagenetic events produced by six diagenetic processes that left their print over on these rocks.

The ramp depositional facies includes: 1) oolitic grainstone, microbialite (stromatolite, thrombolite, and cryptalgal-laminite), 3) pelletal wackestone/packstone, 4) gypsum, 5) bioclastics packstone porites reefs, 6) bioclastic carbonates wackestone/packstone, 7) reworked bioclastic carbonates wackestone/packstone, 8) red algae reefs, 9) reworked red algae packstone. The siliciclastic facies are: 10) Very fine to fine quartz sandstone, and 11) green shale with fish teeth and coprolites.

The six main diagenetic processes that altered the Cyrenaican Miocene platform are: 1) micritization, 2) dissolution, 3) cementation, 4) recrystallization, 5) replacement, and 6) compaction (chemical and mechanical). These diagenetic processes produced a microscopically identifiable succession of alteration events that has been ordered chronologically based the cross-cutting relationships. The paragenetic sequence (Fig. 4) of the Ar-Rajmah Group is: 1) micritization, 2) symmetrical rim cement, 3) asymmetrical rim cement, 4) initial pore-filling cement, 5) initial dissolution , 6) secondary pore filling cement, 7) recrystallization, 8) dolomitization, 9) dedolomitization, 10) secondary dissolution, 11) geopetal infilling, 12) initial fracturing, 13) dissolution seems, 14) gypsum replacement, 15) silicification, 16) fracture filling cement , 17) a second period of fracturing, and 18) a third episode of dissolution.

The quantitative analysis of the type and percentage of grains/fossils, matrix, cement, and pores resulted in numerical data that presented as curves against the vertical thickness of the section A1. These curves will help to identify the reservoir zones that have high porosity and grainy facies and impermeable zones that are highly cemented and have high mud content as a matrix.

The qualitative analysis such as rock textures and sedimentary structures helped to define the high energy grainy reservoir zones versus the low energy muddy impermeable zones. Also, it helped to define the vertical and lateral changes in the homogeneity and heterogeneity of the reservoir zones and reservoir rock types. In addition, the qualitative analysis of rocks textures and fabrics helped to define reservoir zones that still retain their deposition characteristics and zones that are altered by diagenesis and gained new characteristics.

To sum up, the Cyrenaican Miocene ramp carbonate rocks had been through eighteen diagenetic events. These events started with micritization then rim cements and 1st pore-filling cements that partially reduced the primary porosity. Next, the 1st dissolution event that created secondary intercrystalline, biomoldic, and oomoldic porosity, and then followed by the 2nd pore-filling cement that again reduced the porosity. Recrystallization that led to enlargement of matrix crystals led to the reduction of the intercrystalline porosity. Dolomitization and dedolomitization replacement events happened next and they may either have negative or positive effect on the porosity. The 2nd dissolution followed and again enhanced the secondary porosity to a large extent. The first fracturing event enhanced the porosity and permeability by cutting through gains and matrix. The dissolution seems that followed they may have either positive or negative impact to the porosity. The next stage was replacement by gypsum and silica followed by the fracturing fill cement that cause minor growth of silica into pore spaces that might cause minor reduction of the porosity. The following 2nd fracturing event and the following 3rd dissolution events played a major role in enhancing the secondary porosity and the permeability of the Cyrenaican Miocene carbonate ramp rocks.

Porosity in the Miocene is still facies controlled, in spite of the diagenetic enhancement and creation of secondary porosity. The highest porosity values are in the Middle Miocene that dominated with the high energy oolitic grainstone facies, the medial porosity values are in the Early Miocene that dominated by coralline red algae facies, and the lower porosity values are in the Late Miocene associated with the low energy microbial-oolitic grainstone.

Conclusions

The Cyrenaican Miocene ramp has eleven depositional facies that altered by six diagenetic processes to produce a succession of eighteen diagenetic events. The older part of the Cyrenaican Miocene carbonate sequence has different depositional texture and diagenetic pattern than the younger part. The boundary between the two paragenetic successions in the study area ties roughly with a major sequence stratigraphic surface.

The analysis of the petrographic data of the Cyrenaican Miocene carbonate rocks indicates the multiple phases of diagenetic alteration. Also, it shows that the younger part of the Cyrenaican Miocene sequence is affected by the meteoric water diagenesis more than older part. The diagenetic processes enhanced the total porosity and the secondary porosity is dominant, although porosity is still showing depositional facies control trends. In addition, open fractures increased the secondary porosity and enhanced the permeability by connecting open pore spaces in the reservoir-analogue zones of the Cyrenaican Miocene of Ar-Rajmah Group.

Figures Captions:

Figure 1 (A) Location map of the study area in Cyrenaica, northeastern Libya. (B) Landsat image of NE Libya showing the geological boundaries of Cretaceous-Tertiary rocks. The geological boundaries are based on the IRCs sheet-Benghazi (Klen, 1974) and sheet-Soluq (Francis and Issawi, 1977) that were later modified by (El-Hawat et al., 1987).

Figure 2 A tri-part thin sections description scheme; quantitative, qualitative, and diagenetic analysis.

Figure 3 Detailed methodology and components of the tri-part thin sections description scheme.

Figure 4 The Quantitative, qualitative, and diagenetic analysis final results from the tri-part thin sections description scheme.

Figure 5 The paragenetic sequence of the Cyrenaican Miocene carbonate platform, made up of 18 successive diagenetic events (Amrouni et al., 2015, Amrouni and Pope, 2014 and 2015).

Figure 1

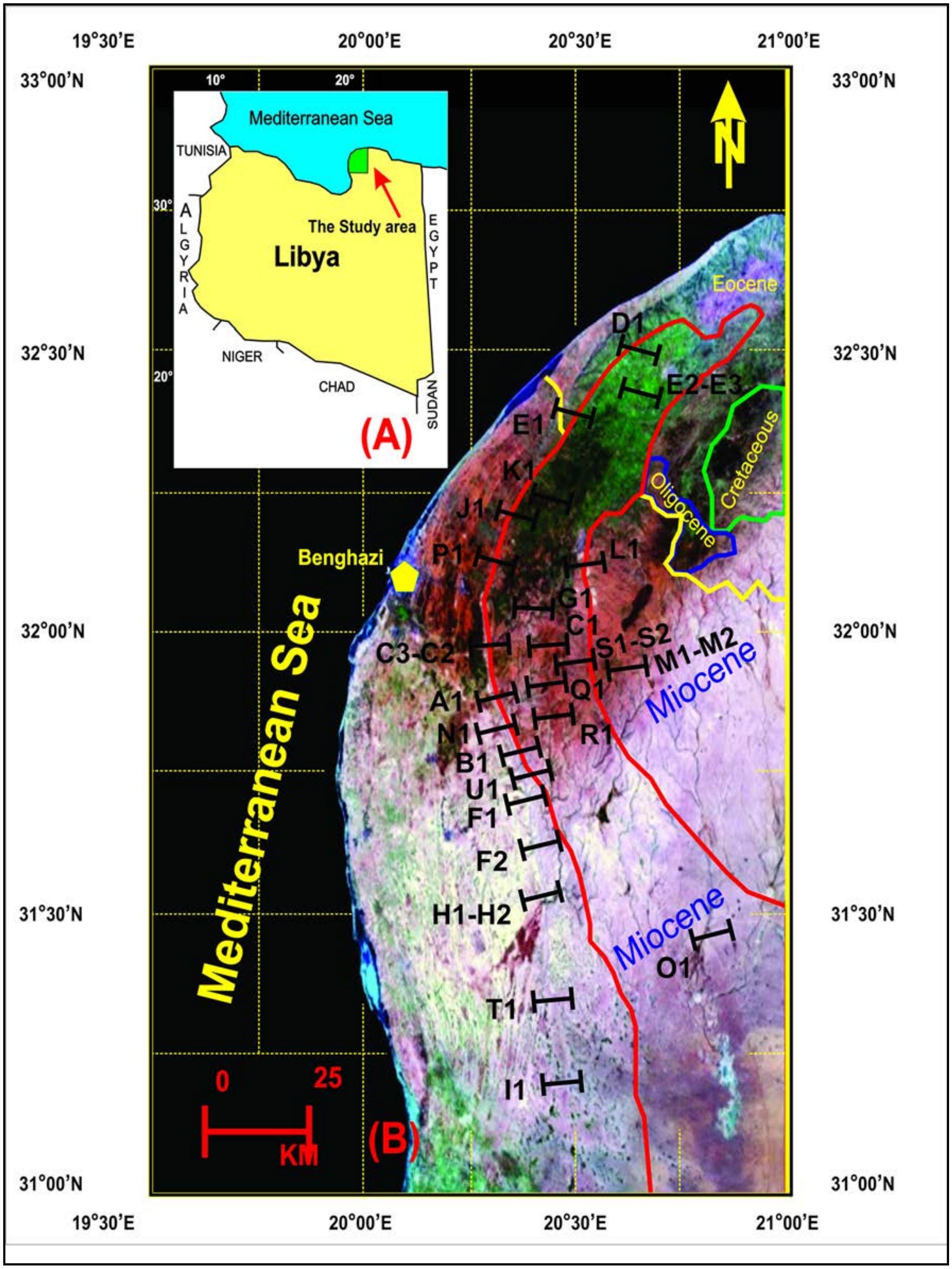

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Figure 2

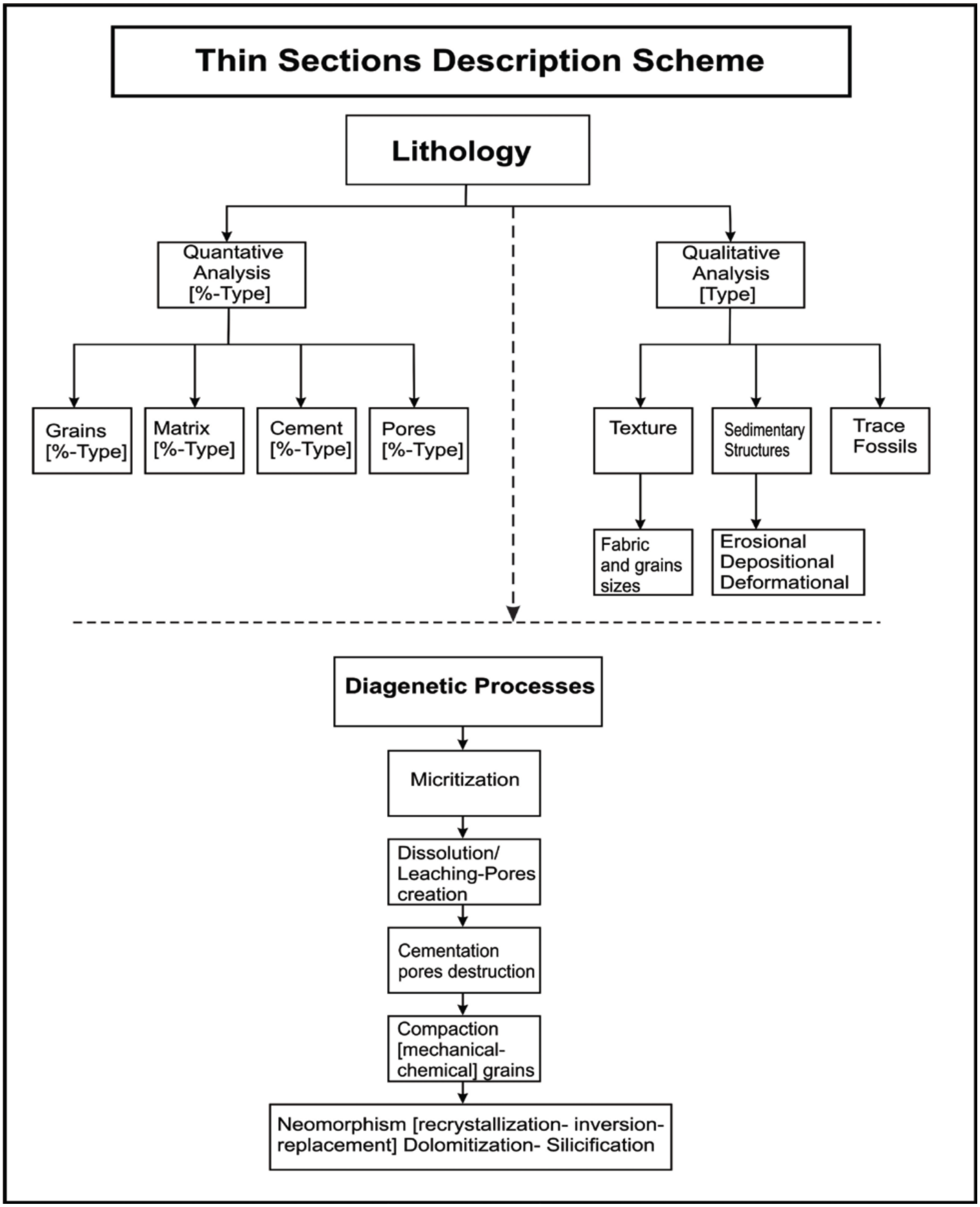

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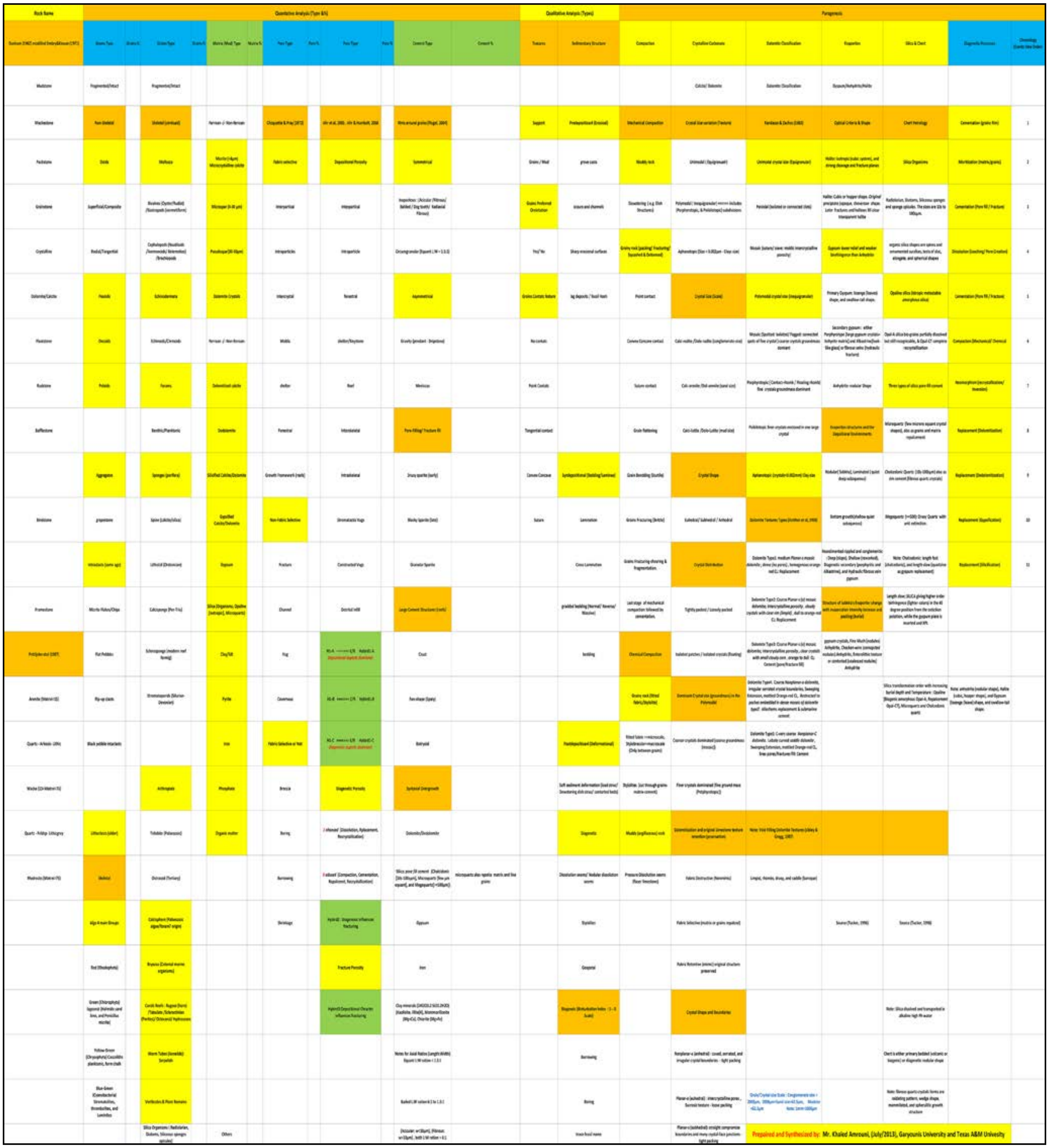
Figure 3



Prepaired and Synthesized by: Mr. Khaled Amrouni, (July/2013), Garyounis University and Texas A&M University

Figure 4

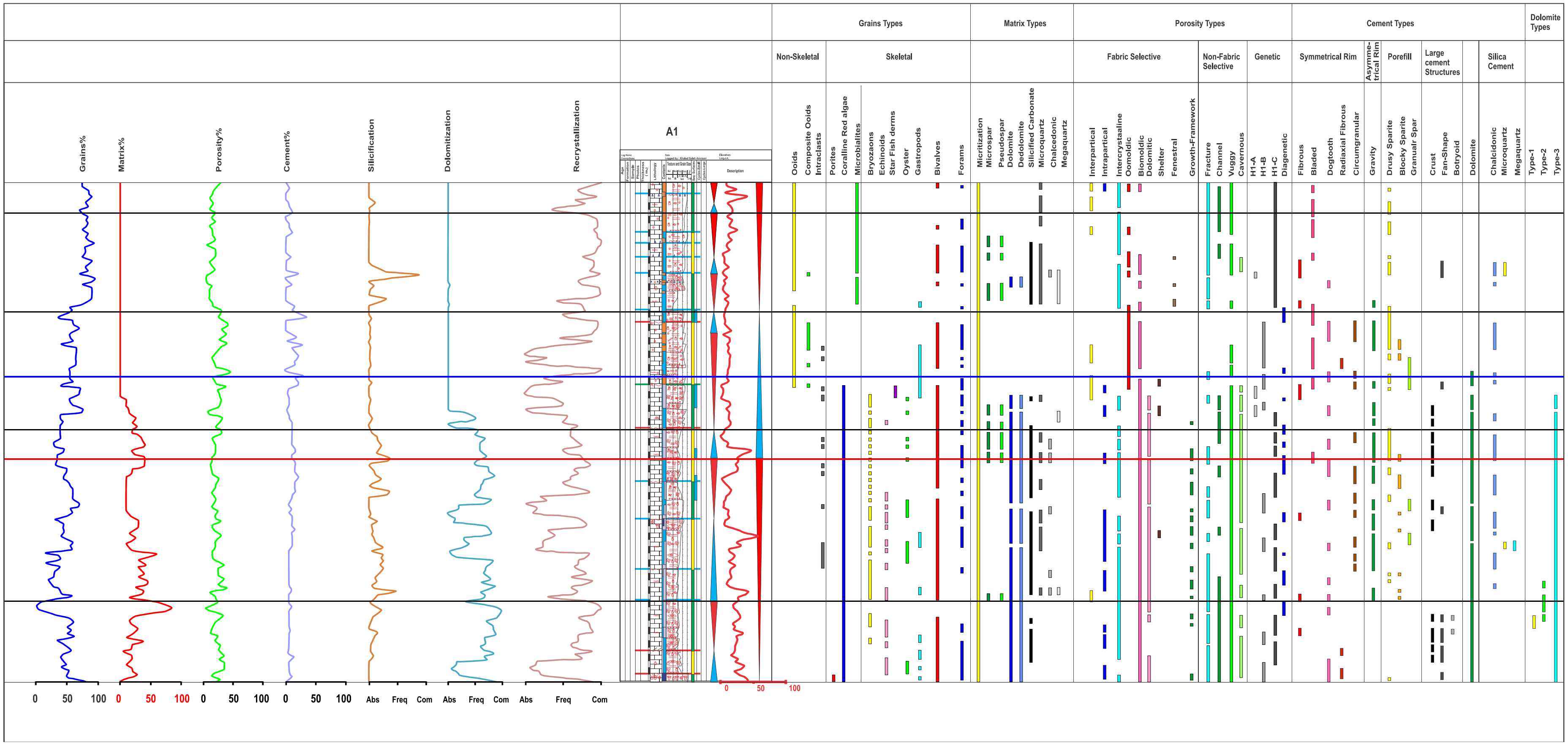


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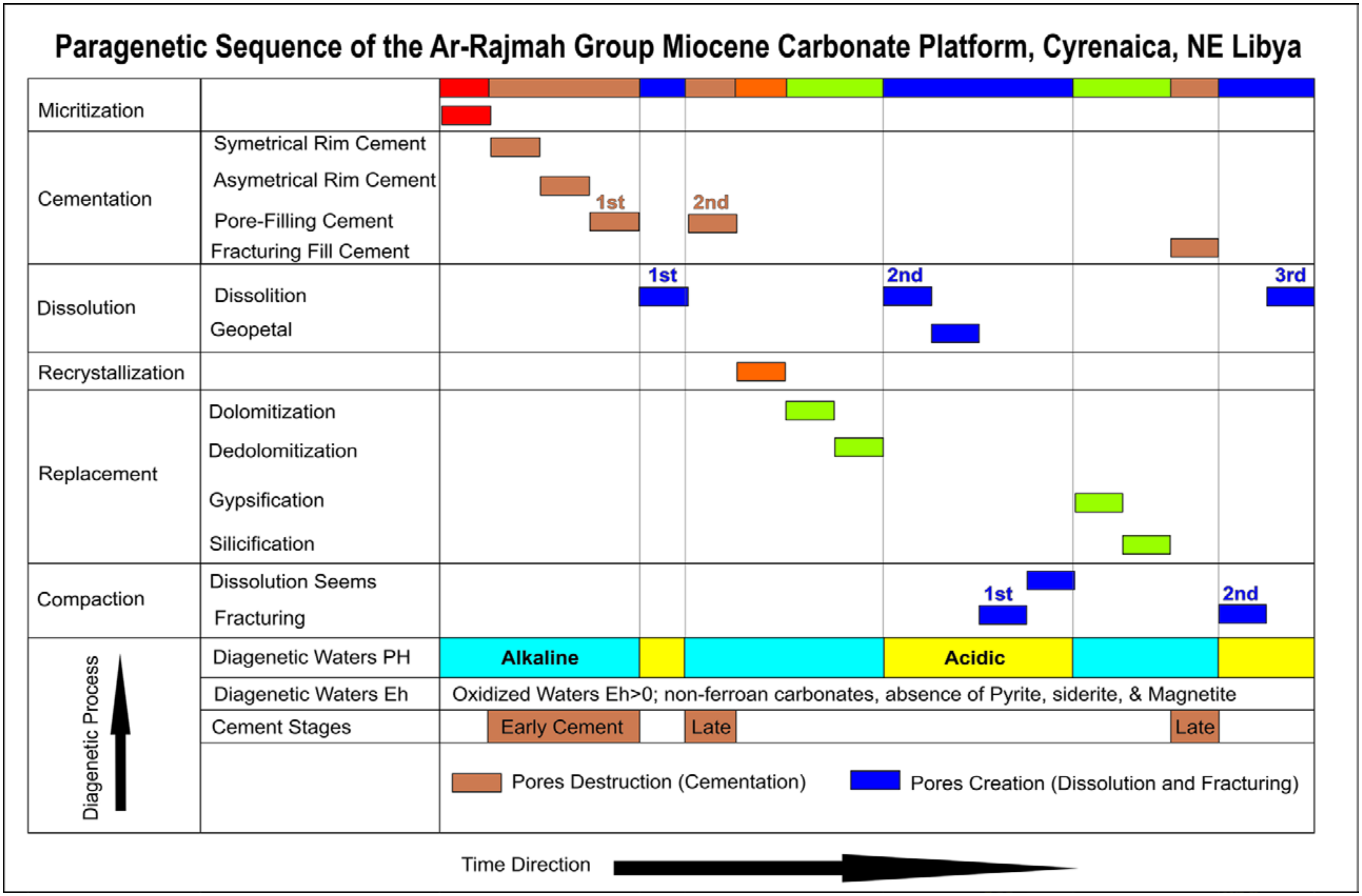
Figure 5



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