Geochemical Analysis of the Carbonate-Evaporite Miocene Outcrops in the Cyrenaica Region of Libya: Cyrenaica Platform and Sirt Basin

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ABSTRACT

This geochemical study investigates the dominant Miocene paleoclimate, weathering and hinterland rocks nature in the Cyrenaica region of Libya as well as the oxygen level of the Miocene Tethys Ocean in which the Cyrenaican carbonate-evaporite sequences were deposited. Sixty seven detailed measured stratigraphic field sections along 500 km were used to define the Cyrenaican Miocene detailed facies relationships and their sequence stratigraphic context. The studied shallow marine Miocene carbonate rocks in Cyrenaica include the Ar-Rajmah Group in Cyrenaica and the Wadi Yunis members in Sirt Basin. The Cyrenaican Miocene facies consists of red algal reefs, bioclastic packstones, bioclastic wackestones, oolitic grainstones, and microbialites that are associated with coarsely crystalline selenite gypsum and siliciclastics tongues of green shale and sandstone. The red algae reefal facies is restricted to the Cyrenaican Platform.

A total of 543 rock samples were collected for X–ray fluorescence (XRF) analysis from five selected measured sections. The XRF data include 8 major elements (Ca, Mg, Si, Al, Fe, Ti, K, and Cl) and 11 trace elements (Rb, Ba, Sr, Cu, Zn, Cr, V, Zr, Nb, Th, and U). The XRF geochemical analysis of the Miocene carbonate-evaporite rocks of Cyrenaica reveals important and fundamental relationships between these major and trace elements.

The concentration of the continental element Al shows positive correlations with Si, Ti, Fe, Rb, Ba, K, Cu, Zn, Cr, and V and confirms the source of these elements are aluminosilicates that were chemically weathered and transported from the hinterland through rivers to the Miocene Tethys Ocean. The K_2O/Al_2O_3 ratio (0.03 to 0.9) indicates that clay minerals and feldspars are the source of the Al. This chemical weathering processes requires a humid climate to occur.

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The Ca vs. Si plot shows a reverse relationship, confirming that these two elements came from different sources: marine for the Ca and continental for the Si. Ca is positively correlated with the Sr and Mg, indicating the marine origin of the Ca. The carbonate minerals are the sole carrier of the Mg and Sr elements. The Mg/Ca ratio (0.01 to 0.4) shows that calcite and dolomite are the dominant carbonate minerals in the Cyrenaican Miocene rocks.

The wide range of Ti/Zr ratio (3.3 to 132.9) indicates that these deposits are chemically mature. The studied sections show dominant low to medium U and authigenic U concentrations as well as dominant low to medium U/Th, Cu/Zn, and V/Cr ratios, suggesting that these sediments formed under suboxic to oxic conditions.

Major and trace elements in the carbonate-evaporite Miocene rocks of Cyrenaica were very useful tools to explain the paleoclimate, weathering nature, hinterland rocks, and the redox status of the shallow marine depositional basin water. Cyrenaica during the Miocene was humid, chemical weathering was dominant, the hinterland rocks were rich in clay minerals and feldspars, and the Cyrenaican shallow part of the Tethys Ocean water was suboxic to oxic.

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2018 GCAGS-GCSSEPM-Talk-Shreveport, Louisiana, USA

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Session Title: Regional Geological Studies and Depositional Facies Analysis – Session 1 – 6 talks

Session Style: Technical-Talk

Session Date: Monday-October,1st, 2017- Morning Session

Session Location: (Shreveport Convention Center and the Hilton Shreveport)

Measurements & Analysis:

(A) 67 detailed measured stratigraphic sections along 500km

(B) Petrographic Analysis (Thin Sections),

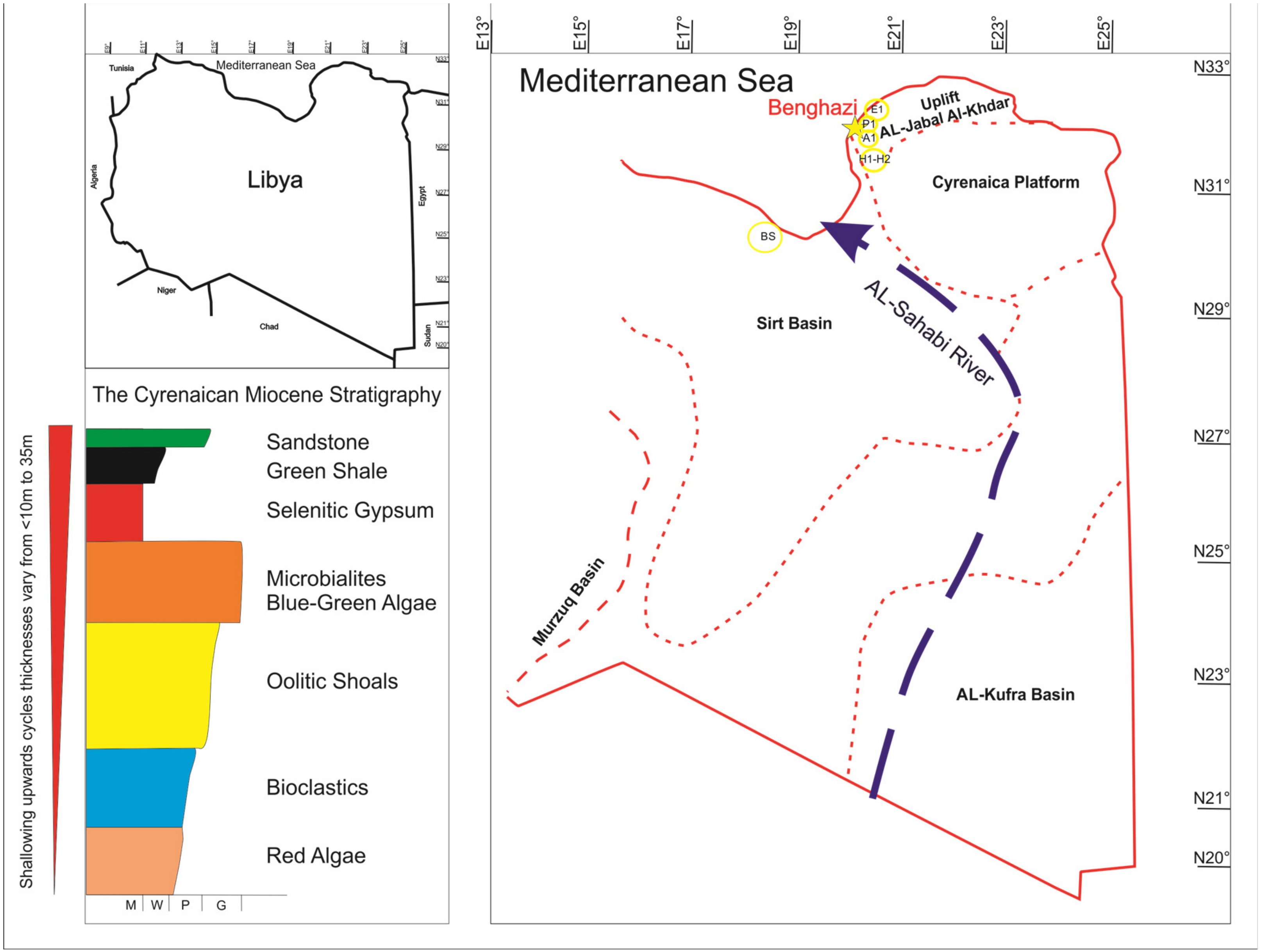
(C) A total of 543 rock samples were collected for XRF analysis from five selected measured section.

(D) The XRF data includes 8 major elements (Ca, Mg, Si, Al, Fe, Ti, K and Cl) and 11 trace elements (Rb, Ba, Sr, Cu, Zn, Cr, V, Zr, Nb, Th and U).

(E) The studied shallow marine Miocene carbonate rocks in Cyrenaica Region include the Ar-Rajmah Group in Cyrenaica and the Wadi Yunis member in Sirt basin.

- **This geochemical study investigates the dominant Miocene paleoclimate, weathering and hinterland rocks nature in Cyrenaica Region as well as the oxygen level of the Miocene Tethys Ocean in which the Cyrenaican carbonate-evaporite sequences were deposited.**

Location maps and shallowing upward cycles in Cyrenaica Region



Sedimentology and Stratigraphy

The studied rocks in Cyrenaica Region are:

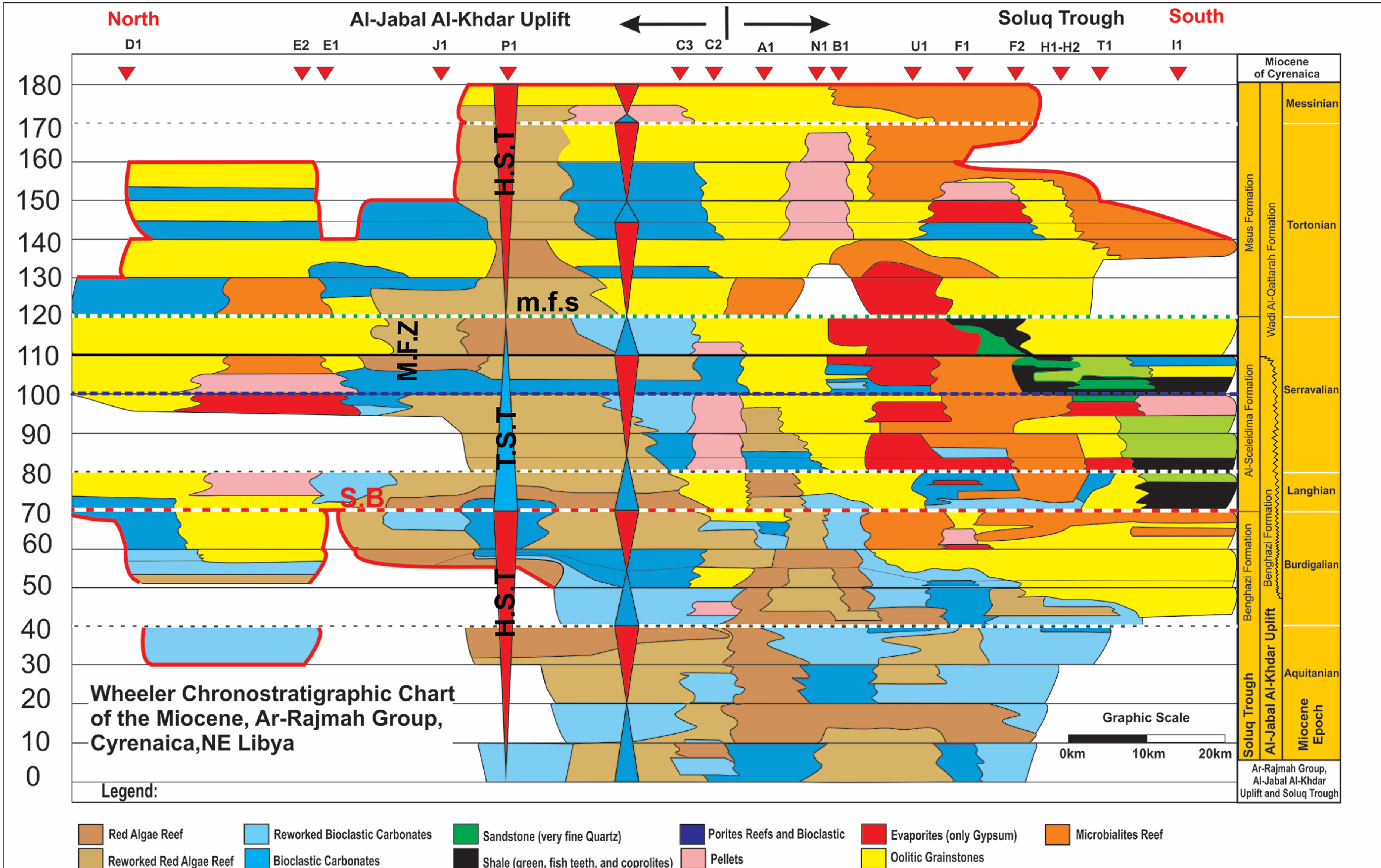
- **The Ar-Rajmah Group in Cyrenaica and the Wadi Yunis members in Sirt basin.**

- **Shallowing upward cycles of shallow marine Miocene carbonate .**

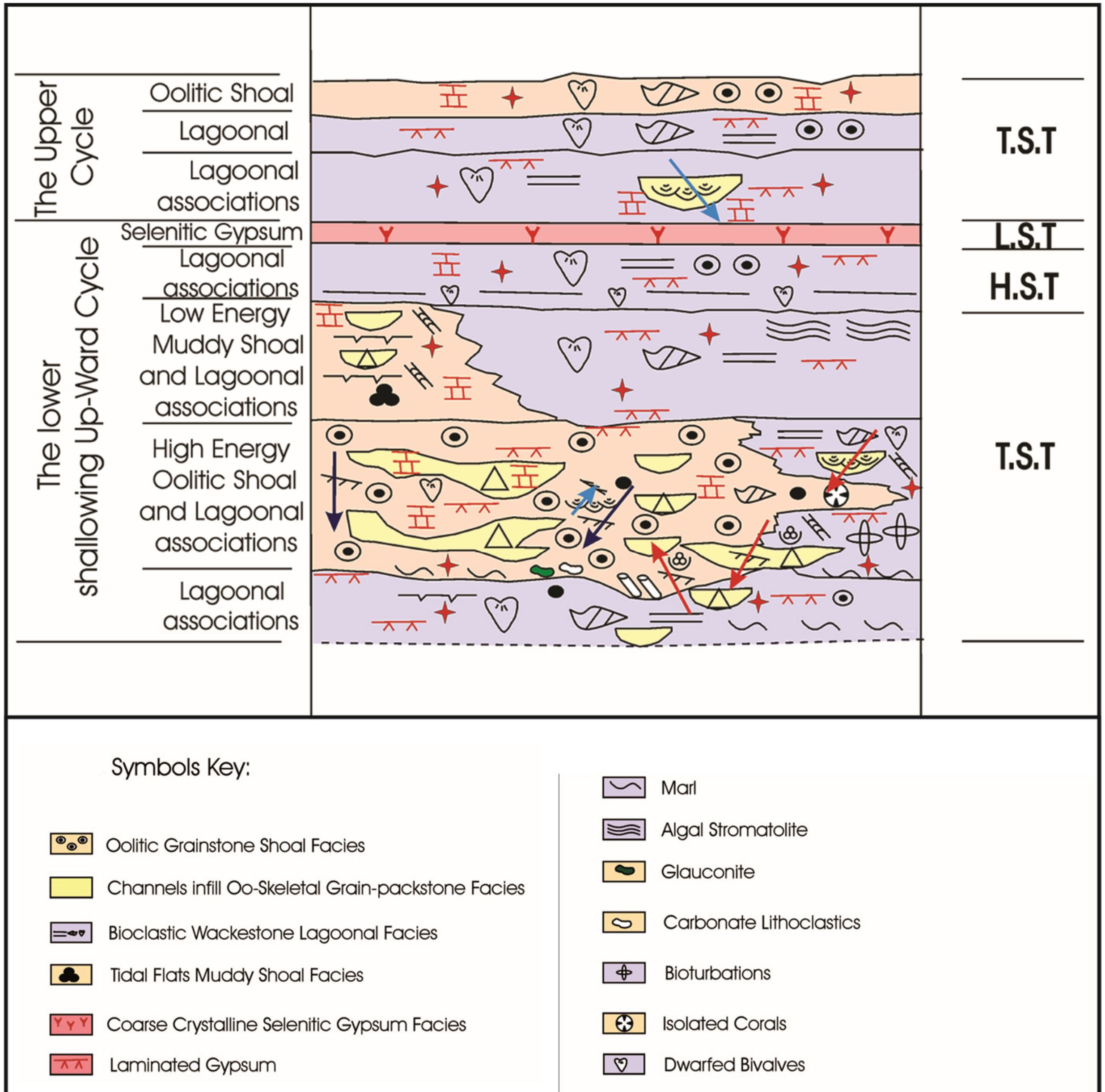
The Cyrenaica Region Miocene depositional facies consists of:

- red algal reefs, bioclastic packstones, bioclastic wackestones, oolitic grainstones, and microbialites that are associated with coarsely crystalline selenite gypsum and siliciclastics tongues of green shale and sandstone.
- The red algae reefal facies is restricted to the Cyrenaican platform.

Stratigraphic correlation of the detailed depositional facies of the Ar-Rajmah Group in the Cyrenaica platform, Cyrenaica Region (Amrouni et al., 2016)



Stratigraphic correlation of the detailed depositional facies of the Wadi Yunis members in Sirt basin, Cyrenaica Region (Amrouni et al., 2016)



XRF geochemical analysis

The studied rocks in Cyrenaica Region

- The 543 samples, collected from stratigraphic sections A1, E1, P1, H1-H2 in Cyrenaica and BS in Sirt Basin at 0.5 m interval, underwent XRF geochemical analysis.

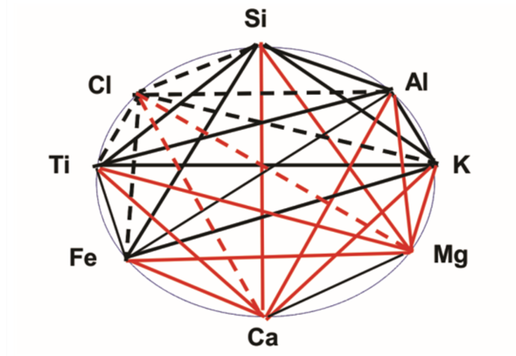
- The carbonate samples were analysed for trace and major elements by using the ED-XRF Niton-XL3t-950-GOLDD+, run at 330 seconds and at four different energy settings and varying filters for detection of up to 40 elements.

- The **8 major elements** (Ca, Mg, Si, Al, Fe, Ti, K and Cl) and 11 trace elements (Rb, Ba, Sr, Cu, Zn, Cr, V, Zr, Nb, Th and U) are implemented in this study to define the Cyrenaicaian Miocene dominant paleoclimate, weathering, hinterland rocks nature, and the oxygen level of the Miocene Tethys Ocean that formed the Cyrenaica Region carbonate-evaporite sequences.

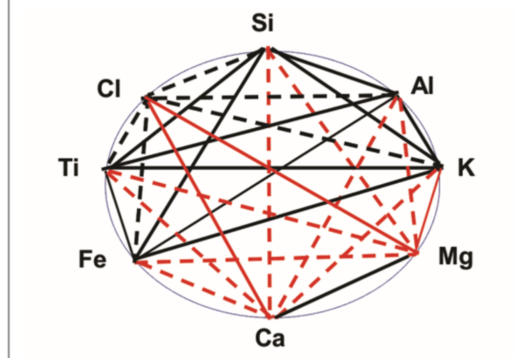
- The vertical log sections' localities were determined by Magellan GPS 310.

Correlations among the major elements in the studied samples of the **Cyrenaica Region** Miocene rocks

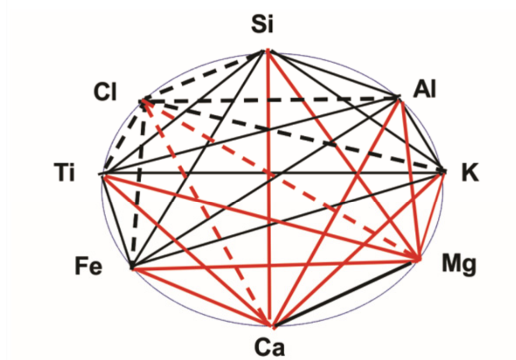
(intensity of lines corresponds to the strength of the correlation coefficient (< 0.4 to > 0.8)) (red line means inverse relation).



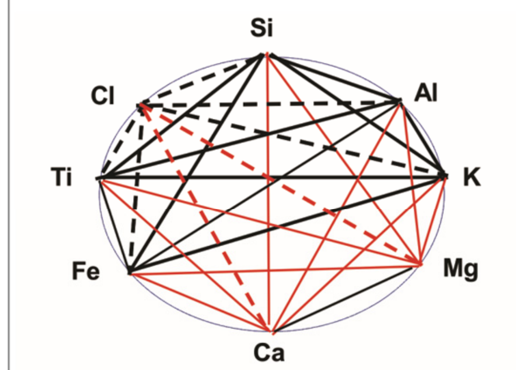
(A) Section A1 Cyrenaica



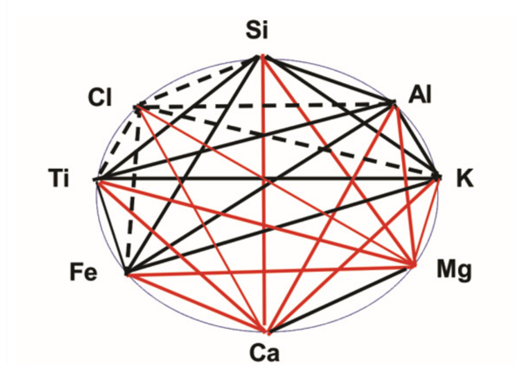
(B) Section BS Sirt Basin



(C) Section E1 Cyrenaica



(D) Section H1-H2 Cyrenaica



(E) Section P1 Cyrenaica

Graphical Presentation of the correlation coefficients among the analyzed major elements in the Cyrenaican carbonate Miocene rocks.

Intensity of lines correspond to the strength of the correlation coefficient (<0.4 to > 0.8). Red lines mean inverse relationship.

Relationships in the studied samples of the Cyrenaica Region Miocene rocks between:

(A) Si and Ca,

(B) Ca and Mg,

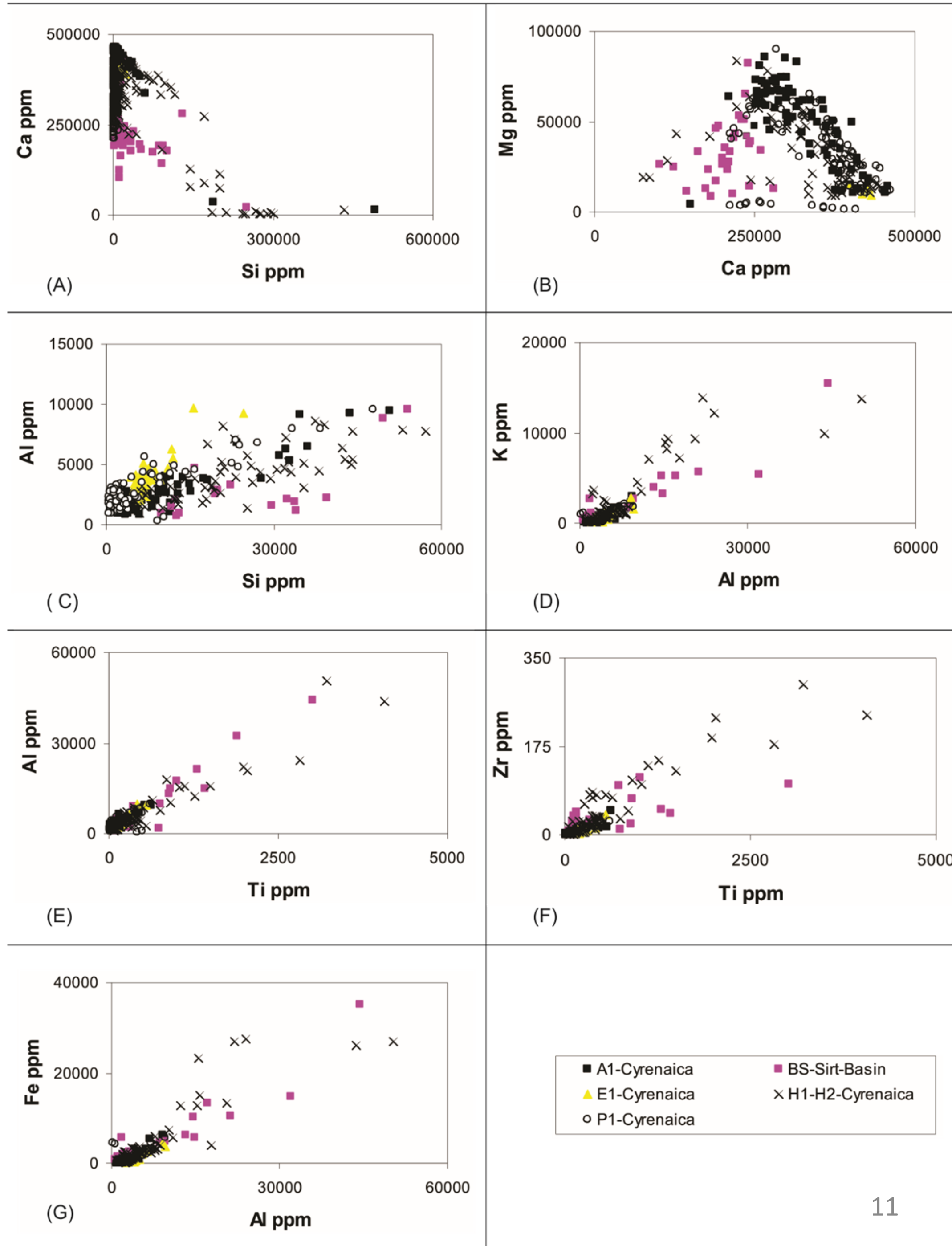
(c) Si and Al,

(D) Al and K,

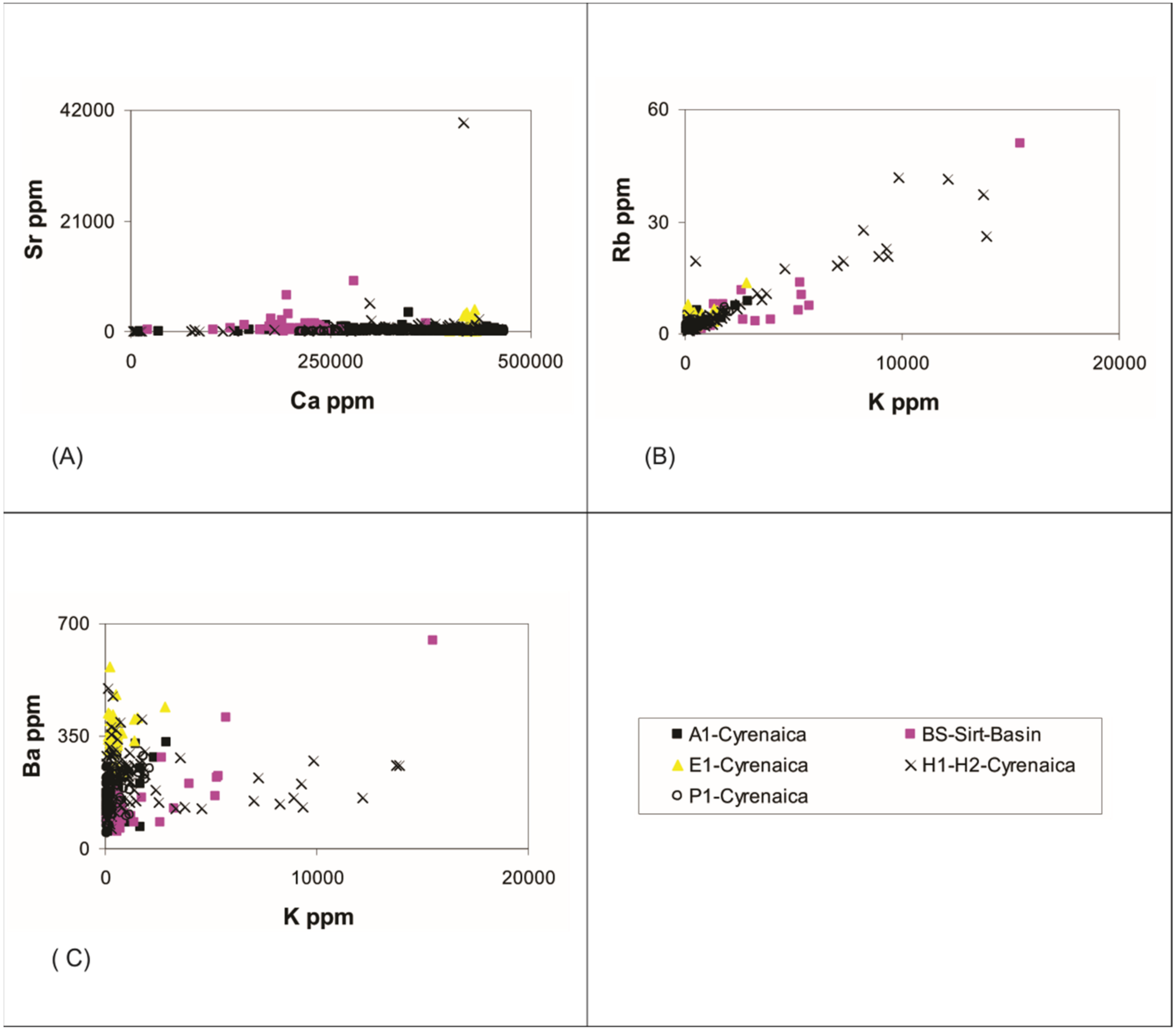
(E) Ti and Al,

(F) Ti and Zr, and

(G) Al and Fe .



Relationships in the studied samples of the Cyrenaica Region Miocene rocks between: (A) Ca and Sr, (B) K and Rb, and (c) K and Ba.



Relationships in the studied samples of the Cyrenaica Region Miocene rocks between:

(A) Al and Cu,

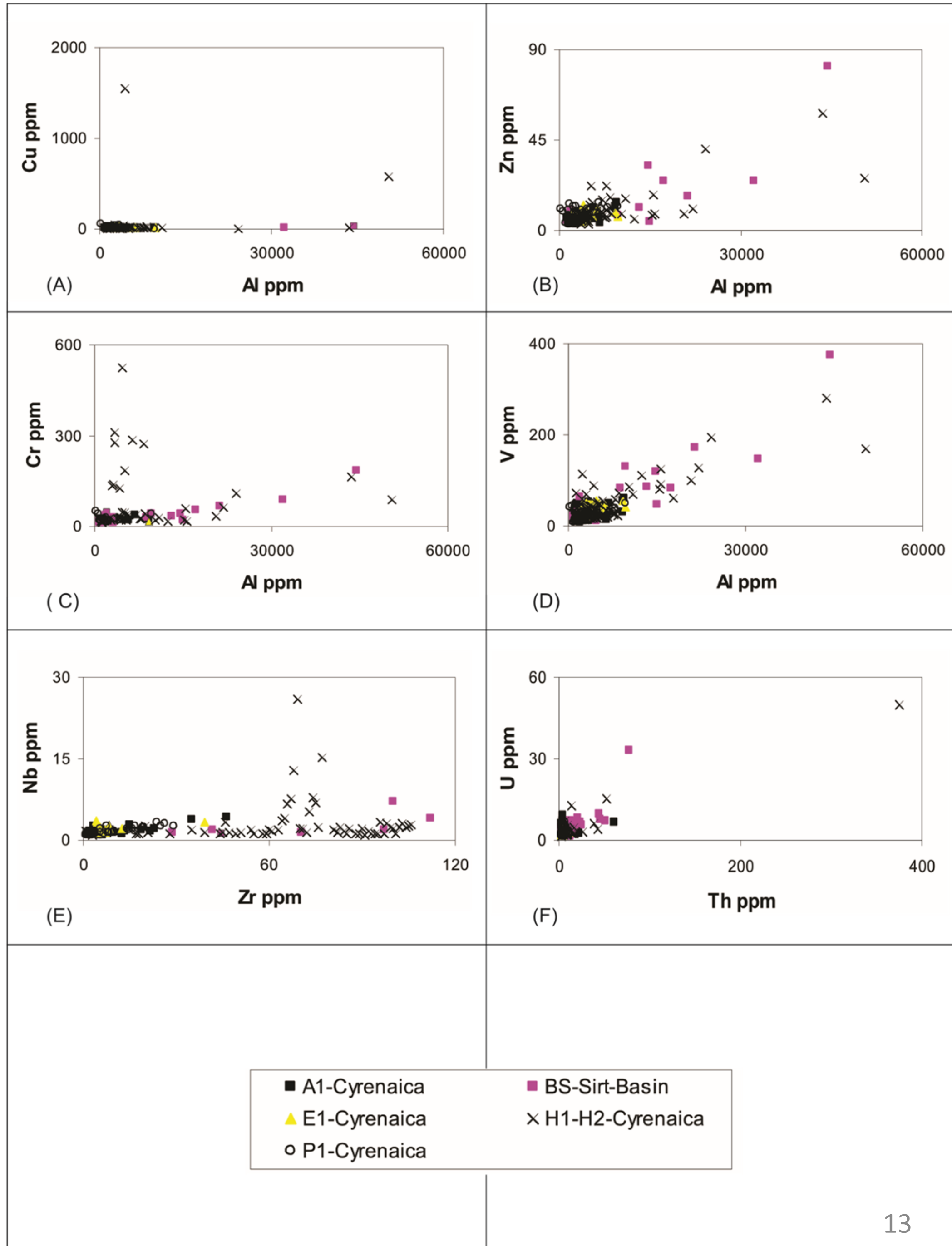
(B) Al and Zn,

(C) Al and Cr,

(D) Al and V,

(E) Zr and Nb, and

(F) Th and U.



XRF Lab Observations: Elements Correlations, Concentrations, and comments

Element	Element	Correlation	% or Ratio	Comment
Ca	Si	(-) Reverse		Different sources: Marine vs Continental.
Ca	Mg	(+) Positive (Except Section A1)		Carbonate minerals the sole carrier of Mg.
Ca	Mg		Mg/Ca (0.01 to 0.4)	Calcite and dolomite dominant carbonate minerals.
Si	Al	Strong (+) positive		Si occurred in silicate and free silicate mode.
Al		Concentration (Except for H1-H2 & BS)	<1.59%	Lower concentrations of Al2O3 than the siliciclastics contaminated carbonates.
K	Al	Strong (+) positive		Bound to alumino-silicate minerals concentrated during weathering processes
K	Al		K2O/Al2O3 % (0.03 to 0.9)%	Clay minerals & feldspars are the source of aluminium
Ti	Al	Strong (+) positive		Ti contained in alumino-silicate
Ti	Zr	(+) positive		Sorting controlled by the depositional environment.
Ti	Zr	Variations wide	Ti/Zr (3.28 to 132.87)	Mature sediments show wide range of variation.
Fe	Al	Strong (+) positive		Fe contained in alumino-silicate
Ca	Sr	Strong (+) positive	Sr high content	Marine origins for the high Sr content
Rb	K	(+) positive		Rb & Ba distribution controlled by alumino-silicates
Ba	K	(+) positive		
Cu, Zn, Cr, V	Al	(+) positive		Accumulate as alumino-silicate during weathering
Cu	Zn	Reduction-Oxidation	Zn/Cu % low	Low = suboxic to oxic conditions
V	Cr	Reduction-Oxidation	V/Cr % Medium	Medium= suboxic to oxic conditions
Zr	Nb	(+) positive	Immobile (not soluble) concentrates in residual materials	Indicates their mutual association as accessory minerals. Indicates their co-existence in stable accessory minerals.
U	Th	(+) positive		
U		Reduction-Oxidation	(1.44 to 54) low to medium	L-M content of U deposits in oxygenated marine environments.
U/Th		Reduction-Oxidation	Below (1.25) low to medium	Low to medium = suboxic to oxic conditions
U authogenic	[U-Th/3]	Reduction-Oxidation	Below (5) low to medium	

Analysis, Integration and Correlation.

Data sets of

sedimentological, stratigraphic, petrographic,

and

Geochemical XRF Major and Trace elements

Results

Facies and depositional sequences

- **1-** The Miocene facies of Cyrenaica Region, Cyrenaican platform and Sirt Basin, is a series of shallowing upward sequences.

- **2-** The vertical facies succession in these shallowing upward sequences starts with red algal reefs and bioclastic packstones, followed by oolitic grainstones, bioclastic wackestones, and microbialites that are associated with coarsely crystalline selenite gypsum and siliciclastics tongues of green shale and sandstone

Geochemical XRF Major and Trace elements

- **1-** The concentration of the continental element Al shows positive correlations with the Si, Ti, Fe, Rb, Ba, K, Cu, Zn, Cr, and V and confirms the source of these elements are alumino-silicates that were chemically weathered and transported from the hinterland through rivers to the Miocene Tethys Ocean.

Results

Geochemical XRF Major and Trace elements

- 2- The K_2O/Al_2O_3 % (0.03 to 0.9) indicates that clay minerals and feldspars are the source of the aluminium. This chemical weathering processes requires a humid climate to occur.
- **3-** The Ca vs. Si plot shows a reverse relationship, confirming that these two elements came from different sources: marine for the Ca and continental for the Si.
- 4- Ca is positively correlated with the Sr and Mg, indicating the marine origin of the Ca. The carbonate minerals are the sole carrier of the Mg and Sr elements. The Mg/Ca ratio (0.01 to 0.4) shows that calcite and dolomite are the dominant carbonate minerals in the Cyrenaicaian Miocene rocks.
- 5- The wide range of Ti/Zr ratio (3.28-132.87) indicates that these deposits are chemically mature. The studied sections show dominant low to medium U and authogenic U concentrations as well as dominant low to medium U/Th, Cu/Zn and V/Cr ratios, suggesting that these sediments formed under suboxic to oxic conditions.

Conclusions

- **1-** This sedimentological, stratigraphic, and geochemical multidisciplinary study explains the dominant Miocene paleoclimate, weathering and hinterland rocks nature in Cyrenaica Region as well as the oxygen level of the Miocene Tethys Ocean that formed the Cyrenaican carbonate-evaporite sequences.

- 2- The Cyrenaica Region Miocene carbonates of the Cyrenaican platform and Sirt Basin are made up of shallow marine facies deposited in a ramp setting and arranged vertically in repeated shallowing upward sequences. The depositional facies in the Cyrenaican Miocene shallowing upward sequences are red algal reefs, bioclastic packstones, bioclastic wackestones, oolitic grainstones, and microbialites that are associated with coarsely crystalline selenite gypsum and siliciclastics tongues of green shale and sandstone.

- **3-** The XRF geochemical analysis of the Miocene carbonate-evaporite rocks of Cyrenaica Region disclosed significant and essential relationships between 8 major elements (Ca, Mg, Si, Al, Fe, Ti, K and Cl) and 11 trace elements (Rb, Ba, Sr, Cu, Zn, Cr, V, Zr, Nb, Th and U).

- 4- During the Miocene, the hinterland of Cyrenaica Region was rich in alumino-silicates as indicated by the positive relationship of the continental element Al with the Si, Ti, Fe, Rb, Ba, K, Cu, Zn, Cr, and V. These elements transported during chemical weathering from the source area through rivers to the Miocene Tethys Ocean. Also, the sources of the aluminium were both clay minerals and feldspars as indicated by the K2O/Al2O3 % (0.03 to 0.9). In addition, the chemical maturity of the weathered sediments was indicated by the wide range of Ti/Zr ratio (3.28-132.87).

Conclusions

➢**5-** A humid climate was also an essential requirement for the sediments chemical maturity and for the chemical weathering processes to take place. During the deposition of the Cyrenaica Region Miocene carbonate rocks, the Sahabi Miocene River was active as indicated by the higher detrital flux (Al_2O_3 concentration > 1.59%) in sections BS-Sirt-Basin and H1-H2-Cyrenaica that are in close vicinity to the mouth area (near Ajdabiya city) of the AL-Sahabi Miocene River.

➢ 6- The Miocene carbonate rocks in Cyrenaica Region are of marine origin as indicated by the positive relationship of the Ca with the Sr and Mg. Calcite and dolomite are the dominant carbonate minerals in the Cyrenaican Miocene rocks as indicated by the Mg/Ca ratio (0.01 to 0.4). However, the two elements Ca and Si came from different sources, marine for the Ca and continental for the Si as suggested by the opposite relationship between them.

➢7- The shallow marine water of the Cyrenaican Tethys Ocean was suboxic to oxic as indicated by the redox parameters in the studied sediments. The concentrations of U and authogenic U were dominantly low to medium as well as the U/Th, Cu/Zn and V/Cr ratios.

➢ 8- XRF major and trace elements analysis in the carbonate-evaporite Miocene rocks of Cyrenaica Region were very useful tools. In combination with the sedimentological analysis they explicated the paleoclimate, weathering nature, hinterland rocks, and the redox status of the shallow marine depositional basin water of the Cyrenaican Miocene.

➢9- Cyrenaica Region during the Miocene was humid in climate and dominated by chemical weathering, the Sahabi River was active, the hinterland rocks were rich in alumino-silicates of clay minerals and feldspars, and the Cyrenaican shallow part of the Tethys Ocean water was suboxic to oxic.

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Thanks

Any Questions?!

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