# Characterization of the Eocene-Oligocene Black Shale Deposits for Biogenic Gas Extraction in Beni Suef Area, Egypt

**Zakaria M. Abd-Allah[1]*, Yasser F. Salama[1], Mohamed I. El-Sayed[1], Samar R. Soliman[1]**

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## Abstract

Black shale deposits are widespread in the Eocene-Miocene successions at Beni Suef area in the stable shelf of Egypt. The studied sections are located on both sides of the Nile Valley at Beni Suef City including Maydoum, Qarara, Heiba, Abiayd, Ghaida Al-Sharqia and Homret Shaibun sections. The observed rock units are from older to younger as follow: Qarara, El Fashn, Beni Suef and Maadi formations of Eocene age, Dabaa Formation of Oligocene age and Moghra Formation of Miocene age. Based on the foraminiferal contents, the age of shale deposits at Maydoum section is of Oligocene – Middle Miocene. However, in the studied sections at the Eastern bank of the Nile Valley, the shale deposits are of Middle –Late Eocene age. Moreover, the lithology, facies and the recorded foraminifer's species of the studied shale deposits suggested an open marine, inner to outer shelf depositional environments of water depth not exceed 200 meters and low to moderate oxygenated condition.

The mineralogical composition of the collected shale samples can be easily approached through X-ray Diffraction (XRD) analysis. Twenty-five shale samples were also analyzed for major and trace elements using X-ray Fluorescence Spectroscopy (XRF). Thirty-five shale samples of the Maydoum and Ghaida Al-Sharqia quarries were carried using LECO C230 carbon analyzer to determine the TOC, TC and TS contents. Moreover, twenty shale samples were analyzed for Rock-Eval pyrolysis to determine the quantity, kerogen types, and the expected hydrocarbons.

In the present work, smectite (montmorolonite) and kaolinite are the most abundant clay minerals encounted in the analyzed samples, but chlorite and illite are absent. Therefore, in the studied locations, the abundance of smectite and kaolinite indicated the detrital origin and deposition in open marine environments. The hydrocarbon potentiality of the source rocks can be evaluated by determining the amount of TOC that represented in wt.% of the analyzed samples. The TOC content reached 2.27 wt.%, TC recorded 8.02 wt.% and TS was 1.52 wt.% at El Fashn Formation in Ghaida Al-Sharqia Quarry, and the percentages reached 0.41, 1.59 and 0.82 wt.% for TOC, TC and TS respectively for Oligocene Dabaa Formation in Maydoum Quarry. The percentage difference indicated that Dabaa Formation deposited in warm and oxic environments that lead to oxidize the organic matter. On the other hand, the middle Eocene El Fashn Formation deposited open marine with suboxic environments that lead to a good preservation of the organic matter that has the ability to yield biogenic gas of terrestrial origin as resulted from the Rock-Eval pyrolysis.

Key words: Hydrocarbon potentiality; mineralogy; geochemistry; black shale deposits; Eocene-Oligocene successions; Beni Suef area

## Conclusions

- Abundance of smectite and kaolinite as clay minerals, and positively correlation of $SiO_2$ with $Al_2O_3$ and Zr in the studied locations mean that these silica are terrigenous origin.

- The results of TOC and TS reflected that the Dabaa Formation at Maydoum quarry is poorly organic matter content of 0.36 wt % TOC, and TS recorded 0.58 wt% due to low preservation efficiency in oxic conditions of very shallow marine environment that led to oxidize the organic matter forming black carbon. However the Middle-Upper Eocene El Fashn Formation were deposited in mainly shallow marine environments with mainly suboxic conditions that led to good preservation the organic matter that reached 2.27 wt% TOC and TS equal 1.52 wt%.

- The relationship between OI and HI indicated that the El Fashn Formation has kerogen Type III of terrestrial and detrital origin that deposited in shallow marine environment under mainly suboxic conditions.

- The relationship between HI versus Tmax, and TOC versus PY indicated that the kerogen of analyzed shale samples of El Fashn Formation existed in immature stage with mainly poor generation potential as they are outcrop samples and present at more than 40m depth only below the earth’s surface.

- The results of PY-GC analysis reflected that the black shale samples of El Fashn Formation has the capability to generate mainly natural gas of C1, C2 and C3 [Methane (CH4), Ethane (C2H6) and Propane (C3H8), respectively] if they are retorted at the earth’s surface.

- From a simplified process of anaerobic fermentation, we can extract the biogenic gas of the black shale deposits of the El Fashn Formation at the study area.

## Acknowledgements

This work is based upon work supported by Science, Technology & Innovation Funding Authority (STDF) under younger research grant (no. 25665) funded for Dr. Zakaria Abd-Allah (PI). Deep thanks are extended also to the StratoChem Services Company, Faculty of Postgraduate Studies, Beni-Suef University and National Research Center, Egypt for analyzing the shale samples.

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- **Lithostratigraphy**
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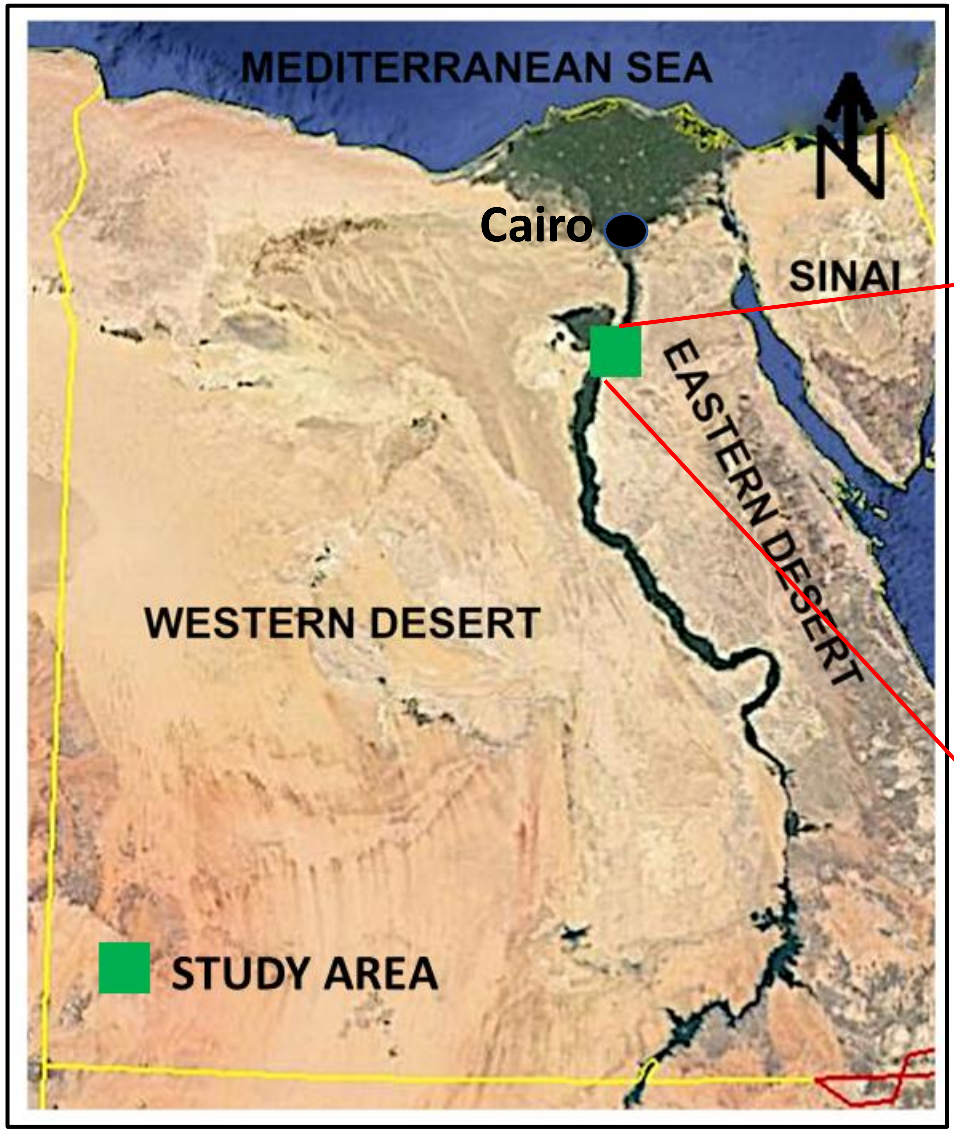
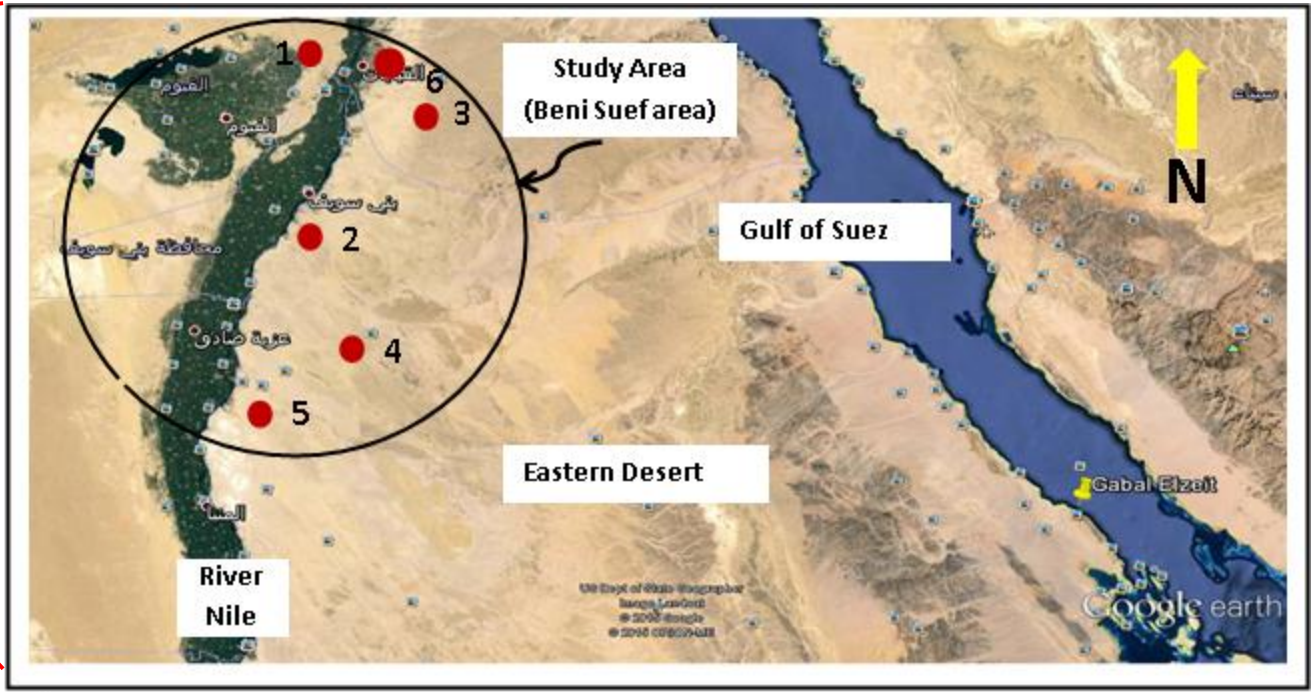
# Study Area

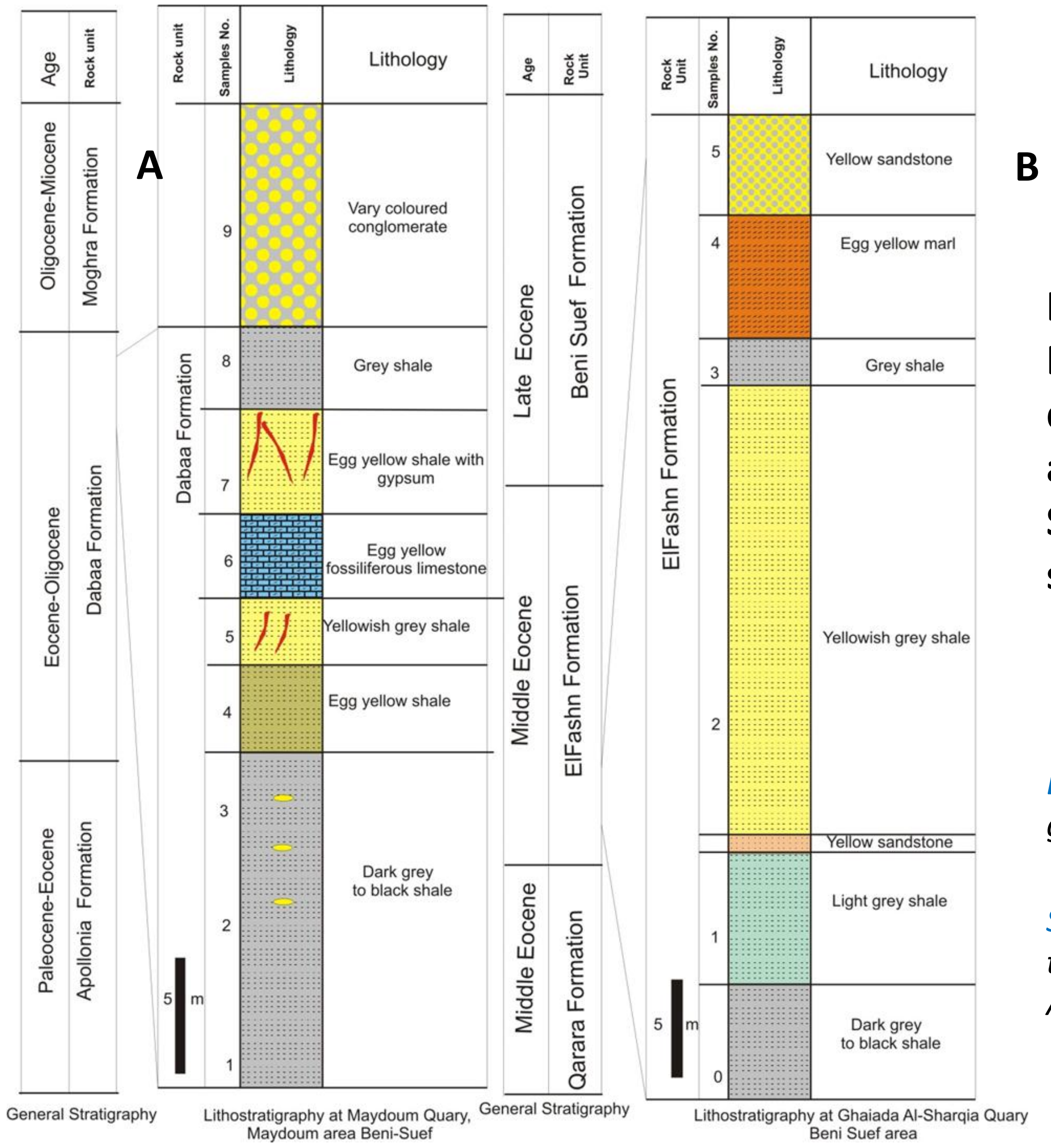



Satellite image of the study area (Beni Suef area with green square), Egypt.




Satellite image focused on the studied locations at Beni Suef area, Egypt

# Lithostratigraphy




**Lithostaratigraphy of the shale deposits in two quarries at Beni Suef area. A) the lithostratigraphic section in Maydoum quarry at West Beni Suef area; the generalized Stratigraphy after (EGPC 1992). B) lithostratigraphic section in Ghaida Al-Sharqia quarry at East Beni Suef area; the generalized stratigraphy after (Saber and Salama 2017).**

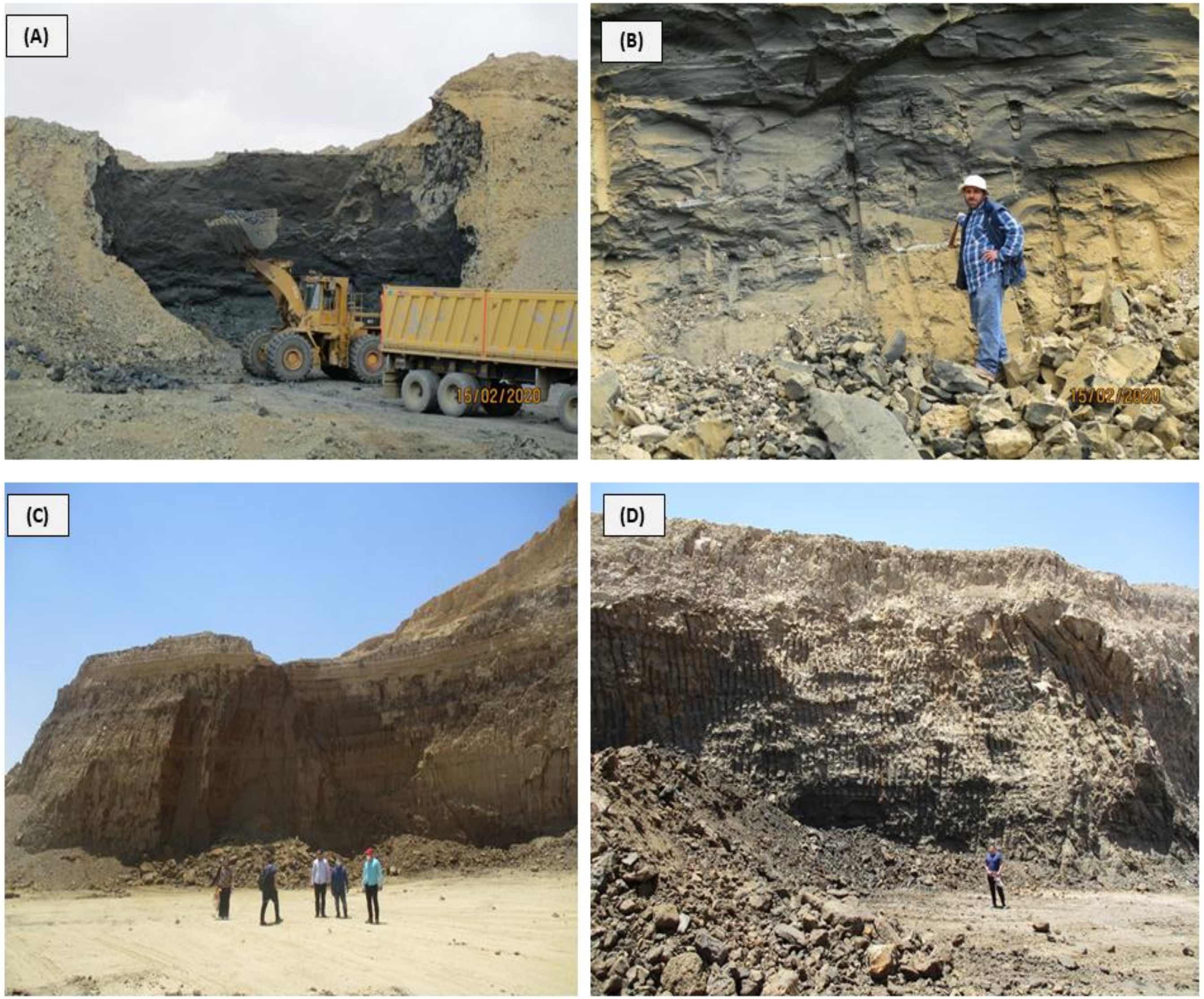
*EGPC (Egyptian General Petroleum Corporation), 1992. Western Desert, oil and gas fields (a comprehensive overview). EGPC, Cairo, Egypt, 431 P.*

*Saber, S. G., and Salama, Y.F., 2017. Facies analysis and sequence stratigraphy of the Eocene successions, east Beni Suef area, eastern Desert, Egypt. Journal of African Earth Sciences. 135, 173-185.*

# Aim of the work

- Determine the lateral distribution and vertical thickness of the black shale deposits in the study area.
- Collect representative rock samples of the studied locations.
- Doing XRD analysis to determine the mineralogical composition.
- Doing XRF analysis to determine the major and trace elements.
- Doing TOC and TS to determine the organic carbon richness, and conditions of the deposition environments.
- Doing Rock-Eval Pyrolysis analysis to determine the quantity of the organic matter, types of kerogen and maturity levels.
- Doing Pyrolysis-Gas Chromatography (PY-GC) analysis to determine the type of organic groups  (expected hydrocarbons yield) of the analyzed shale samples.

# Sampling and Analytical Methods




## 1- Sampling

**Field photos of Beni Suef area showing: (A) and (B) refer to quarry activities of black shale of Dabaa Formation in Maydoum quarry; (C) and (D) refer to black shale of El Fashn Formation in Ghaida Al-Sharqia quarry.**

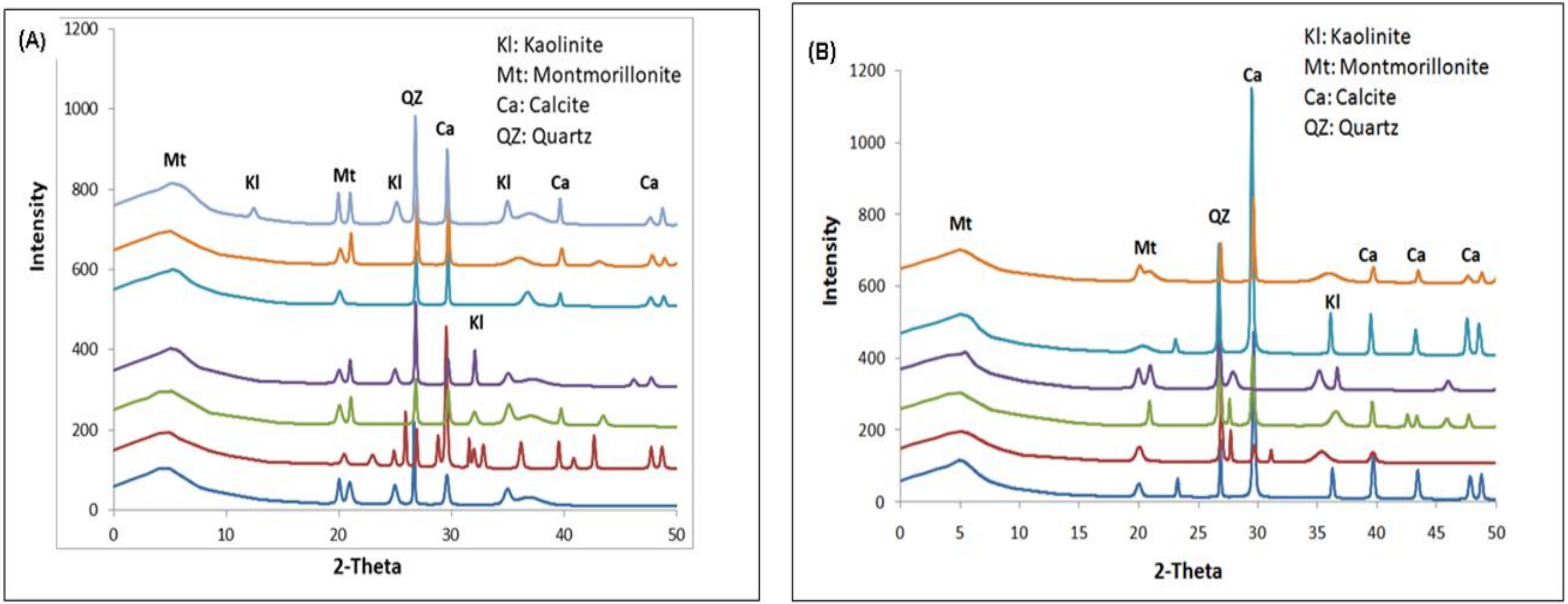
# Sampling and Analytical Methods

## 2- Analytical Methods

- XRD and XRF analyses.
- TOC and TS analyses.
- Rock-Eval Pyrolysis analysis.
- Pyrolysis- Gas Chromatography analysis

# Results and Discussion

- **Mineralogical composition**



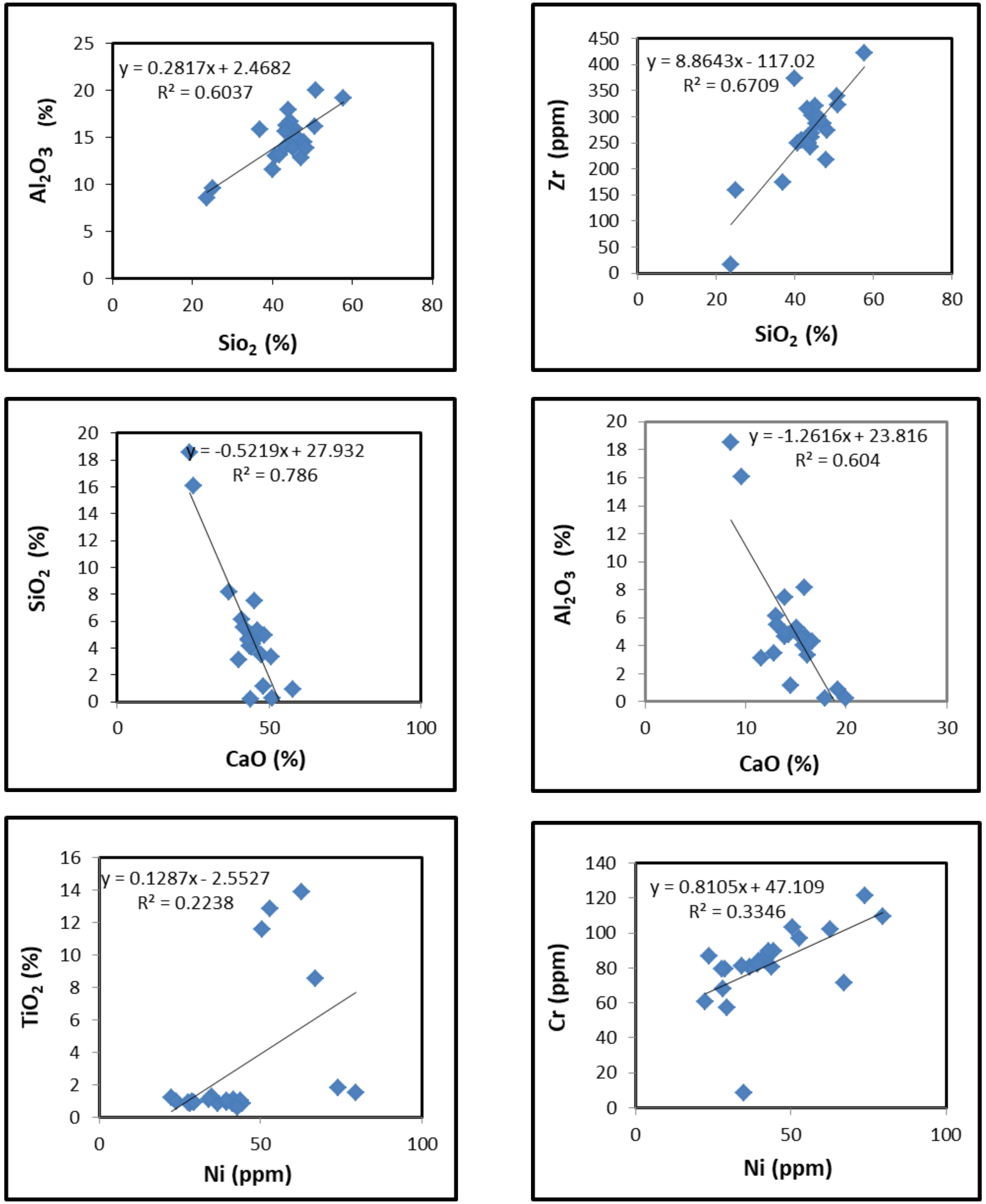

**X-ray diffraction (XRD) patterns for studied sample of Dabaa Formation (A) and El Fashn Formation (B) in the study area.**

# Results and Discussion

- **Major and trace elements**

| Location | Formation Name | Sample No. | $SiO_2$ (%) | $Al_2O_3$ (%) | CaO (%) | MgO (%) | $Fe_2O_3$ (%) | $TiO_2$ (%) | $P_2O_5$ (%) | $K_2O$ (%) | $Na_2O$ (%) | $SO_3$ (%) | Sr ppm | Ba ppm | V ppm | Ni ppm | Cr ppm | Zn ppm | Cu ppm | Zr ppm | Rb ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maydoum Quarry | Dabaa (black shale) | D1 | 45.60 | 15.9 | 4.62 | 1.85 | 7.80 | 0.85 | 0.21 | 1.20 | 2.25 | 1.02 | 250.6 | 111.6 | 93.9 | 41.3 | 85.6 | 123.1 | 10.7 | 287.7 | 55.8 |
| | | D2 | 44.25 | 15.75 | 4.05 | 1.80 | 9.02 | 0.85 | 0.22 | 1.27 | 2.51 | 1.36 | 287.4 | 127.4 | 98.0 | 36.7 | 80.6 | 112.7 | 10.8 | 249.2 | 51.8 |
| | | D2′ | 40.83 | 12.99 | 6.10 | 2.01 | 12.69 | 0.85 | 0.46 | 1.25 | 2.05 | 0.77 | 282.8 | 110.1 | 77.7 | 41.5 | 84.3 | 116.2 | 10.5 | 254.7 | 53.3 |
| | | D3 | 41.77 | 13.13 | 5.52 | 1.45 | 12.76 | 1.09 | 0.21 | 1.48 | 1.97 | 1.46 | 264.3 | 150.8 | 91.7 | 39.6 | 83.9 | 116.6 | 10.2 | 260.4 | 54.6 |
| | | D3′ | 44.19 | 14.31 | 4.81 | 1.78 | 9.19 | 0.93 | 0.23 | 1.30 | 2.16 | 1.23 | 301.6 | 239.7 | 87.2 | 43.8 | 80.3 | 118.5 | 10.5 | 262.0 | 53.7 |
| | | D4 | 43.40 | 13.94 | 4.65 | 1.59 | 10.97 | 1.01 | 0.20 | 1.44 | 2.23 | 1.30 | 280.1 | 149.6 | 91.1 | 42.8 | 89.8 | 189.7 | 9.9 | 302.5 | 50.8 |
| | | D5 | 44.64 | 16.64 | 4.32 | 1.87 | 9.71 | 0.61 | 0.23 | 0.94 | 2.01 | 0.14 | 321.6 | 129.6 | 66.8 | 28.2 | 68.2 | 74.9 | 8.6 | 321.0 | 47.4 |
| | | **Average** | **50.00** | **16.66** | **5.94** | **2.02** | **11.14** | **1.00** | **0.29** | **1.58** | **2.36** | **1.19** | **323.33** | **162.77** | **98.10** | **43.23** | **93.17** | **135.06** | **11.51** | **319.60** | **60.26** |
| Ghaiada Al-Sharqia Quarry | El Fashn (black shale) | E0 | 46.09 | 15.08 | 5.30 | 1.73 | 7.32 | 0.95 | 0.25 | 1.34 | 1.97 | 0.14 | 254.0 | 208.8 | 122.4 | 79.5 | 109.7 | 118.3 | 19.5 | 421.9 | 51.9 |
| | | E1 | 57.84 | 19.19 | 0.90 | 2.18 | 13.74 | 1.51 | 0.28 | 0.95 | 2.00 | 0.19 | 266.5 | 226.6 | 133.6 | 74.0 | 121.5 | 120.3 | 16.4 | 217.0 | 55.8 |
| | | E2 | 48.08 | 14.51 | 1.12 | 1.70 | 13.74 | 1.83 | 0.17 | 1.16 | 1.30 | 0.15 | 209.9 | 209.9 | 92.2 | 52.9 | 97.1 | 108.3 | 12.9 | 286.4 | 50.8 |
| | | E3 | 47.29 | 12.82 | 3.48 | 1.62 | 11.76 | 12.82 | 0.53 | 1.20 | 2.00 | 0.21 | 220.9 | 242.0 | 118.7 | 50.6 | 103.0 | 99.4 | 13.2 | 373.4 | 48.6 |
| | | E4 | 40.01 | 11.59 | 3.14 | 1.52 | 22.76 | 11.59 | 0.24 | 2.28 | 2.47 | 0.12 | 193.3 | 173.5 | 86.1 | 62.6 | 102.3 | 105.5 | 13.5 | 273.2 | 51.2 |
| | | E5 | 48.34 | 13.89 | 4.92 | 1.80 | 13.59 | 13.89 | 0.36 | 1.33 | 1.66 | 0.14 | 16.9 | 277.0 | 64.7 | 67.1 | 71.4 | 96.8 | 13.7 | 16.9 | 2319.7 |
| | | **Average** | **47.94** | **14.51** | **3.14** | **1.75** | **13.81** | **7.09** | **0.30** | **1.37** | **1.9** | **0.15** | **193.5** | **222.9** | **102.9** | **64.45** | **100.83** | **108.1** | **14.86** | **264.8** | **429.66** |

**Major and trace elements results of the shales of Dabaa and El Fashn formations.**




# Results and Discussion

- **Major and trace elements**

**Cross plot of $SiO_2$ with $Al_2O_3$ and Zr, and CaO with $SiO_2$ and $Al_2O_3$, and Ni with Cr and $TiO_2$ for the analyzed samples using XRF analysis (after Temraz, 2005).**

*Temraz, M. G. 2005. Mineralogical and geochemical studies of carbonaceous shale deposits from Egypt. MSc Thesis at Bauingenieurwesen und Angewandte Geowissenschaften der Technischen Universität Berlin, 113P.*

# Results and Discussion

- **TOC, TS and Rock-Eval Pyrolysis results**

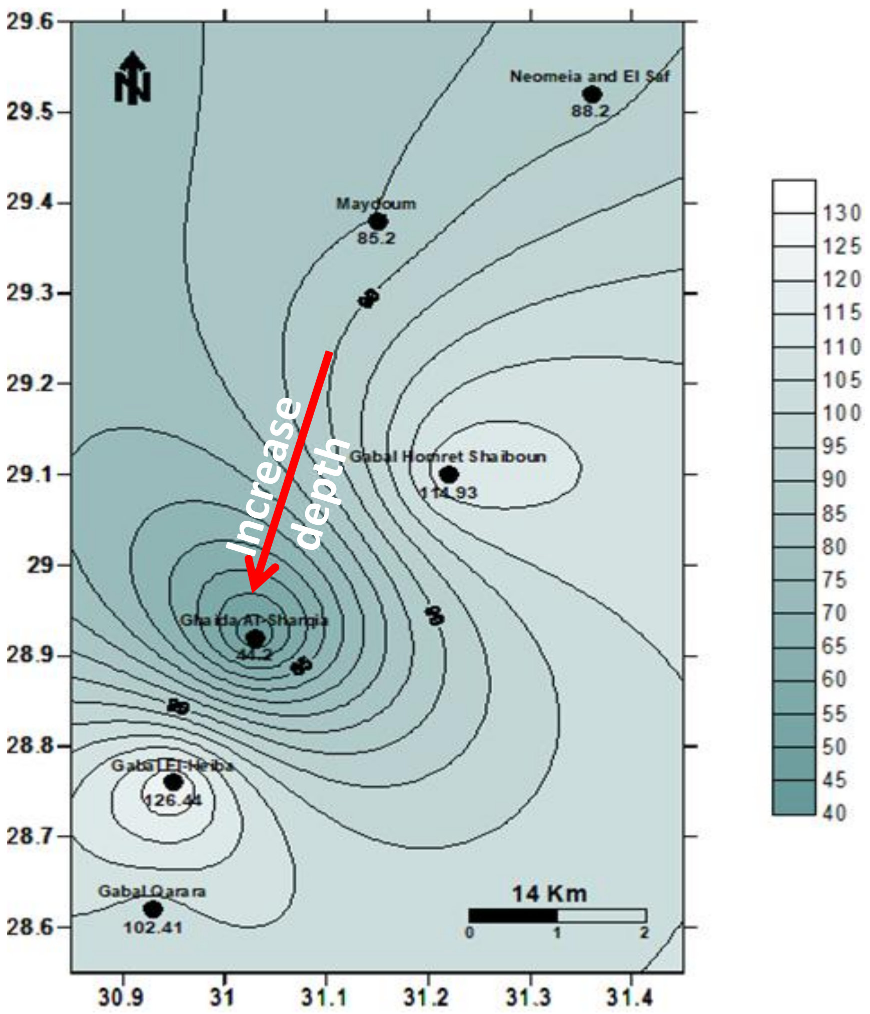
| Location | Formation Name | Sample No. | TOC (wt %) | TS (wt %) | Rock- Eval Pyrolysis results | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | S1 (mg/g) | S2 (mg/g) | S3 (mg/g) | Tmax (°C) | HI (mg/g) | OI (mg/g) | PI | PY (mg/g) |
| **Maydoum Quarry** | Dabaa Fm. (black shale) | D1a | 0.31 | 0.4 | N | N | N | N | N | N | N | N |
| | | D1b | 0.33 | 0.46 | N | N | N | N | N | N | N | N |
| | | D1c | 0.36 | 0.58 | N | N | N | N | N | N | N | N |
| | | D2a | 0.31 | 0.34 | N | N | N | N | N | N | N | N |
| | | D2b | 0.23 | 0.14 | N | N | N | N | N | N | N | N |
| | | D3a | 0.32 | 0.43 | N | N | N | N | N | N | N | N |
| | | D3b | 0.31 | 0.20 | N | N | N | N | N | N | N | N |
| | | D3c | 0.35 | 0.51 | N | N | N | N | N | N | N | N |
| | | D4 | 0.13 | 0.01 | N | N | N | N | N | N | N | N |
| | | D5 | 0.33 | 0.32 | N | N | N | N | N | N | N | N |
| **Ghaiada Al-Sharqia Quarry** | El Fashn Fm. (black shale) | **E0a** | **0.82** | **0.29** | **0.07** | **0.21** | **1.22** | **421** | **26** | **149** | **0.25** | **0.28** |
| | | **E0b** | **0.94** | **0.27** | **0.03** | **0.21** | **1.62** | **428** | **22** | **173** | **0.13** | **0.24** |
| | | **E0c** | **0.99** | **0.30** | **0.10** | **0.29** | **1.02** | **430** | **29** | **103** | **0.26** | **0.39** |
| | | **E0d** | **1.30** | **0.29** | **0.07** | **0.23** | **1.37** | **428** | **18** | **105** | **0.23** | **0.3** |
| | | **E1a** | **0.87** | **0.07** | **0.11** | **0.25** | **1.56** | **425** | **29** | **180** | **0.31** | **0.36** |
| | | **E1b** | **2.27** | **1.52** | **0.20** | **1.03** | **2.90** | **427** | **45** | **128** | **0.16** | **1.23** |
| | | **E1C** | **0.83** | **0.06** | **0.03** | **0.19** | **1.25** | **427** | **23** | **151** | **0.14** | **0.22** |
| | | E2a | 0.15 | 0.04 | N | N | N | N | N | N | N | N |
| | | E2b | 0.13 | 0.11 | N | N | N | N | N | N | N | N |
| | | E3a | 0.12 | 0.03 | N | N | N | N | N | N | N | N |
| | | E4 | 0.18 | 0.06 | N | N | N | N | N | N | N | N |
| | | E5 | 0.10 | 0.05 | N | N | N | N | N | N | N | N |

**Results of TOC & TS and Rock-Eval pyrolysis of the shales of Dabaa and El Fashn formations.**

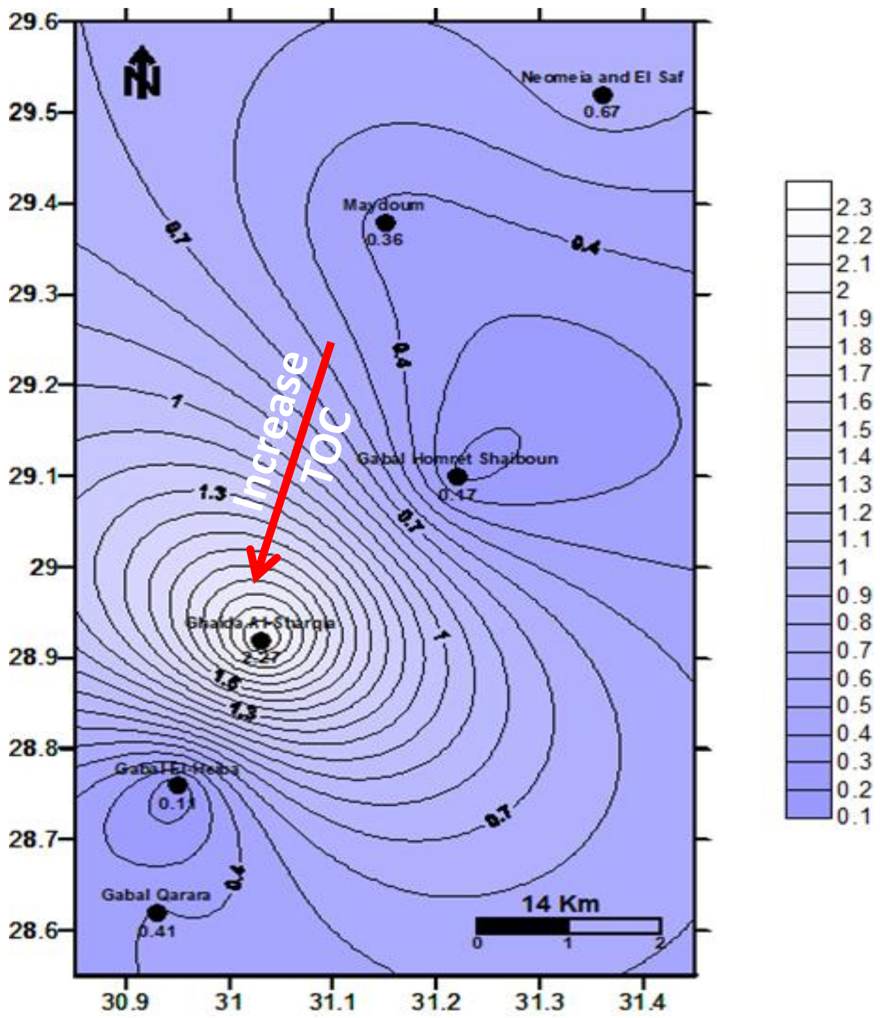
# Results and Discussion

- **Organic Carbon Richness**

(A)

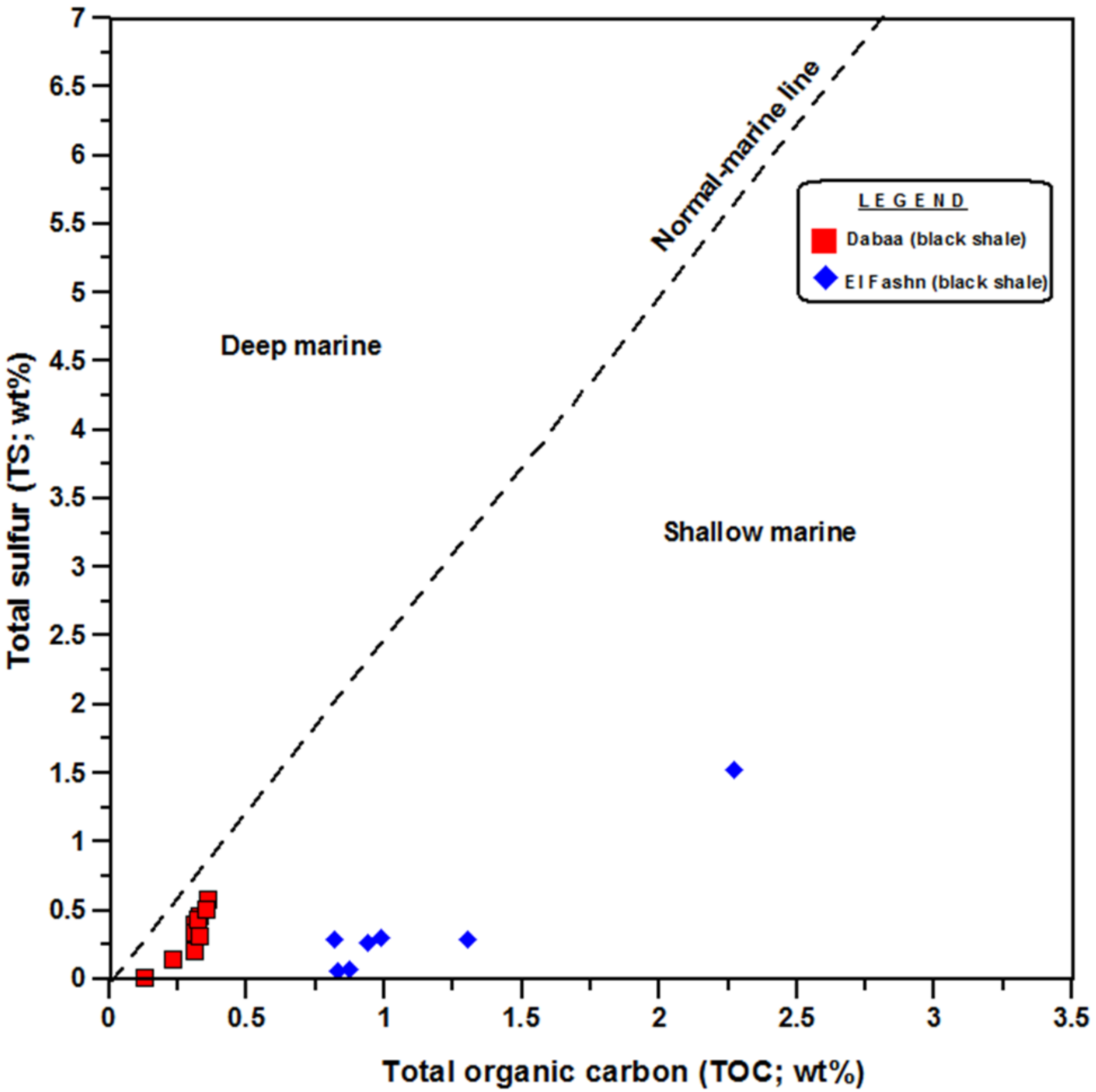



(B)




**Contour maps show the topographic map (A) of the studied areas, and distribution of maximum TOC values (B), in the study area.**

# Results and Discussion




- **Relationship between TOC and TS**

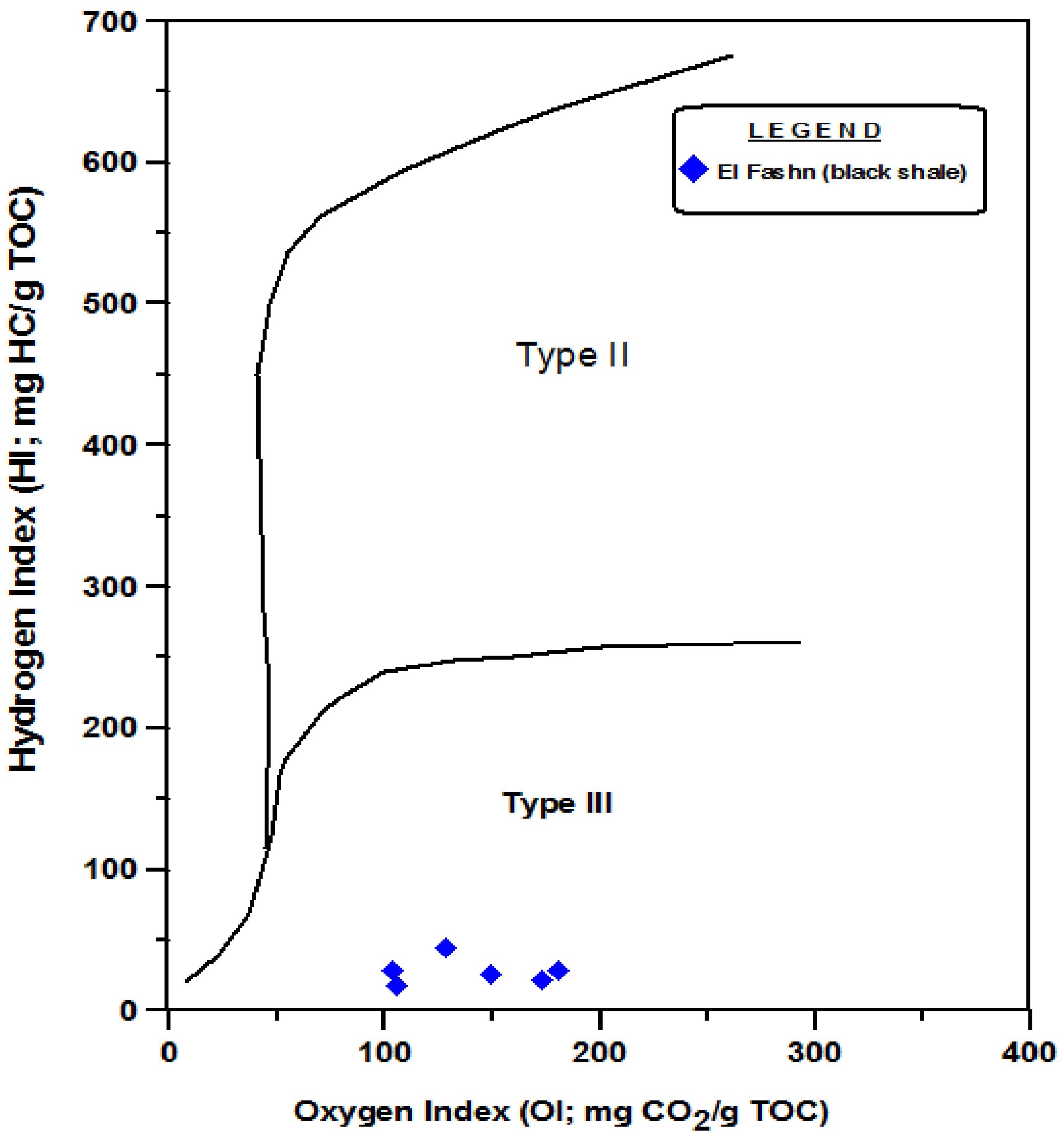
**The relationship between TOC and TS contents, reflecting a shallow marine depositional environment the analyzed shale samples was dominantly a shallow marine for El Fashn Formation and very shallow marine (lacustrine) of Dabaa Formation (modified after Berner & Raiswell1983 and Hakimi et al., 2016).**


*Berner RA, Raiswell R., 1983. Burial of organic carbon and pyrite sulfur in sediments over Phanerozoic time: a new theory. GeochimCosmochimActa., 47, 855-62.*

*Hakimi M. H., Abdullah W. H., AlqudahM., MakeenY. M., Mustapha Kh. A., 2016. Organic geochemical and petrographic characteristics of the oil shales in the Lajjun area, Central Jordan: Origin of organic matter input and preservation conditions. Fuel, 181, 34-45.*

# Results and Discussion

- **Kerogen types and origin of organic matter**



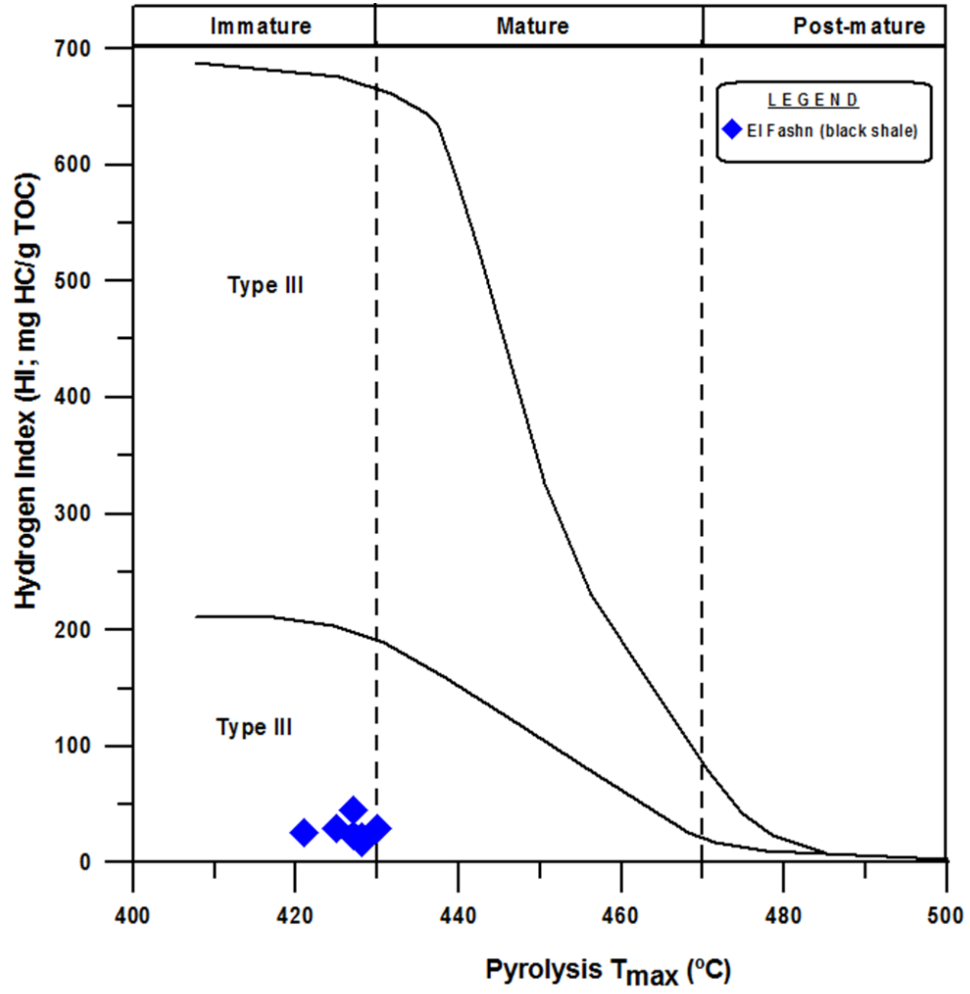

**Relationship between HI and OI, showing the types of organic matter of El Fashn black shale samples (modified after Hunt 1996 and Abd-Allah et al., 2019).**

*Hunt, J.M., 1996. Petroleum Geochemistry and Geology. W. H. Freeman and Company Press, New York. 743p.*

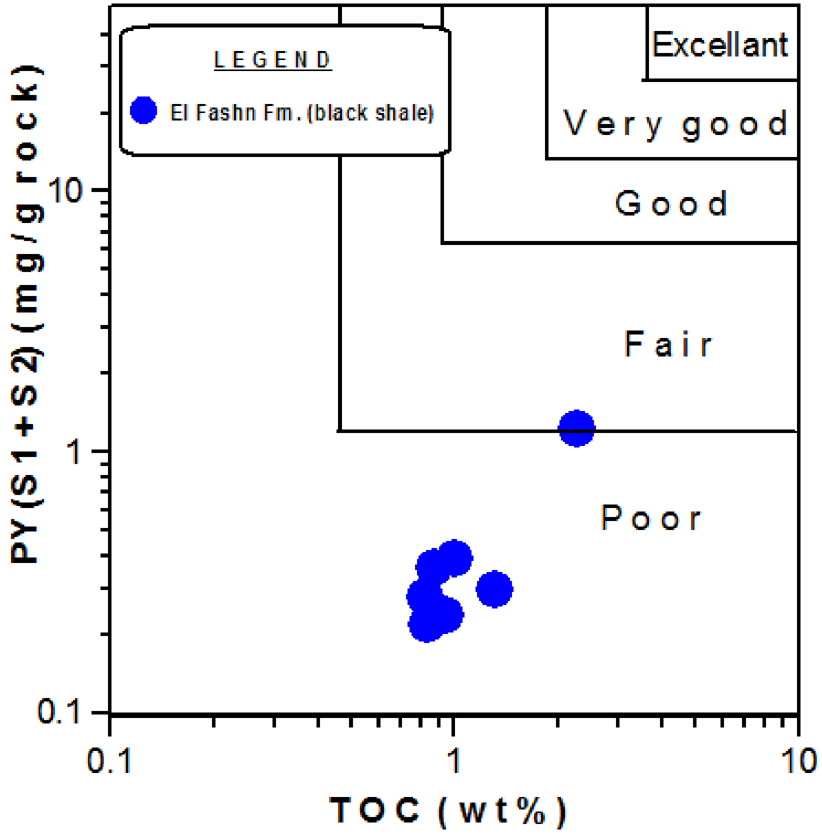
*Abd-Allah, Z.M, Abdullah, W.H. and Abdel-Fattah,M.I,2019. Assessment of Eocene, Paleocene and Cretaceous Source Rocks in the West Feiran area, Offshore Gulf of Suez, Egypt. Journal of Petroleum Science and Engineering,180,756-772.*

# Results and Discussion

- **Thermal maturation and generation potential**



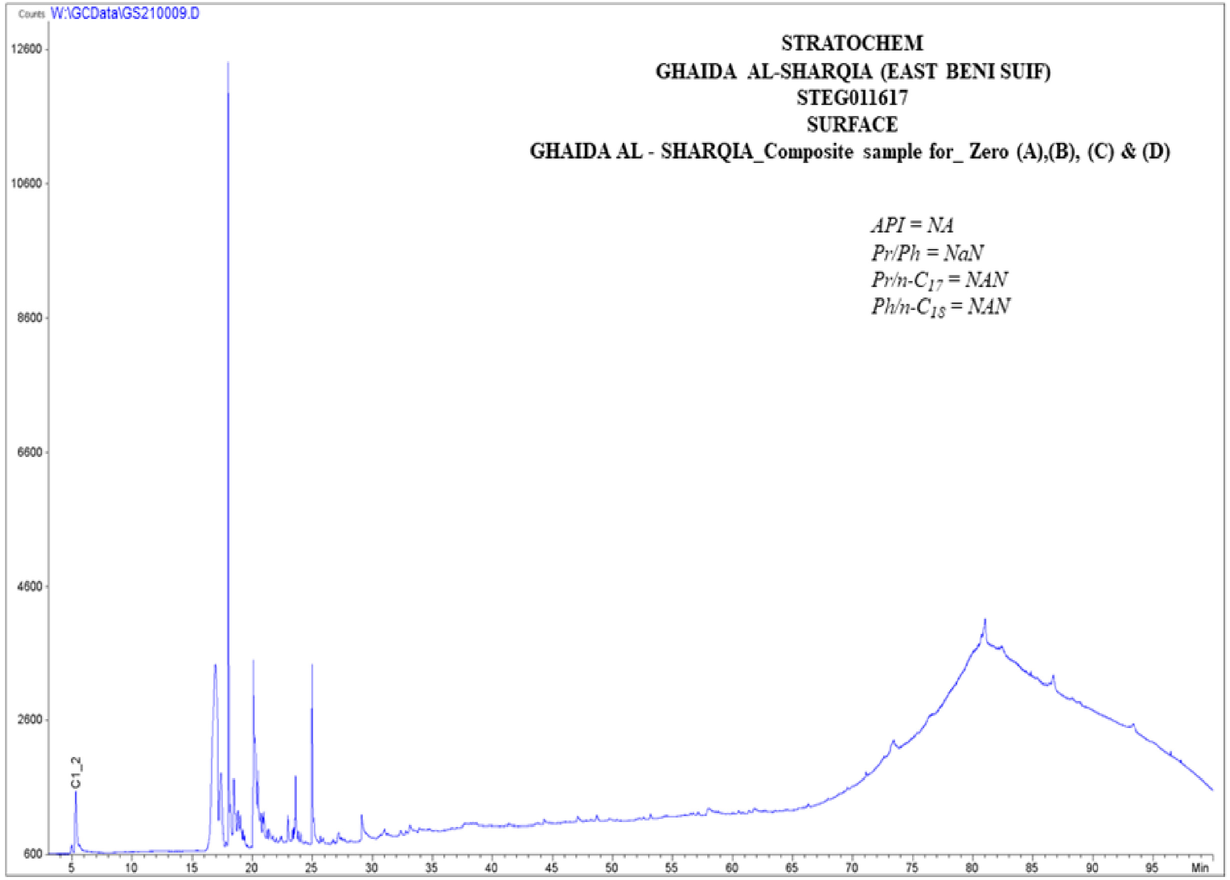

**Plots of Hydrogen Index (HI) versus pyrolysis Tmax, indicating the kerogen quality and maturity level of El Fashn black shale samples (modified after Hunt 1996 and Hakimi et al., 2016)**

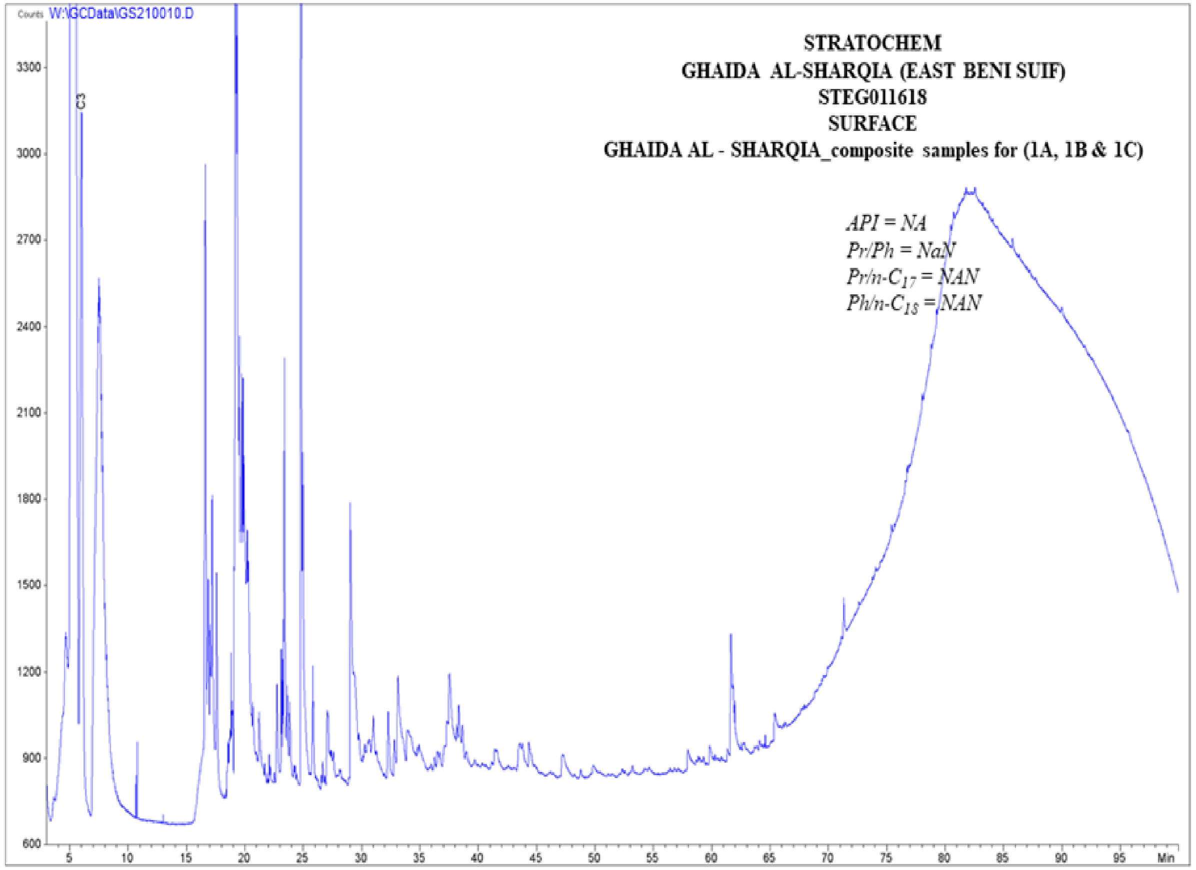



**The relationship between TOC and Potential yield (PY), reflecting mainly poor to fair generation potential of the analyzed shale samples of Beni Suef Fm. at Neomeia & El Saf quarries and El Fashn Fm. at Ghaida Al-Sharqia quarry (modified after Abd-Allah et al., 2019).**

# Results and Discussion

- **Expected Hydrocarbons Yield**

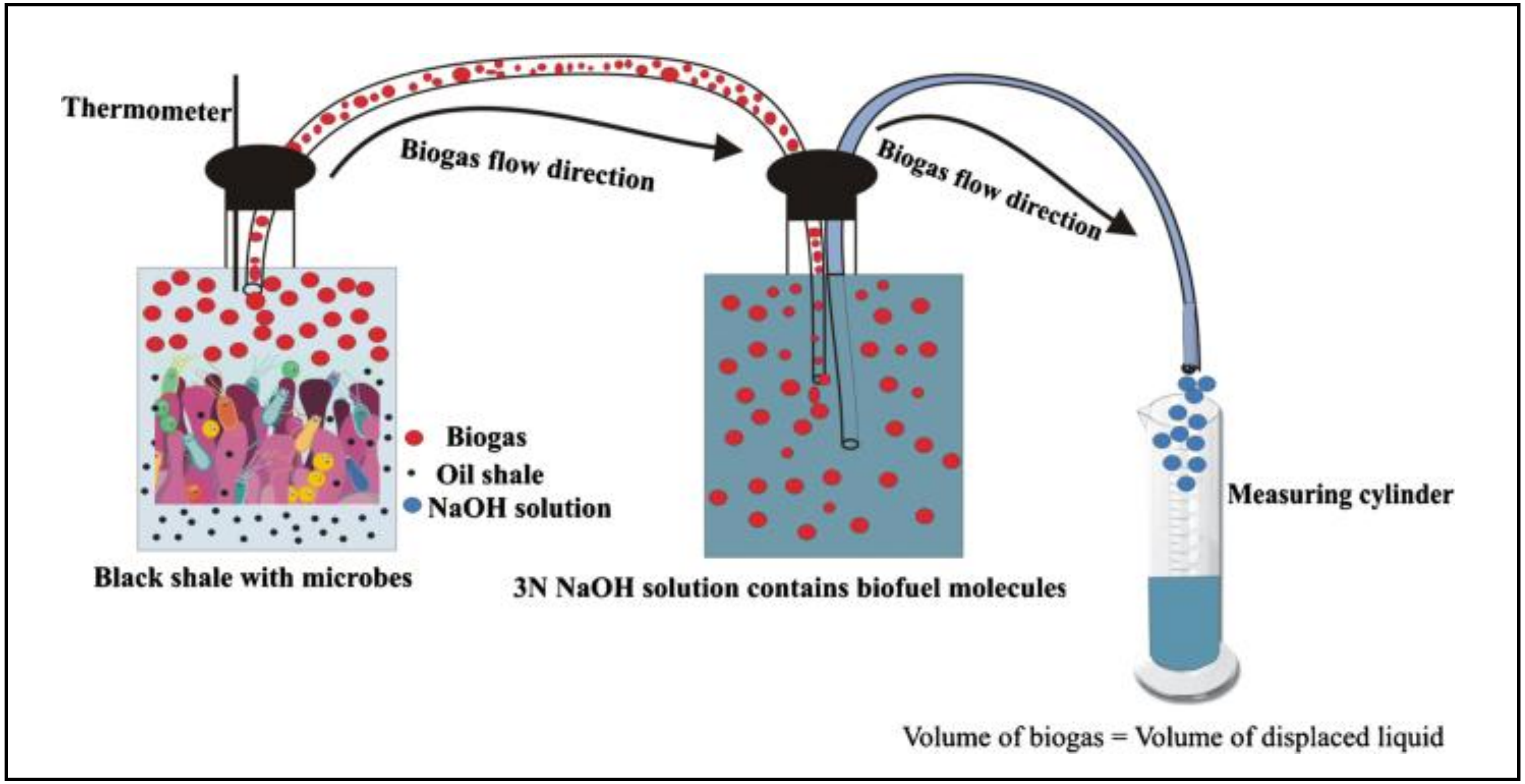



**Results of Pyrolysis-Gas Chromatography (PY-GC) of two composite samples of El Fashn Formation at Ghaida Al-Sharqia quarry that represented by C1, C2 and C3 [Methane ($CH_4$), Ethane ($C_2H_6$) and Propane ($C_3H_8$), respectively] if they are retorted at the earth's surface.**

# Results and Discussion

- **Bogenic gas extraction process**




**A model of simplified process shows the anaerobic fermentation of the black shale deposits to extract the biogenic gas ( From El-Habaak et al., 2020).**


El-Habaak, G., Khalaphallah, R., Hassan, M., Askalany, M., Abdel-Hakeem, M., 2020. Characterization and exploitation of black shale as unconventional source of biohydrogen: a case study from the Abu-Tartur mine, Western Desert, Egypt. Arabian Journal of Geosciences 13: 467.

# Conclusions

- Abundance of smectite and kaolinite as clay minerals, and positively correlation of $SiO_2$ with $Al_2O_3$ and Zr in the studied locations mean that these silica are terrigenous origin.
- The results of TOC and TS reflected that the Dabaa Formation at Maydoum quarry is poorly organic matter content of 0.36 wt % TOC, and TS recorded 0.58 wt% due to low preservation efficiency in oxic conditions of very shallow marine environment that led to oxidize the organic matter forming black carbon. However the Middle-Upper Eocene El Fashn Formation were deposited in mainly shallow marine environments with mainly suboxic conditions that led to good preservation the organic matter that reached 2.27 wt% TOC and TS equal 1.52 wt%.
- The relationship between OI and HI indicated that the El Fashn Formation has kerogen Type III of terrestrial and detrital origin that deposited in shallow marine environment under mainly suboxic conditions.
- The relationship between HI versus Tmax, and TOC versus PY indicated that the kerogen of analyzed shale samples of El Fashn Formation existed in immature stage with mainly poor generation potential as they are outcrop samples and present at more than 40m depth only below the earth's surface.
- The results of PY-GC analysis reflected that the black shale samples of El Fashn Formation has the capability to generate mainly natural gas of C1, C2 and C3 [Methane (CH4), Ethane (C2H6) and Propane (C3H8), respectively] if they are retorted at the earth's surface.
- From a simplified process of anaerobic fermentation, we can extract the biogenic gas of the black shale deposits of the El Fashn Formation at the study area.

# Acknowledgements

This work is based upon work supported by Science, Technology & Innovation Funding Authority (STDF) under younger research grant (no. 25665) funded for Dr. Zakaria Abd-Allah (PI). Deep thanks are extended also to the StratoChem Services Company, Faculty of Postgraduate Studies, Beni-Suef University and National Research Center, Egypt for analyzing the shale samples.

# Thank You