ISSN: 2639-7536

Research Article

Petroleum and Chemical Industry International

Petro-Physical and Geo-Mechanical Analysis of the Unconventional Upper Safa Formation, Western Desert, Egypt

Mohamed A. F. Omran* & Tharwat Hassen

Norwegian University of Science and Technology, Trondheim Norway

***Corresponding author**
Mohamed A. F. Omran, British university in Egypt, Egypt, E-mail: mohameo@stud.ntnu.no

Submitted: 17 Dec 2018; **Accepted**: 29 Dec 2018; **Published**: 08 Jan 2019

Abstract

World energy consuming at an all-time very high, where all resources are required such as renewable energies including solar, wind, besides nuclear energy, and biofuel. Now a days, there is not any source of renewable energy can supply and fulfill our increasing world demands of the energy consumption. Unconventional reservoirs can transform the world global energy market through advances in reservoir characterization, drilling, and completion technologies. Moreover, unconventional sources can be defined by their difference of intrinsic of their geological sittings, origins, and tapping mechanisms, thus having different methodologies for exploration, production, and development methods. Therefore, it is very important to well express and identify the necessary parameters for unconventional characterization of these reservoirs for defining reservoir rock and fluid properties in terms of total organic carbon content, gas adsorption, level of maturity, grains surface roughness, original fluids in place, and etc.

According to the petro-physical and geo-mechanical analysis of the case study, Upper Safa formation which is considered as a shale source rock of hydrocarbon gases can be considered as a shale gas unconventional resource play through with total organic carbon content values range between 2% to 3% and the determination of the total gas in place equals to 15.53 BCF/section after considering both of free gas and adsorbed gas in place. In addition to its applicability for sustaining multistage hydraulic fractures for making production stimulation, with a formation brittleness ratio up to 80%.

Introduction

Tissot et al. (1984) reported that shale plays are characterized by their organic rich mud reservoirs, which are mostly deposited in the marine environment [1]. These organic matters types depend on the deposition environment. There are many kinds of organic matter that called kerogen in the mudstone organic rich besides contacting more amounts of oil and gas than conventional reservoirs around the globe. There are three main types of this kerogen, type I and type II are from algal and herbaceous materials to generating oil after having the thermal maturation, while type III kerogen is mainly composed of materials of woody coaly to generate gas by thermogenic maturation. Thus, Type I and type II kerogen are characterized by their high hydrogen index and low oxygen index values, but type III kerogen is characterized by its high oxygen index value and lower hydrogen index as shown in the next Fig. 1.1.

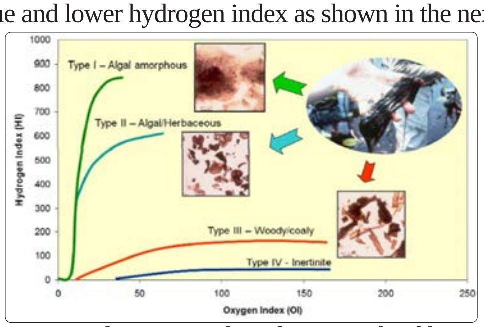

Figure 1.1: Principle types and evolution path of kerogen (Passey et al., 2010)

Chelini et al. (2010) reported that gas shale reservoirs are composed of matrix non clay minerals, clay, and solid kerogen, in addition to the fluids volume of water, oil, and gas in these unconventional reservoirs as shown in Fig. 1.2 [2]. Both shale gas and tight gas reservoirs are mainly classified by Kerogen type III that containing the majority of gas fluids more than other oil Unconventional reservoirs as tar sand and oil shale.

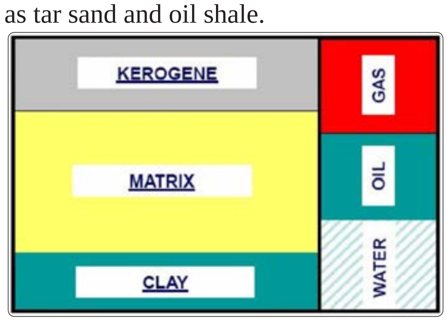

Figure 1.2: General Petrophysical model of shale gas reservoir (Chelini et al., 2010) [2]

Chopra et al. (2012) reported that shale gas reservoirs are both source and reservoir rocks that have permeability near to zero, where this gas is sorbet to kerogen and clay particles surface with very low production rates ranges between (20 – 50 Mcf/d) [3]. However, these resources are found all over the world with high thickness up to 450 meters. Also, these gas shale resources are characterized by high organic contents with total organic content ranges between 1 to 20 weight percentages. While these resources have a low recovery factors up to 20% with very rapid initial decline rates.

Ashayeri et al. (2015) presented the distribution of unconventional shale resources all over the globe which is technically recoverable oil and gas shale resources in Egypt [4]. Unconventional resources in Egypt are mainly composed of oil shale resources where Oil shale reserves are estimated 11.5 billion barrels.

Elshafiey (2012) reported that Egypt has 2 substantial resources of oil shale [5]:

1. Safaga Eastern Desert reserve oil in place is estimated 4.5 billion barrels
2. Abutartur Western Desert reserve oil in place is estimated 1.2 billion barrels

EIA (2013) reported that Egypt also has unproved technically recoverable reserves of wet shale gas up to 100 trillion cubic feet, in addition to 4.6 billion barrels of unproved technically recoverable reserves of tight oil [6].

Upper Safa formation is located in the Jurassic geological age at the western desert of Egypt. It is considered as source rock of hydrocarbon gases. There are Joint venture organization between some multinational companies and the Egyptian government for production and development from these formation reservoirs. While, these reservoirs are classified as complex fields with huge uncertainties especially in the permeability distribution and original gas in place calculations. Upper safa formation is a sub unit of Khatatba stratigraphic column of the western desert, which is a shale gas unconventional resource play as shown in Fig. 1.3. [7].

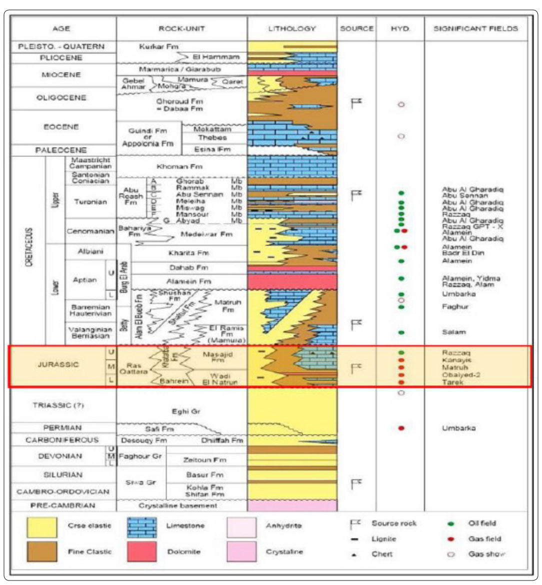

Figure 1.3: Stratigraphic column of the Western Desert, the red border indicates Jurassic Khataba Formation [8]

Techniques for Unconventional Reservoirs Formation Evaluation

Passey et al. (2010) reported the geological and petrophysical characterization for unconventional shale gas reservoirs [9]. Some of the gas shale reservoirs are over mature of oil prone source formations. For characterizing these reservoirs by defining parameters as keys for characterization as total organic content TOC, level of maturity LOM, mineralogy, thickness and type of kerogen. Thus, there are many techniques for analyzing the gas shale plays through using of x ray diffraction, adsorbed canister gas, vitrinite reflectance, thin section description, permeability, porosity, saturations of fluids, and electron microscope. Then, by interpretation these outputs data with well logs data for having a fully characterization for these reservoirs.

Gorney et al. (2011) showed the usage of nuclear magnetic resonance NMR for characterization of unconventional gas play reservoir [10]. NMR can be used for characterization of unconventional low pressure hydrocarbon formations through integration with other Logging while drilling logs LWD, and other logs as density, neutron, and sonic logs to make a combination of interpretation for petro-physical and petro-facies properties. Through making interpretation of NMR porosity curves with density log to define the zonation of pay zones. Porosity estimation from NMR, is independent of mineralogy, so it is more accurate and reliable if it compared with crossover neutron density. The density NMR crossover methodology (DMR) in enhancing the understanding accuracy of formation conditions, porosity and permeability computations to determine the actual lithology of unconventional gas play.

Ghanima et al. (2015) reported that identifying unconventional reservoir resources by integrated petrophysical, geochemical, and operational approaches [8]. The integrations of all petrophysical and geochemical data, are defining the total organic carbon and brittleness ratio of the formation. These integrations between petrophycal and geochemical data depend on logs outputs, where total organic content was identified by using Delta LogR Passey technique. However, the formation brittleness was identified by using sonic logs which includes shear and compressional slowness outputs. Geochemical sources were used for recognizing the type of kerogen and level of maturation of hydrocarbons in place. Finally, it was recommended to use nuclear magnetic resonance NMR, SEM, and dielectric measurements to reduce the uncertainties of petrophysical data.

Results and Discussion

A) Geochemical Analysis:

1. Kerogen Type:

The analysis of the geochemical output data is indicting that Upper Safa formation which is a sub unit of Khatatba formation consists of shales and coals with kerogen type III. In addition, the pyrolysis analysis through relationship between oxygen index and hydrogen index, are also supporting the kerogen type III from the obtained and analyzed samples by Ghanima et al. (2015).

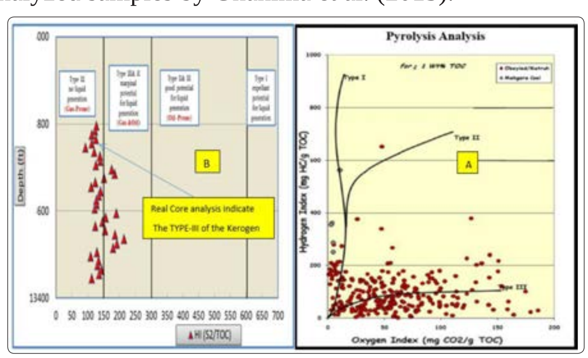

Figure 1.4: (Fig:A) Pyrolysis analysis of Upper Safa formation. (Ghanima et al., 2015), where (Fig:B) indicate the real core analysis for this data [8]

2. Level of Maturity LOM:

The Vitrinite reflection (VR) is the main important factor used for determination of level of maturity, which is the percentage of incident light reflected from surface of particles of vitrinite in shale rocks. However, Upper safa formation is characterized by an average percentage value ofvitrinite reflection equal 1.5%. Thus, LOM for Upper Safa formation equals to 12% from the graphical relation between VR and LOM as shown in Fig. 1.5.

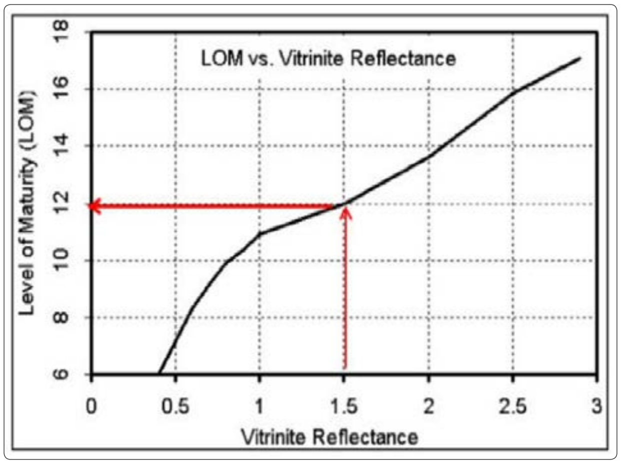

Figure 1.5: Chart describes the relationship between VR and LOM (Ghanima et al. 2015)

3. Total Organic Carbon TOC:

According to the available outputs from geochemical measurements for Upper Safa formation, is characterized by a range of TOC from 0.2% to 2.8% that is a qualitative measure of the hydrocarbon potential.

Hence, Passey equations method can be used for determining total organic carbon content TOC average value that is mainly function of the level of maturity percentage value and Delta-logR values, by having LOM equals to 12% as an average value for Upper Safa formation.

Delta Log R Density = log10 (Res/Res BL) – 2.5*(Den – Den BL)
Res: True formation resistivity, Ohm.m.
Res BL: True formation resistivity baseline equals 4.486 Ohm.m.
Den: Bulk density, g/cc.
Den BL: Bulk density baseline equals to 2.54 g/cc.
TOC = DeltalogR*10*(2.297 – 0.1688*LOM)
TOC = 2.64 %

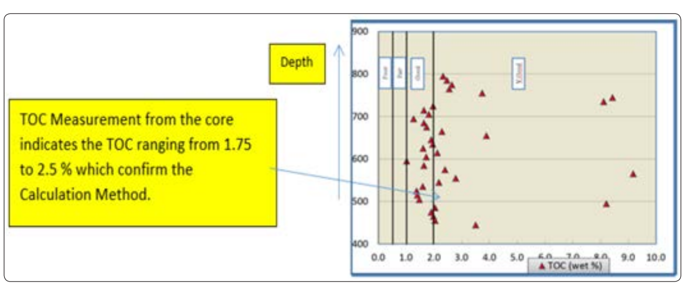

Figure 1.6: Indicate the TOC Volume with Depth from Core analysis

Therefore, Upper safa formation is a good candidate for having hydrocarbon gases as an unconventional shale gas reservoir with TOC value within the range of the potential of hydrocarbon gases which is more than 2% of TOC content.

4. Hydrogen Index:

The determination of the hydrogen index of the hydrocarbon fluids is very important parameter which is directly related to the amount of the adsorption gas in place and free gas in place for any unconventional reservoir play. In addition, total organic carbon content also is directly influenced by the value of the hydrogen index and its fluid type either oil or gas. Hydrogen index directly depends on the hydrocarbon density either gas or oil for all unconventional plays. According to this case study of having hydrocarbon density equals 0.17 g/cc of shale gas fluid, thus having hydrogen index value equals 0.3 for Upper Safa formation [8].

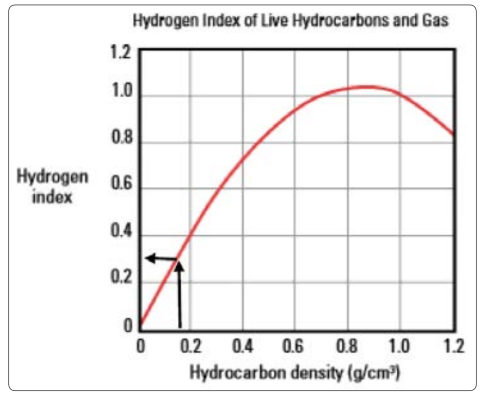

Figure 1.7: Hydrogen index of free hydrocarbons and gas [8]

B) Petrophysical Analysis:

There is few logs data information obtained and given about Upper Safa formation. By using TechLog software for performing our petrophysical analysis, to harmonize the given data, perform evaluations, and obtain results.

1. Log Analysis:

Upper safa formation is characterized by high formation resistivity which is more than 10 OHMM with high gamma ray interval, besides high gas readings as shown in Fig. 1.8.

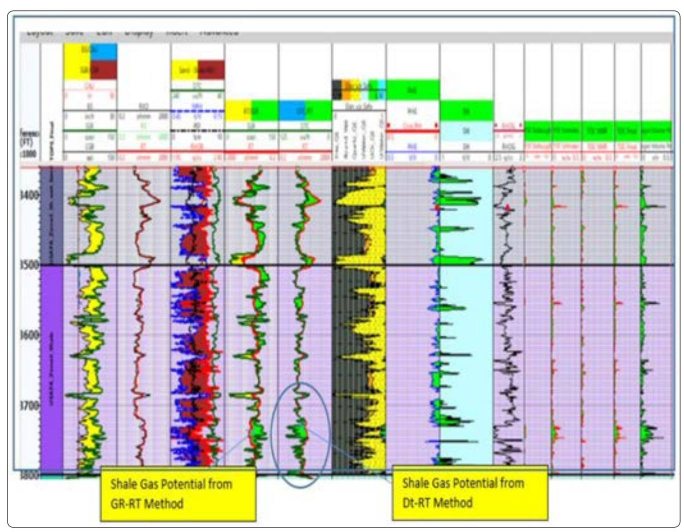

Figure 1.8: Logs analysis from Techlog outputs

2. Interpretation Analysis:

Also, for interpretation of the given density of bulk with net porosity data values to form a lithology indication relationship using TechLog software cross plot, that indicating Upper Safa formation consists mostly of shale zone plays as shown in Fig. 1.9.

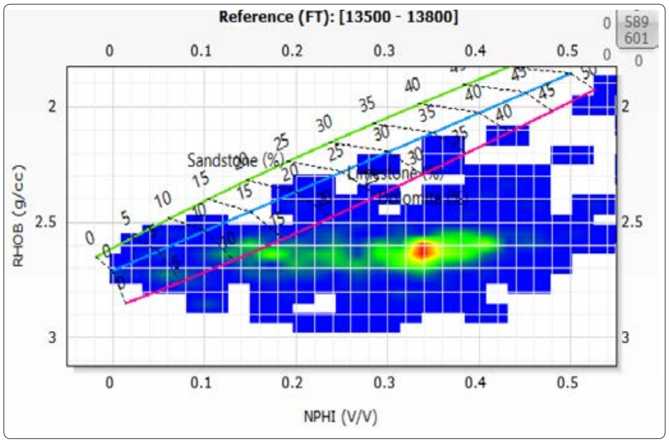

Figure 1.9: Relationship between neutron porosity values and bulk density values

Hence, Upper Safa formation which is unconventional shale play formation which consists mainly of Kaolinite clay and other mixed clay types after correlating thorium verses potassium outputs the as shown in Fig. 1.10.

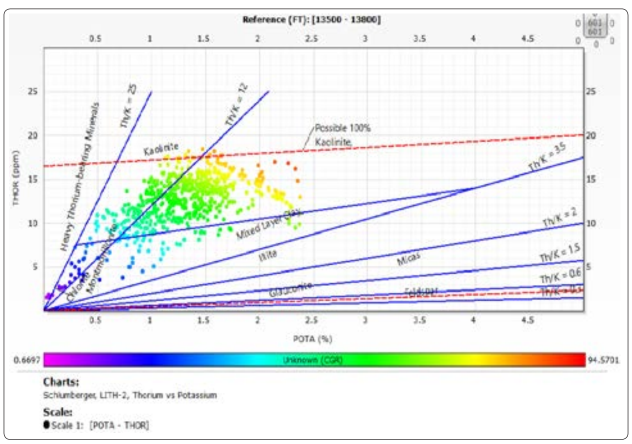

Figure 1.10: Cross plot between Thorium and Potassium outputs from TechLog

3. TOC Logs and Values Analysis:

In order to evaluating TOC for logs data using TechLog software, there are many methods can be used to obtain TOC, as Delta Log R, modified Delta Log R, Schmoker, modified Schmoker, NMR, and Uranium methods. However, there are many parameters that affect each method of estimation of TOC using logs data. Thus according to the available inputs, some methods of estimations are having the higher certainty and accuracy output TOC values as TOC modified Schomker (2.1%), TOC NMR (1.8%), TOC Schomker (2.5%), and TOC Uranium (1.7%) which are very close and/or within the given range of TOC values between 2% to 3%.

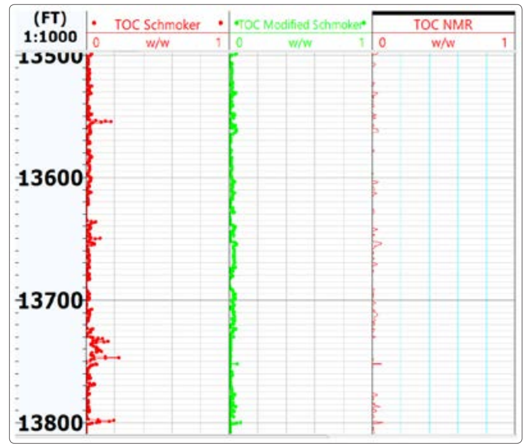

Figure 1.11: TOC Techlog values of Schomker, Modified Schmoker, and NMR

4. Total Original Gas in Place TOGIP:

By using of TechLog shale gas unconventional reservoir section that can compute the free gas in place and adsorbed gas in place due to the presence of smooth surface clay grains roughness from the case study data and total organic carbon content inputs. The results of free gas in place FGIP for the given reservoir section as an average value equals 5.07 BCF, while the volume of adsorbed gas in place AGIP as an average value equals 6.75 BCF. Thus, after applying the correction Ambrose and adding the free gas in place to adsorbed gas in place, the total gas in place TGIP equals 11.83 BCF as shown in Fig. 1.12.

TGIP = FGIP + AGIP = 11.83 BCF

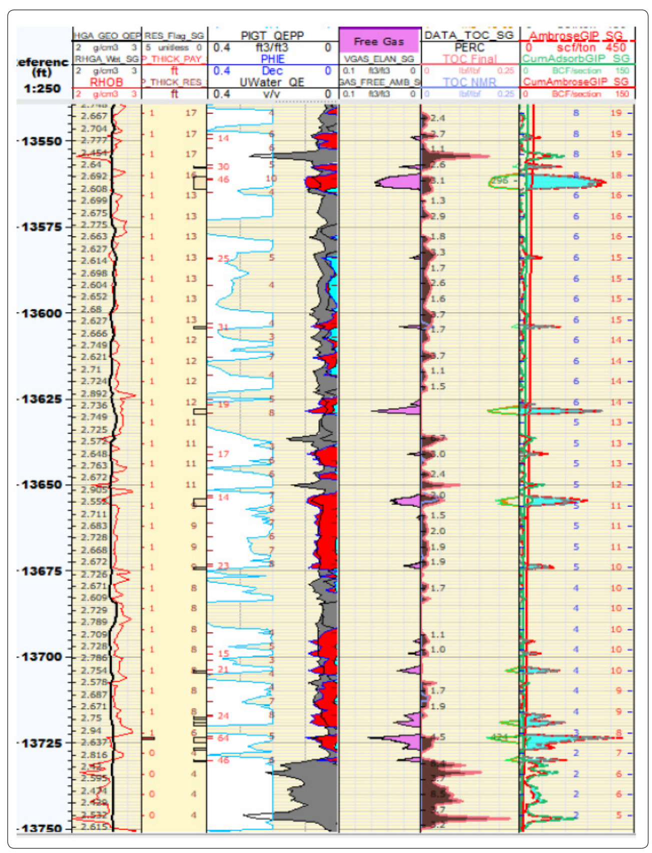

Figure 1.12: Shale gas outputs from TechLog

C) Rock Mechanics Analysis:

As operational aspects, where all shale rocks are characterized by their very low permeability to nano-darcy ranges. Thus, shale gas reservoirs are highly recommended to have multi hydraulic fractures for stimulation hydrocarbon production. Fracture stimulation job is mainly depending on rock mechanics analysis and its mechanical properties especially determination of the brittleness ratio and the dynamic elastic rock properties as Poisson ratio, Shear modulus, Young modulus, Bulk modulus, and bulk compressibility.

The concept of the brittleness estimation for shale gas and tight oil reservoirs is very important for the development of these reservoirs that can reflect their ability to maintain or fail any hydraulic fracture job. Rock brittleness can be also obtained from analysis of logs data using TechLog software through performing a relationship between compression and shear sonic logs to determine Young modulus and Poisson ration as elastic properties.

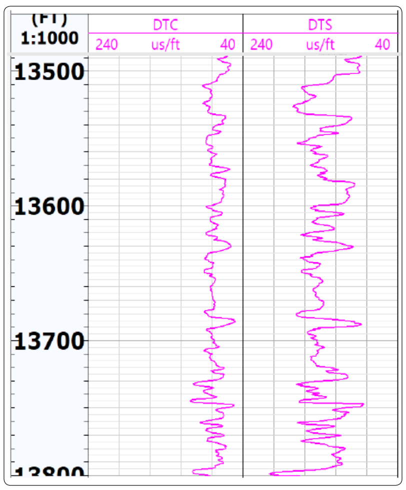

Figure 1.13: Compression and shear slowness tracks for Upper Safa formation

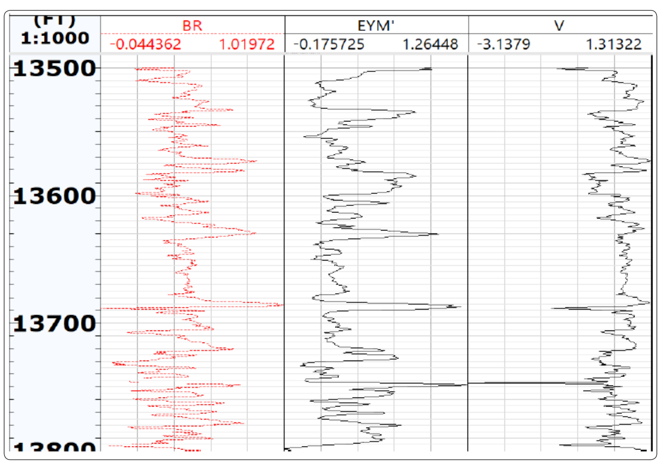

Figure 1.14: Brittleness ratio, Young modules and Poisson ratio tracks

Where Brittleness ratio (BR) can be determined and calculation though using of Rickman 2008 equation as:

EYM' = (EYM - EYMmin) / (EYMmax – EYMmin)

V= (V - Vmin) / (Vmax – Vmin)

BR = (EYM'+V)/2

BR = 50%

Thus, BR values are very important for determination of the shale gas formation ability to perform hydraulic fracture through it average value equals 50% brittleness for Upper Safa formation. Thus, it is required to have a high brittleness value more than 40% for shale gas formations as in Upper Safa formation with brittleness percentages up to 80%.

BR: Brittleness Ratio, EYM': Young Modulus, G: Shear Modulus, KbM: Bulk Modulus (GPa), CbK: Bulk Compressability (1/GPa), & V: Poisson Ratio as shown in Fig. 1.15.

V=0.5*((DTSDTC)^2)−1((DTSDTC)^2)−1) G=RHOBDTS2

EYM′=2*G*(1+V) KbM=RHOB*(1DTC2−43*DTS2)*1.34*1010

CbK = 1/KbM

RHOB: Bulk density, g/cc.

DTS: shear time, micro.sec.

DTC: compressional time, micro.sec.

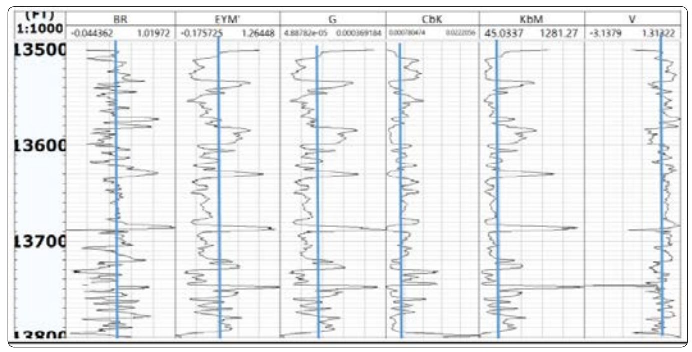

Figure 1.15: Dynamic Elastic Properties tracks for Upper Safa formation

General Empirical Correlations for Upper Safa Formation:

From the given data of well logs for Upper Safa formation to make a full integration between petrophysical, geochemical, and geomechanical analysis by using software TechLog. This software is also used for estimating any applicable parameter to be estimated about reservoir rock properties as permeability, effective permeability, and fluids saturations as shown in Fig. 1.16. Then using the outputs from Quanti Elan TechLog run for reservoir rock properties to make different methods for reservoir rock typing that is very important information to determine the number of inputs to fill any static and/or dynamic reservoir simulation software in addition to having very accurate estimations for reservoir reserves to characterize Upper Safa formation.

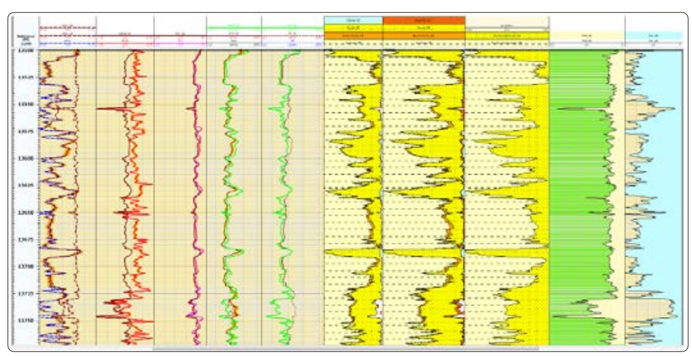

Figure 1.16: Quanti Elan TechLog run for reservoir rock properties estimations

1. Volume of Kerogen and Total Organic Carbon Content

Total organic carbon content depends on many parameters and factor that affect its values from unconventional gas reservoir to another as level of maturity, vitrinite reflection, hydrogen index and volume of kerogen. Thus, through establishing a direct a relationship between total organic carbon and volume of kerogen for Upper Safa formation with an empirical equation with very consistent accuracy up to 99.1 % as shown in Fig. 1.17.

Kerogen Volume = 1.8573*(TOC) + 0.0066

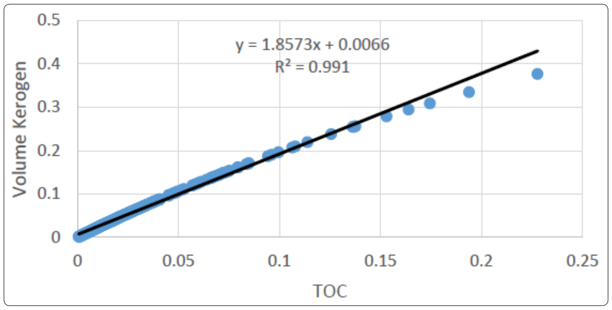

Figure 1.17: Empirical Relationship between Kerogen volume and TOC for Upper Safa Formation

2. Adsorption Gas in Place AGIP and TOC

The consideration of adsorbed gas can be desorbed due to pressure reduction while production process is very vital. This gas becomes free and follows the transportation mechanism as original free gas in the unconventional gas reservoir. Thus, it's very important to establish a direct relationship between TOC and adsorption gas in place which are function on each other as the adsorption of gas is mainly depending on the presence of kerogen volumes with reasonable amounts as in shale gas reservoirs.

AGIP = -0.311*ln(TOC) + 5.5777

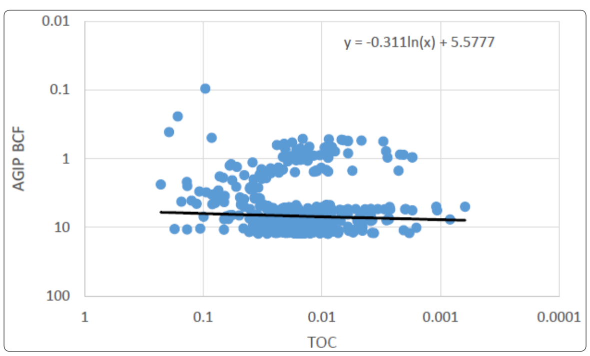

Figure 1.18: Empirical relationship between AGIP and TOC for Upper Safa formation

Conclusion

- Upper Safa formation is a shale gas unconventional resource play that consists mainly of Kaolinite clay and other mixed clay types after correlating thorium verses potassium outputs from the well logs.
- Geochemical pyrolysis analysis is used to confirm the presents of Kerogen type III as a shale gas potential reservoir. The methodology applied in this report depends on interpretation analysis to confirm the presence of hydrocarbon potential in shale reservoirs depending on the relationship between high formation resistivity and high compressional slowness readings that indicating most of shale plays.
- Brittleness ratio (BR) values are significantly important for determination of the shale gas formation ability to perform hydraulic fracture through it average value equals 50% brittleness for Upper Safa formation. High brittleness value of more than 40% for shale gas formations as in Upper Safa formation with brittleness percentages up to 80%.
- Integration between results of TOC from both of geochemical and petrophysical analysis methods within the same range. The used petrophysical analysis methods for determination of TOC results are applicable to Upper Safa formation as Schomker, Modified Schmoker, NMR, and Uranium TOC., while Passy delta logR method is not applicable to be applied for Upper safa formation [10].
- TOC results which are obtained within the ranges of very good petroleum potential according to Rock Eval pyrolysis from 2% to 4% TOC.
- The adsorbing gas in the calculations of original gas in place that increasing the gas reserve and total gas in place from 7.18 BCF to be 16.7 BCF.
- Thus, having an absolute error value between the values of the total gas in place before and after considering the gas absorption volume equals to 57%.

References

1. Tissot BP, Welte D (1984) Petroleum formation and occurrence, Springer-Verlag: New York, 699.
2. Chelini V, Muttoni A, Mele M, Rossi E, Galimberti R et al., (2010) Gas shale reservoir characterization, Paper SPE 134292 presented at the SPE annual technical conference and exhibition held in Florence, Italy.
3. Chopra S, Sharma RK, Keay J, Marfurt K (2012) Shale gas reservoir characterization workflows. Arcis Seismic solutions, Calgary; The University of Oklahoma, Norman, USA.
4. Ashayeri C, Ershaghi I (2015) OPEC and Unconventional resources, Paper SPE 174961 presented at the SPE annual technical conference and exhibition held in USA.
5. Elshafeiy MA (2012) Characterization and economic potentiality of oil shales in Alquseir and Abu-tartur areas, Egypt. PhD thesis, Cairo University.
6. EIA (2013) Countries: Egypt: Overview. Retrieved November 2013, from U.S. energy information administration (EIA).
7. Omran MF, Fawzy TH (2018) Analyzing of Formation Evaluation of the Unconventional Upper-Safa Formation, Western Desert, Egypt, Paper SPWLA 2018.
8. Ghanima A, Elbendary A, Taha A, Farag Y, Gamal A et al., (2015) An integrated petrophysical, geochemical, operational approach to identify unconventional resource, case study, Obaiyed field, Western Desert, Egypt, Paper SPE.
9. Passey QR, Bohacs KM, Esch W, Klimentidis R, Sinha S (2010) From oil prone source rock to gas producing shale reservoir geologic and petrophysical characterization of unconventional shale gas reservoirs, China.
10. Orlandi M, Bartelucci P, helini V (2011) Unconventional reservoir characterization methods using core and well logging data: shale gas and tight gas sand examples, Paper presented at the 10th offshore Mediterranean conference and exhibition in Ravenna, Italy.