Analyzing of Formation Evaluation of the Unconventional Upper-Safa Formation, Western Desert, Egypt

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Abstract

Unconventional reservoirs can add huge amounts of additional energy to our world resources bases like organic shale in terms of Shale gas, shale oil, tight gas and coal-bed methane. These reservoirs can transform the world global energy market through advances in reservoir characterization, drilling, and completion technologies. Reservoir characterization and properties have great influences on the exploration and development processes, it is not through a single discipline that can provide a fulfill description of the reservoir characteristics especially for unconventional reservoirs. 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. Hence there are many developed correlations and methods to get these parameters that can define each one of them, but most of them are not correlated with each other. According to the 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 the analysis of its total organic carbon content values range between 2% to 3% by using different methods and the determination of the total gas in place, after considering both of free gas and adsorbed gas in place.

Keywords: Unconventional reservoirs; Shale reservoirs; Fluids; Upper Safa formation

Introduction

Rose, et al. identified that in conventional analysis for unconventional reservoirs, have the highest potential for future energy supply which can be furnishing up to 50% of the world energy demands [1]. Unconventional resources definition is mainly based on economical restrictions and situations rather than technological

restrictions, which are reservoirs with properties that prevent their resources to be recovered at the current economic situation.

Stark, et al. predicted that unconventionals play importance increasing role in supplying world energy for the next years [2]. Unconventional petroleum resources have already started to affect and influence the world energy map such as US tight oil and gas reservoirs, Canadian Oil Sands, and Venezuelan extra heavy oil. In addition to improving scientific researching and understanding of the unique characteristics and petrophysical properties of these formations, are leading the way to have a cleaner energy in the future. Huge unconventional resources are close to established infrastructure and to large markets all over the world including North America, Europe, Asia, and Middle east. Although shale resource estimates will likely be changed over time, the initial estimate of technically recoverable shale gas resources in 41 contraries is 7,299 trillion cubic feet. To put that into perspective, where just 1 trillion cubic feet is enough to heat 15 million homes for a year. So, by increasing uncertainties, the attraction of resource plays can be summed up as low risk.

WEC, presented oil shale total resources around the globe are estimated up to 2.8 trillion barrels [3]. So, oil shale resources are estimated to contain the largest potential if they compared with the other resources of unconventional oil. Oil shale is having the largest production potential. In addition, Gas shale resources are constituting some of the largest components of the remaining natural gas resources around the globe which are widespread. "Interest is growing, however, and during the last decade development of unconventional gas reservoirs has been occurred in Canada, Australia, Mexico, Venezuela, Argentina, Indonesia, China, Russia, Egypt, and Saudi Arabia". Shale gas resources are estimated 16000 trillion cubic feet of gas in place widespread all over the world, while tight gas sands are estimated 7400 trillion cubic feet of gas in place.

Unconventional Reservoirs Characteristics

Tissot reported that shale plays are characterized by their organic rich mud reservoirs, which are mostly deposited in the marine environment. 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 (Figure 1).
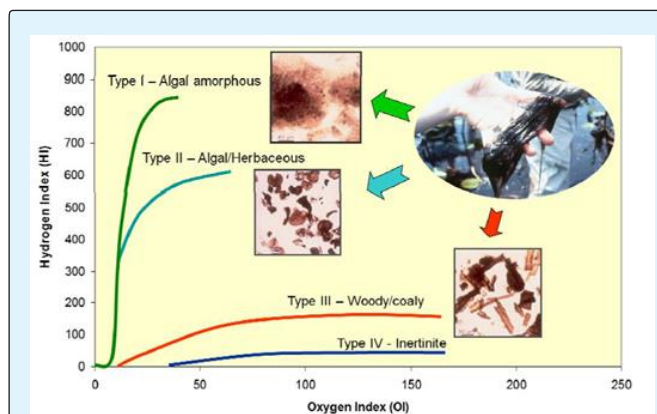

Figure 1: Principle types and evolution path of kerogen.

Chelini 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 Figure 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.
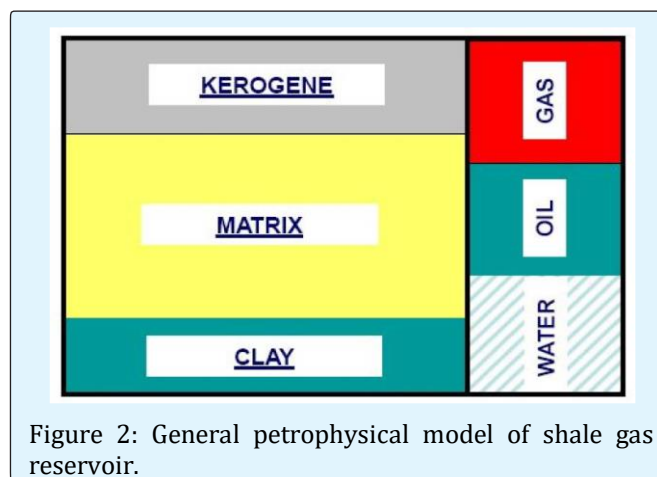

Figure 2: General petrophysical model of shale gas reservoir.

Chopra, et al. 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) [4]. 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 percentage. While these resources have a low recovery factors up to 20% with very rapid initial decline rates.

Egyptian Unconventional Oil and Gas Reservoirs

AmCham reported that petroleum industry is covering 94% of the Egyptian primary energy requirements with their reserves 4.4 billion barrels of oil and 77.2 trillion cubic feet of gas [5]. Thus, the main solution of this complex economical Egyptian situation is exploitation of tremendous unconventionally potential, including oil shale and tight gas sands that will be the major

contributors of the Egyptian primary energy consuming in the energy market of Egypt.

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

Elshafiey reported that Egypt has 2 substantial resources of oil shale:

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 (Figure 3).
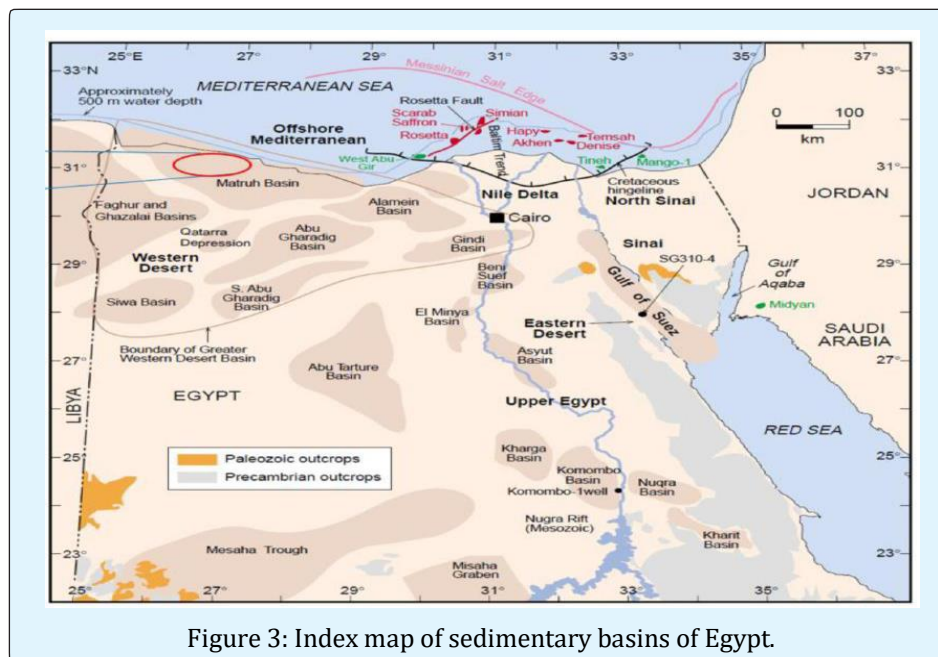

Figure 3: Index map of sedimentary basins of Egypt.

Techniques for Unconventional Formation Evaluation

Passey, et al. reported the geological and petrophysical characterization for unconventional shale gas reservoirs [6]. 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.

Orlandi, et al. presented that Coring and well logging data are methods for characterization of unconventional reservoirs [7]. Tight gas reservoirs & Gas Shale are contained the largest volume of gas of all unconventional reservoirs. Sweet spots are zones located inside the rock due to action of less compaction and cementation between grains of the rock, and/or natural fractures are present, in which tight gas is accumulated. Through defining the concept of Non Archie rocks and other petrophysical models as NMR logs to produce robust formation evaluation of tight gas and gas shale reservoirs.

Chopra, et al. reported the workflows of gas shale reservoir characterization using three dimensional seismic data [4]. Shale gas reservoirs need some properties as total organic content, level of maturity, thickness, fluid in place, mineralogy, permeability, brittleness, in addition to pore pressures to have a full successful characterization for any shale gas reservoir.

Kou, et al. presented the coupling of Darcy equation with molecular transport and their applications to upscaling the permeability of kerogen [8]. There are large uncertainties in the measurements of organic rich shale because of the presence of many mechanisms for gas transport at multi pore scales. Adsorbed molecules are not mobile and contribute some portions to the mass total flux. The adsorbent phase transport velocity is strongly dependent on the pressure changes that allow usage of modified Hagen Poiseullie equation and estimate the enhancement of transport.

Upper Safa Formation

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 Figure 4.
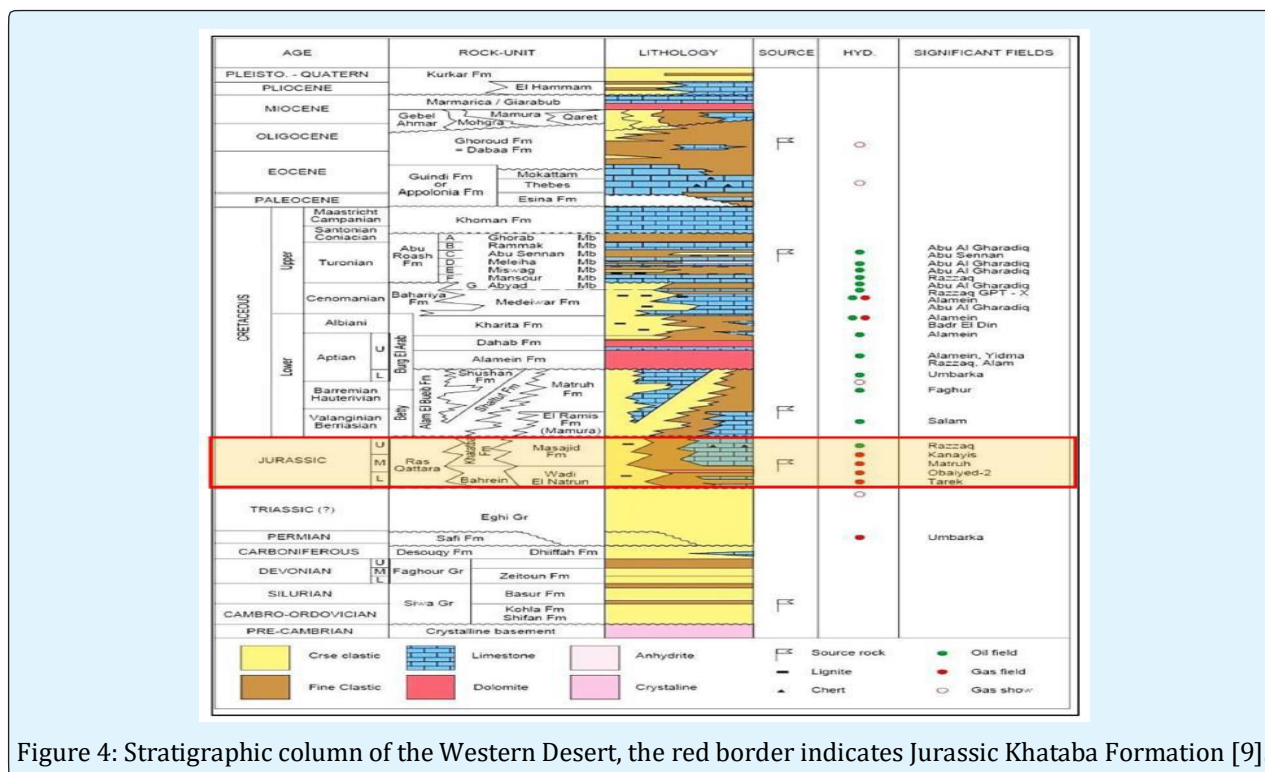

Figure 4: Stratigraphic column of the Western Desert, the red border indicates Jurassic Khataba Formation [9].

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Results and Discussion

Geochemical Analysis

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 5).
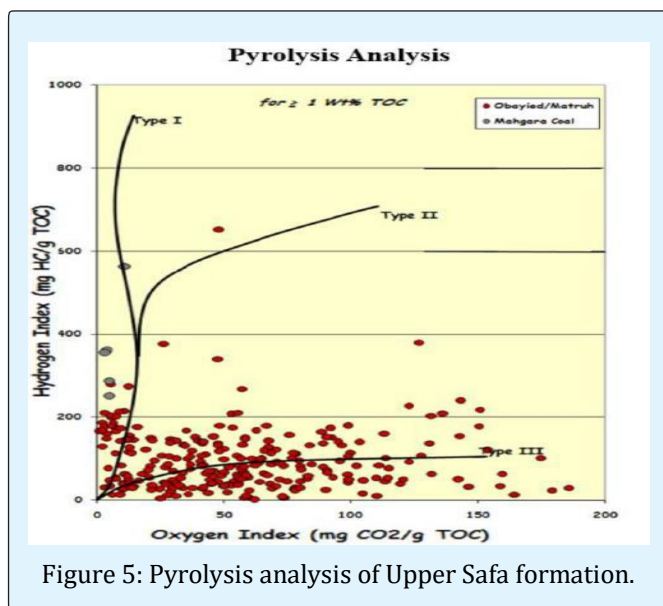

Figure 5: Pyrolysis analysis of Upper Safa formation.

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 of vitrinite reflection equal 1.5%. Thus, LOM for Upper Safa formation equals to 12% from the graphical relation between VR and LOM as shown in Figure 6.
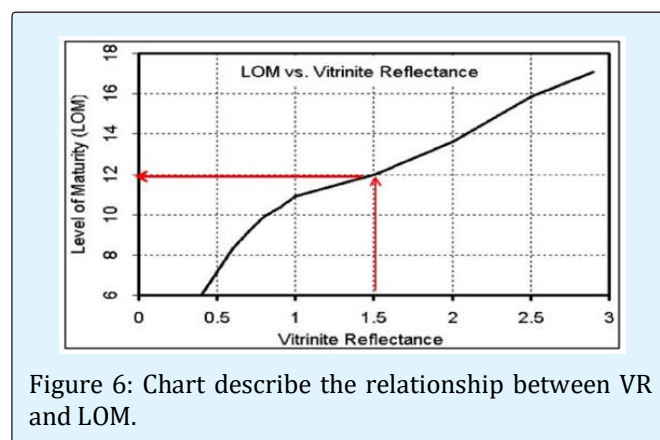

Figure 6: Chart describe the relationship between VR and LOM.

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. Moreover, Rock Eval pyrolysis shows that the degree and ranges of this quality as shown in Table 1.

Petroleum Potential of Immature Source Rock						
Organic Matter						
Petroleum Potential	TOC wt. %	Rock-Eval Pyrolosis		Bitumen		Hydrocarbons
		S1	S2	wt.%	ppm	ppm
Poor	(0-0.5)	(0-0.5)	(0-2.5)	(0-0.05)	(0-500)	(0-300)
Fair	(0.5-1)	(0.5-1)	(2.5-5)	(0.05-0.1)	(500-1000)	(300-600)
Good	(1-2)	(1-2)	(5-10)	(0.10-0.2)	(1000-2000)	(600-1200)
Very Good	(2-4)	(2-4)	(10-20)	(0.2-0.4)	(2000-4000)	(1200-2400)
Excellent	>4	>4	>20	>0.4	>4000	>2400

Table 1: Different quality degrees of source rocks.

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 foration resisitivity 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 %

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.

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 [10]. 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 (Figure 7).
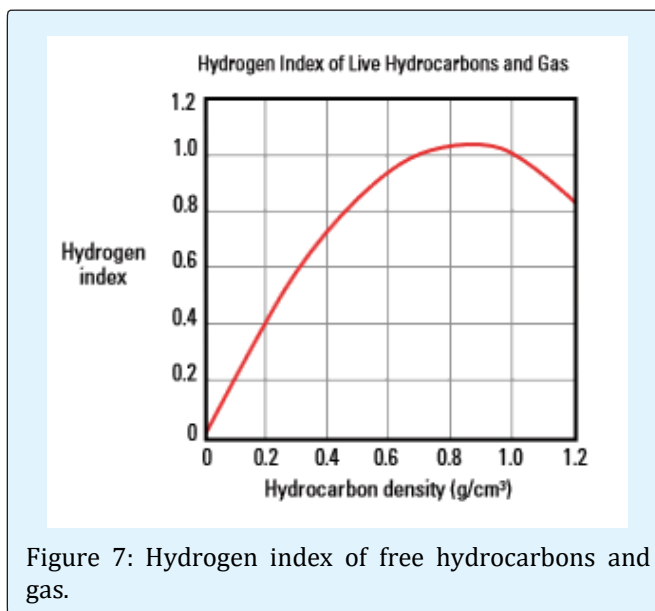

Figure 7: Hydrogen index of free hydrocarbons and gas.

Petrophysical Analysis

There are 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.

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 Figure 8.
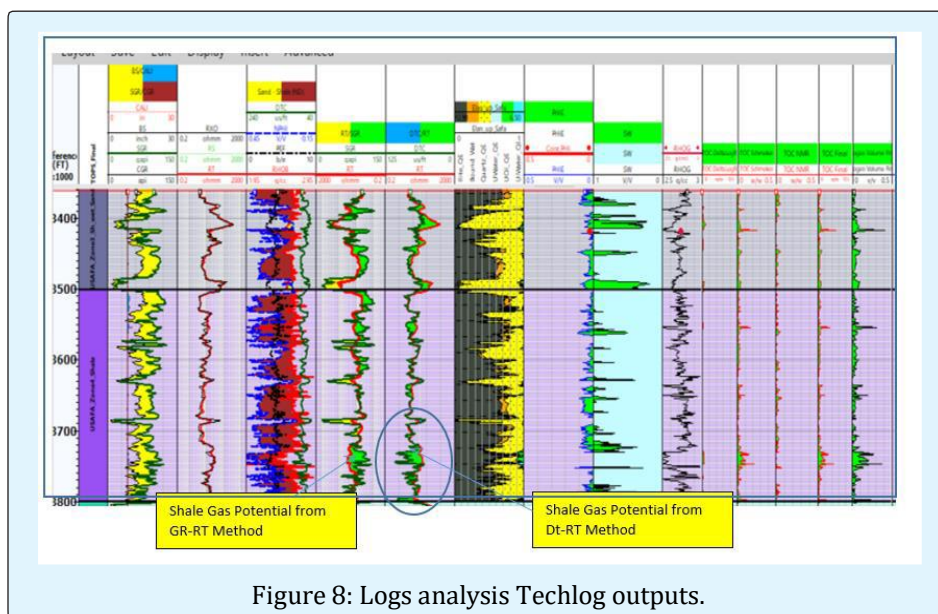

Figure 8: Logs analysis Techlog outputs.

Interpretation Analysis: The relationship between the true formation resistivity and acoustic compressional slowness constructed using TechLog software, that indicating most of shale plays in green color with high resistivity and high compressional slowness zone as shown in Figure 9.
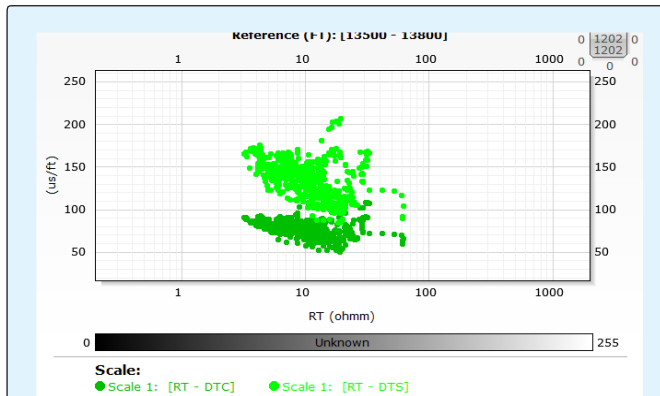

Figure 9: Screen shot for relationship between formation resistivity and compressional slowness.

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 Figure 10.
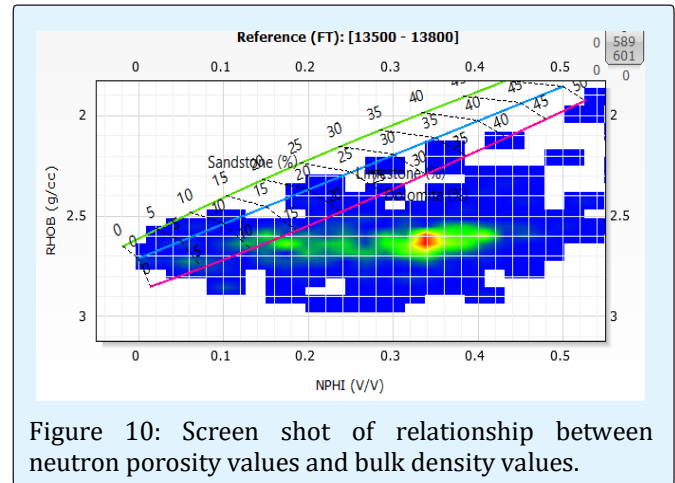

Figure 10: Screen shot of relationship between neutron porosity values and bulk density values.

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 Figure 11.
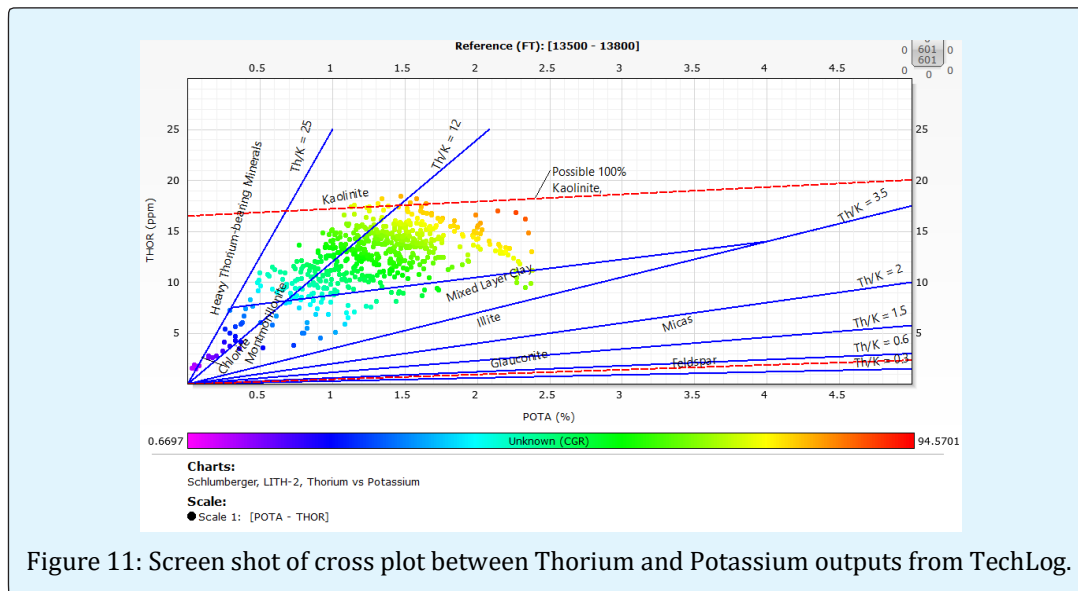

Figure 11: Screen shot of cross plot between Thorium and Potassium outputs from TechLog.

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 12).
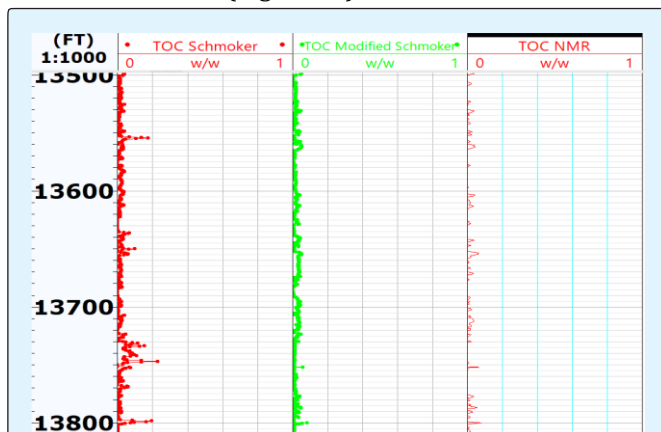

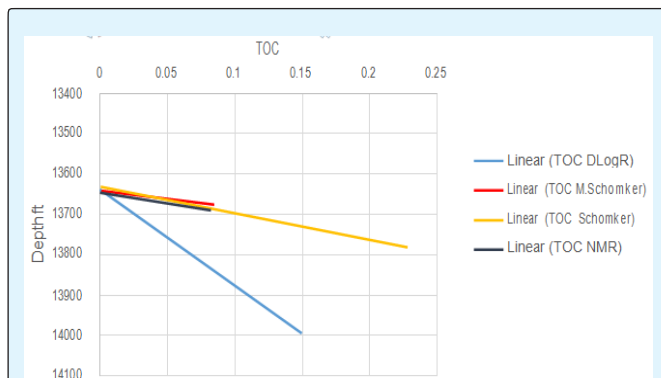Figure 12: Screen shot of TOC Techlog values of Schomker, Modified Schmoker, and NMR.

Figure 13: TOC analysis using differ logging evaluation methods.
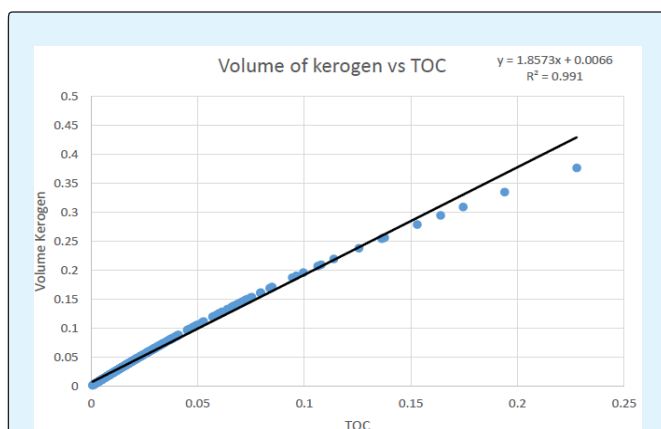

Figure 14: Empirical correlation for Upper safa formation between kerogen volume and TOC.
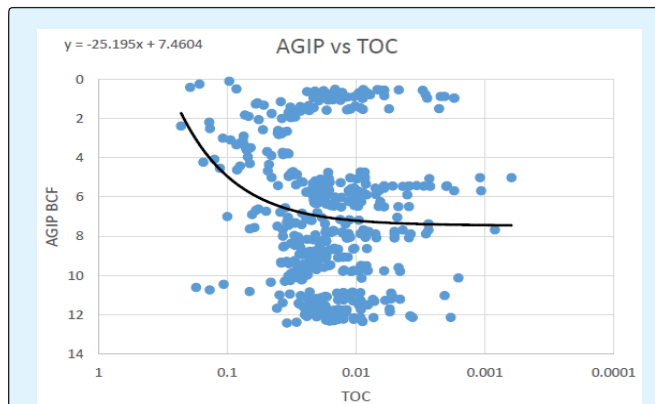

Figure 15: Empirical correlation for Upper safa formation between adsorbed gas in place and TOC.

Total Original Gas in Place TOGIP: By using of TechLog shale gas unconventional 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 Upper Safa formation section as an average value equals 7.18 BCF, while the volume of adsorbed gas in place AGIP as an average value equals 9.52 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 16.7 BCF.

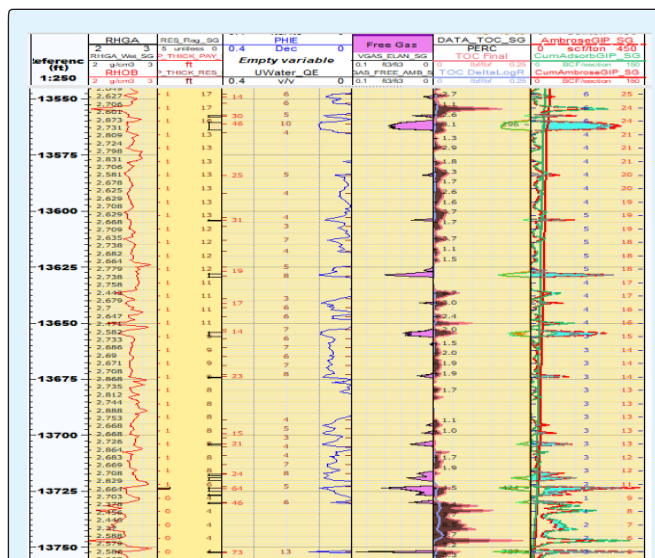Figure 16: Screen shot of shale gas outputs from TechLog.

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Rock Mechanics Analysis

As operational aspects, where all shale rocks are characterized by their very low permeability to nanodarcy 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 compressional and shear sonic logs to determine Young modulus and Poisson ration as elastic properties.
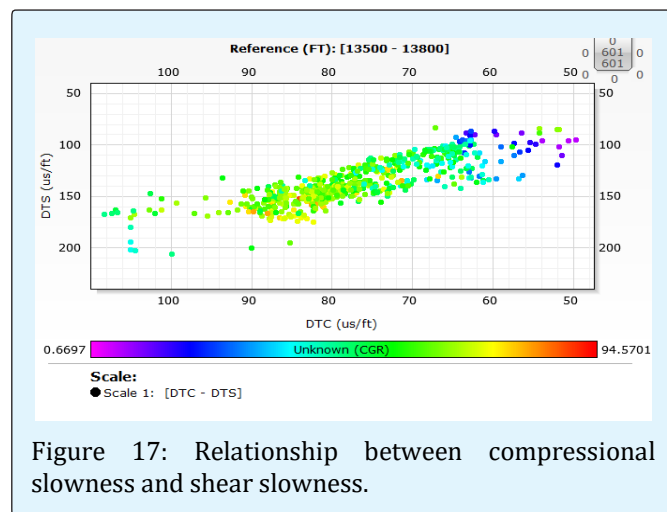

Figure 17: Relationship between compressional slowness and shear slowness.

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%

Dynamic Elastic Properties

BR: Brittleness Ratio, EYM': Young Modulus, G: Shear Modulus, KbM: Bulk Modulus (GPa), CbK: Bulk Compressability (1/GPa), & V: Poisson Ratio as shown in Figure 18.

$V = 0.5 * ((DTS/DTC)^2) - 1/((DTS/DTC)^2) - 1)$
$G = RHOB/DTS^2$
$EYM' = 2*G*(1+V)$
$KbM = RHOB*(1/DTC^2 - 4/3*DTS^2)*1.34*10^{10}$
$CbK = 1/KbM$
RHOB: Bulk density, (g/cc)
DTS: shear time, (micro. Sec.)
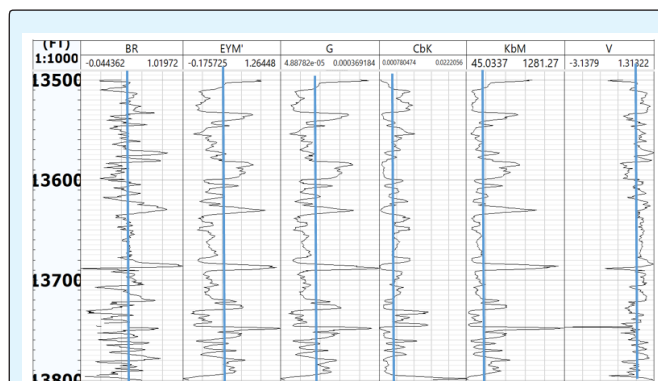DTC: compressional time, (micro. Sec.)

Figure 18: Dynamic Elastic Properties tracks for Upper Safa formation.

Thus, BR values are very important for determination of the shale gas formation ability to perform hydraulic fracture through it an 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%.

Conclusion

1. 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.
2. 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.

3. Brittleness ratio (BR) values are significantly important for determination of the shale gas formation ability to perform hydraulic fracture through it an 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%.

4. 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.

5. TOC results which are obtained within the ranges of very good petroleum potential according to Rock Eval pyrolysis from 2% to 4% TOC.

6. 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.

7. 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%,

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