Research Article

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New Approach for Unconventional Reservoirs Rock Typing Characterization: Egyptian Unconventional Gas Reservoirs

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Abstract

The main objective of this research is to enhance unconventional reservoir characterization by developing and/or establishing new correlations through using a real case study of unconventional shale gas reservoir called Upper Safa formation that located in the western desert of Egypt. In addition to describing its geochemical and petro physical reservoir rock and fluid properties more consistently through a full integration among unconventional rock parameters as permeability, porosity, tortuosity, surface roughness, adsorption, type of kerosene, level of maturity, total organic carbon content, and etc.

The results showed that Upper Safa formation is a shale gas unconventional resource play that consists mainly of Kaolinite clay and other mixed clay types. Geochemical pyrolysis analysis is used to confirm the presents of Kerogen type III as a shale gas potential reservoir. Interpretation analysis has been used also to confirm the presence of hydrocarbon potential in shale reservoirs depend on the readings that indicating most of shale play. Hence, after applying the surface roughness factor to Total gas in place equation through multiplying the (1-0.4) factor to volume of adsorbed gas in place to get new more accurate value for total gas in place TGIP' equals 9.12 BCF. Moreover, brittleness ratio average value equals to 50% brittleness. However, TOC results which are obtained within the ranges of very good petroleum potential according to Rock Eval pyrolysis from 2% to 4% TOC. Hence, the results obtained from using of Dykstra Parson permeability variation, Upper Safa formation is highly heterogeneous formation which is very close to 100% heterogeneous formation, as any unconventional shale reservoirs due to the huge variation in the permeability ranges from milli-Darcy ranges to nano-Darcy ranges. Thus, several conventional and unconventional rock typing methods have been applied to overcome this zonation problem, besides establishing a new approach for unconventional reservoirs rock typing.

Introduction

OPEC (2013) presented that the global economy is strongly based mainly on consuming the Fossil Fuels as a primary source of world energy, that represents more than 90% of the primary energy produced in the world. Fossil Fuels are non-renewable sources of energy, and their amounts are very limited. These fossil fuels are the crude oil and natural gas which have been the major source of energy for the modern civilization since the past century. However, they are considered as nonrenewable sources of energies which are the most important depletable resources all over the world.

In 2012, EIA estimated that the total world use and consume of the produced hydrocarbons in 2035 will range from 107 to 113 million barrels per day. Fig. 1.1 shows the history and forecasting of the world production, discovery and demand of the conventional oil starting from 1900 until 2100. This figure shows the increase of world energy demand with time, in addition to presenting the expected future discoveries and production of the world conventional oil. The reserves of the world oil are estimated between 850 to 900 billion barrels. Moreover, signaling the end of conventional oil is expected with the lack of possibility of large future discoveries.

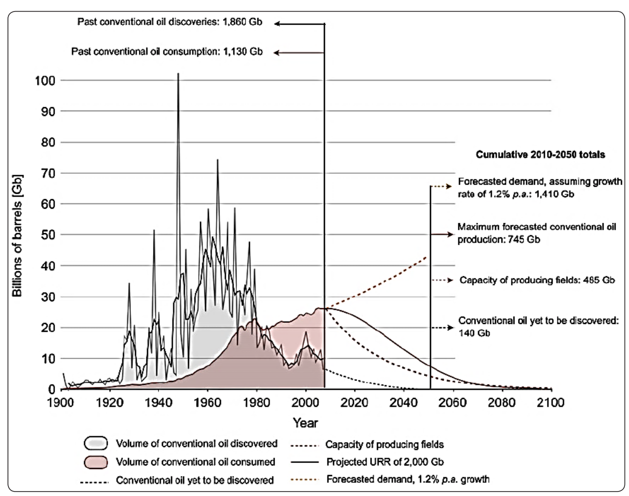

Figure 1.1: History and forecast of production, discovery and demand of conventional oil; Gb =Giga or billion barrels

Rose et al. (1982) 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. (2007) 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.

Unconventional Reservoirs

Tissot, et al. (1984) 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 Fig. 1.2.

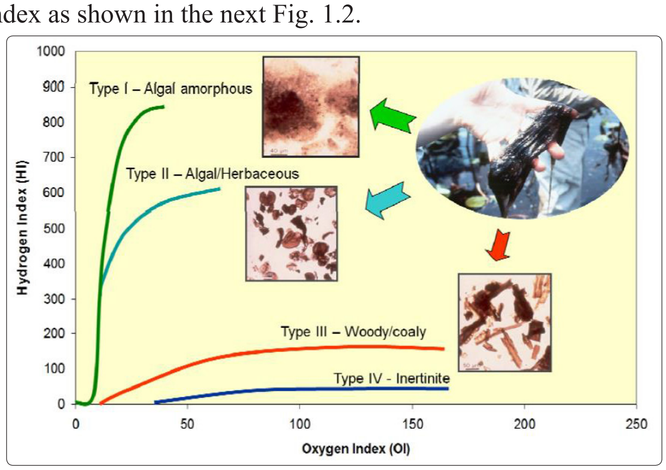

Figure1.2: Principle types and evolution path of kerogen

WEC (2007), 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 [4]. 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.

Shale Gas Reservoirs

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. 1.3. 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.

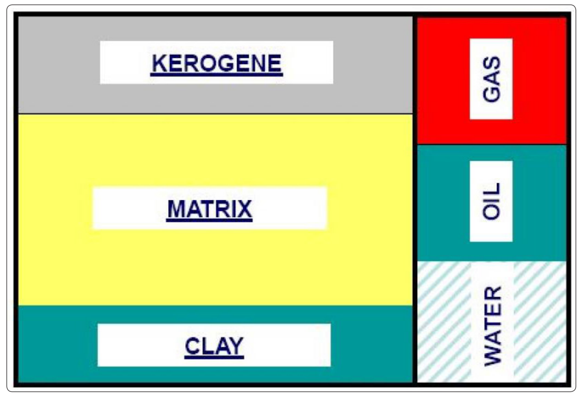

Figure 1.3: General petrophysical model of shale gas reservoir

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). However, these resources are found all over the world with high thickness up to 450 meters [5,6]. 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. Fig. 1.4 shows the expected production of the unconventional resources that will dominate the future oil and gas production.

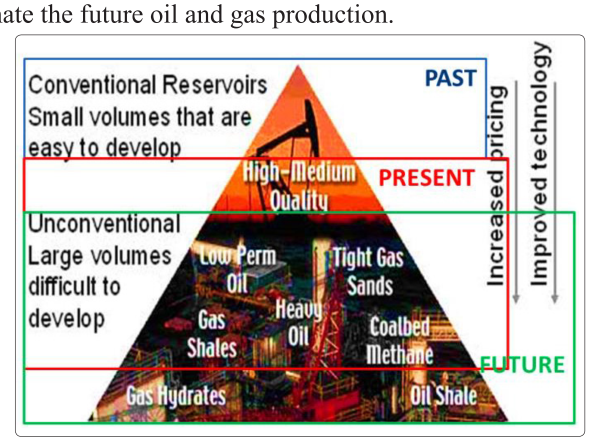

Figure 1.4: Resource Triangle Concept

Egyptian Unconventional Oil and Gas Reservoirs

Egyptian industries are facing energy crisis in supplying the needed amount of energy which is predicted to be increasingly in the near future due to the rapid increasing in the gap between petroleum supplying and consuming. Egyptian industrial activity in the economy is mainly depend on oil and gas sector. AmCham (2009) 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 [7]. 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, 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 as shown in Fig 1.5 (blue circle). While the Asian Middle east which is one of the major petroleum industry global suppliers include the major OPEC members such as Saudi Arabia, UAE, Qatar, Iraq, Iran, and Kuwait, have not any unconventional shale resources (Red circle).

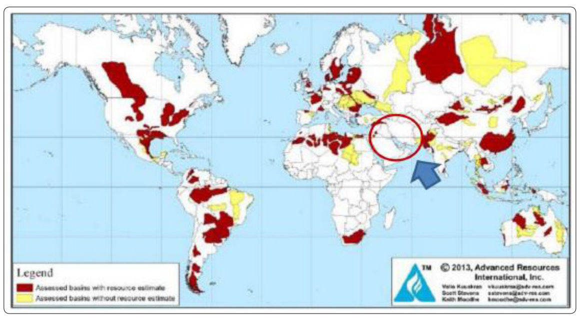

Figure 1.5: Global Shale assessment map (EIA, 2013)

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:

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.

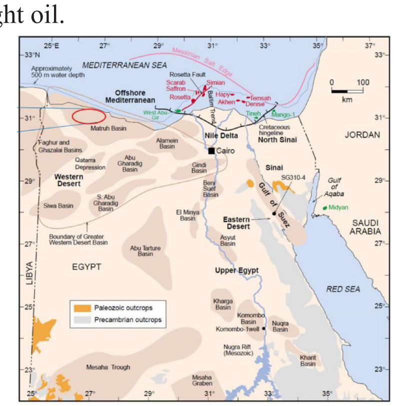

Figure 1.6: Index map of sedimentary basins of Egypt

Reservoir Characterization Damsleth et al. (1994), Reservoir characterization and properties have great influences on the exploration and development processes [8]. To understand more and more about reservoir properties, it is not through a single discipline that can provide a fulfill description of the reservoir characteristics. For reservoir understanding, integrated reservoir models have become increasingly important. The main objective of reservoir characterization is to define and identify the features that directly influencing the location, amount, availability, and production flow of reservoir fluids. These features mainly consist of structural aspects, faults, flow units, and spatial distribution for petro physical parameters. Masoud- Nikravesh (1999) defined the intelligent reservoir characterization through creating an integrated methodology that identified the un-linear relationships in which Oil industry is targeting to delineate strategies for having better reservoirs characterization and understanding through reducing the cost of data collection and reserve evaluations uncertainties. Understanding reservoir rocks and fluids characterization accurately can be delivered by using mixture of characterization methods of petro technical tools and services for down hole measurements, formation testing, and laboratory analysis.

Conventional Techniques for Unconventional Characterization Rushing, et al. (2001), presented an integrated work flow model to characterize unconventional gas resources through modifying the petro physical integration process model (PIPM). PIPM is divide into four stages of analysis, data integrations from multi sources, and different scales of reservoir with main goal for this modeling to create realistic three dimensional well bore and flow of reservoir for prediction future performance with optimizing field development plan.

Slatt et al. (2008) presented a workflow for stratigraphic characterization for unconventional shale reservoirs. For having accurate and more reliable characterization for unconventional reservoirs as shale requires multi scale characterization sedimentology, lithology stratigraphy, bio stratigraphy and geochemistry of the cores, in addition to integrating well logs with stratigraphy, seismic data, petro-physical properties and organic geochemical properties. Thus, the results of these integrations can provide more reliable identifications for unconventional shale reservoirs to improve their drilling and production processes. Orlandi, et al. (2011) presented that Coring and well logging data are methods for characterization of unconventional reservoirs [5]. Tight gas reservoirs & Gas Shale are contained the largest volume 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 petro physical models as NMR logs to produce robust formation evaluation of tight gas and gas shale reservoirs.

Kou, et al. (2016) presented the coupling of Darcy equation with molecular transport and their applications to up scaling the permeability of kerosene [9]. 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 allows usage of modified Hagen Poiseullie equation and estimate the enhancement of transport.

Zhang, et al. (2017) described the direct determination of reservoir rocks and fluid properties and their brittleness by elastic impedance inversion to define sweet spots and fractured area especially in the unconventional reservoirs. Seismic data is crucial for characterization and development of unconventional reservoirs in identifying fluids and level of brittleness.

Instrumental Techniques for Unconventional Characterization

Passey, et al. (2010) reported the geological and petro physical characterization for unconventional shale gas reservoirs. Some of the gas shale reservoirs are over mature of oil prone source formations [4]. 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.

Knackstedt, et al. (2012) showed the petro physical characterization of unconventional reservoirs cores at multiple scales methods. Multi scale imaging is done on core rocks at nanometer scales to understand heterogeneity, nature fracture densities, pores types, pore throats connectivity, minerals and organic contents. Three dimensional imaging modes technology can be used for mineralogy and micro porosity characterization, while scan electron microscopy SEM with focus ion beam FIB imaging, are used for reveal nonporous micro structure through the phases of materials of the core.

Zhang, et al. (2012) showed the identification of hydraulic flow unit of shale gas that based on scanned electron microscopy with focused ion beam tomography SEM FIB. Shale gas is a large amount produced of gas in which stored in complex sub-micron pore structures. The predictions of shale economical gas productivity and hydraulic fracturing risky presence due to the absence of a significant hydraulic flow unit HFU model for shale gas reservoirs. Thus, determining of pore size distribution, permeability, pore connectivity, and other petro physical characteristics are very important for having accurate reservoir performance predictions and effective reservoir management decisions. By using the dual beam SEM FIB instruments for gas shale reservoir tomography with reconstructing three dimensions' submicron pore model to provide insights into the petro physical properties of shale gas reservoirs, including their pore size distribution and porosity determination.

Jacobs (2015) presented the instrumental methods and techniques for accurately and deeply identifying the unconventional resources characteristics [10]. There are many new instruments that can be used for identifying accurately the properties of rock matrix such as Scan electron microscopy SEM, X ray diffraction XRD, X ray fluorescence XRF, well logs, and Porosity/Permeability studies models. Identification of macro fractures can be through production data analysis and seismic data analysis, while identification of micro fractures by using scanning electron microscopy SEM and optical microscopy. Fluid interactions can be identified though Swelling/minimum miscibility model, Pressure studies, Extraction studies, and Gas chromatography. These wide ranges of technologies and models for reservoir characterization lead to better reflect the reality of the unconventional formations.

Results and Discussion

In defining the rock typing methods that are applicable to be used after determining the degree of heterogeneity of Upper Safa formation by using Dykstra Parson permeability variation (1950). Upper Safa shale gas formation as any unconventional reservoirs which are characterized by their very high degree of heterogeneity, is requiring to make zonation as dividing the Upper Safa formation into homogenous zones. Hence, this zonation is requiring to apply different methodologies for defining all available rock typing for this shale gas reservoir [11].

There are many difference methods that can be used for both of conventional and unconventional reservoirs rock typing as Amaefule et al. (1993) method, Modified Winland-Zheng method, Discrete rock typing method (DRT), permeability predictive model, and Flow zone indicator (FZI) groups.

However, applying two new developed rock typing techniques that can be applicable for unconventional shale reservoirs rock typing as specific surface area per grain volume rock typing method (SG), and by using total organic carbon content (TOC) values in rock typing by using the classification of Rock Eval pyrolysis for unconventional petroleum potential.

Most applicable methods for rock typing of gas shale unconventional reservoirs from the highest accuracy to the lowest respectively, depending on the previous methodologies of rock typing methods that have been used, are:

1- DRT

Table 1: DRT method results

DRT	Frequency	R2	Equation
13	12	88.9%	$K = 0.1225e^{49.818Q}$
12	9	83.2%	$K = 0.0661e^{44.357Q}$
11	14	94.1%	$K = 0.0018e^{93.693Q}$
10	21	84.11%	$K = 0.0029e^{60.961Q}$
9	28	93.9%	$K = 0.0002e^{112.19Q}$
8	41	86.9%	$K = 0.0003e^{58.679Q}$
7	63	83.9%	$K = 5E\text{-}05e^{66.321Q}$
6	49	85.6%	$K = 5E\text{-}05e^{41.814Q}$
5	51	73.6%	$K = 9E\text{-}06e^{47.13Q}$
4	46	91.9%	$K = 5E\text{-}07e^{140.06Q}$
3	92	92.7%	$K = 2E\text{-}07e^{137.32Q}$
2	30	84.6%	$K = 2E\text{-}07e^{115.47Q}$
1	7	80.4%	$K = 2E\text{-}07e^{72.528Q}$

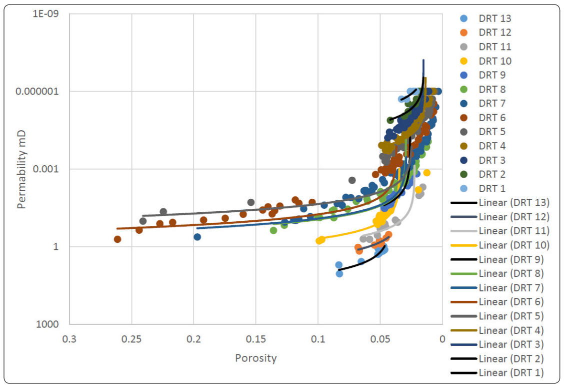

Figure 1.7: Relationship between permeability and porosity for discrete rock typing method

2- Specific surface area per unit grain volume rock type

Table 2: Specific surface area per unit grain volume rock type method results

SG group	Frequency	R2	Equation
More than 10	12	93.98%	$K = 1E\text{-}07e^{92.641Q}$
From 5 to 10	114	89.54%	$K = 2E\text{-}07e^{146.5Q}$
From 1 to 5	328	87.21%	$K = 77.011Q^{3.5211}$
From 0 to 1	76	60.49%	$K = 0.0001e^{149.81Q}$

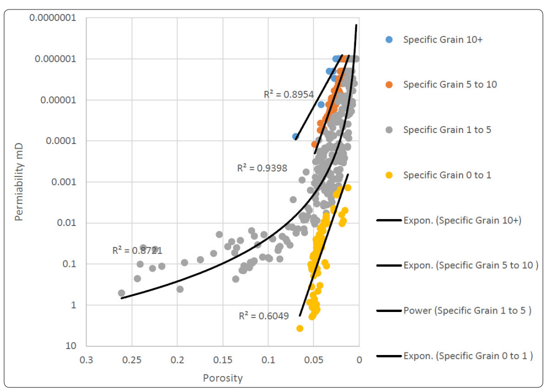

Figure 1.8: Relationship between permeability and porosity for SG method.

3- Amafuel et al. Method

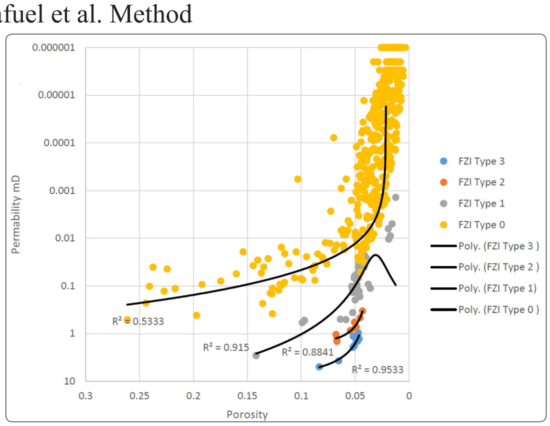

Figure 1.9: Relationship between permeability and porosity for Amaefule Rock typing.

Table 3: Amafuel rock typing method results

FZI	Frequency	R2	Equation
3	11	95.55%	$k = -987.49Q^2 + 235.18Q - 7.6935$
2	9	88.41%	$k = -838.25Q^2 + 130.24Q - 3.7235$
1	43	91.5%	$k = 211.32Q^2 - 13.126Q + 0.2262$
0	539	53.33%	$k = 2.7448Q^2 + 0.2531Q - 0.0067$

4- TOC

Table 4: Different quality degrees of source rocks. (Ghanima et al., 2015)

Petroleum Potential of an Immature Source Rock						
Organic Matter						
	TOC	Rock Eval-Pyrolysis		bitumen		hydrocarbons
Petroleum Potential	Wt.%	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 5: TOC groups method results

TOC Group	Frequency	R2	Equation
Excellent More than 4%	53	67.6%	k = 371.66Q4.4146
Very Good From 2 to 4%	132	66.4%	k = 207247Q6.0001
Good From 1 to 2%	138	71.95%	k = 1E-07e236.04Q
Fair From 0.5 to 1%	54	46.9%	k = 7E-07e199.39Q
Poor From 0 to 0.5%	109	80.23%	k = 3E-07e259.67Q

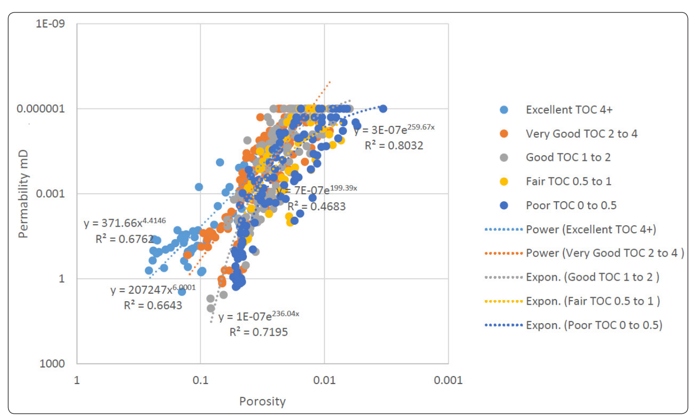

Figure 1.10: Relationship between permeability and porosity for TOC method.

5- Modified Zheng Winland

Rock Type	Nanoport	Microport	Mesoport	Marcoport	Megaport
Pore throat class	Less than 0.01 micron	0.01 to 0.5 micron	0.5 to 2 micron	2 to 10 micron	More than 10 micron
Reservoir	72.55%	21.6%	5.3%	0.55%	0%

Table 6: Modified Zheng Winland rock typing method results

R35 Zheng	Frequency	R2	Equation
Macroport	3	48.04%	k = 7940.3Q2.8059
Mesoport	22	18.39%	$k = -832.61Q^2 + 116.36Q - 2.881$
Microport	121	49.72%	$k = 1.4416Q^{1.5214}$
Nanoport	404	44.78%	$k = 6.2894Q^{3.242}$

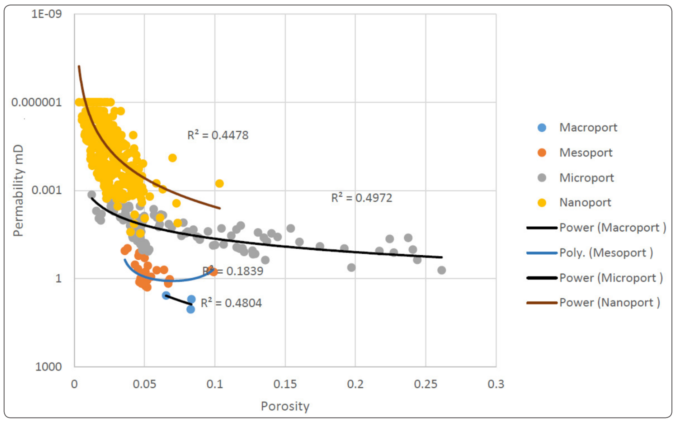

Figure 1.11: Relationship between permeability and porosity for Modified Zheng Winland

6- Permeability Group

Table 7: Permeability predictive rock typing model results

Permeability Group	Frequency	R2	Equation
More than 1 mD	15	24.9%	K = 0.828e13.223Q
0.1 to 1 mD	26	4.23%	K = 0.2996e-1.994Q
0.01 to 0.1 mD	59	15.9%	K = 0.0206e5.3506Q
0.001 to 0.01 mD	51	7.59%	K = 0.002e14.793Q
Less than 0.001 mD	335	37.48%	K = 1E-06e110.72Q

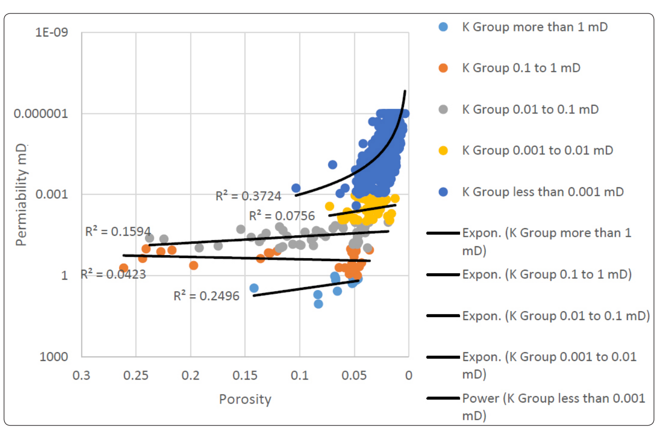

Figure 1.12: Relationship between permeability and porosity for Permeability group method

Summary of Rock Typing Methods Results

Table 8: Summary for the results of rock typing methods

Rock Type Method	Technique	Applicability R2 %	Number of Types
DRT	Conventional	87%	13
SG	New, Unconventional	85%	4
Amafuel	Conventional	84%	5
FZI Group	Conventional	70%	4
TOC Group	Unconventional	67%	5
Winland & Modified	Both	41%	4
Permeability Group	Conventional	18%	5

Conclusion

The results obtained from using of Dykstra Parson permeability variation, Upper Safa formation is highly heterogeneous formation which is very close to 100% heterogeneous formation, as any unconventional shale reservoirs due to the huge variation in the permeability ranges from milli-Darcy to nano-Darcy ranges [12].

The most applicable methods applied for rock typing of gas shale unconventional reservoirs ranging from the highest accuracy to the lowest respectively, depending on the discussed methodologies of rock typing, are the following:

1- Discrete Rock Typing DRT:
Discrete rock typing with the highest average accuracy of 87% and having a reservoir with 13 different discrete rock types. Thus, it is very applicable for both of conventional and unconventional reservoirs as the given case study of a shale gas reservoir.

2- Specific Surface Area per Unit Grain Volume Rock Type:
Specific surface area per unit grain volume rock typing is a new established approach of unconventional rock typing method with average accuracy of 85% and having a reservoir with 4 different rock types, after establishing new equation for estimating the specific surface area per unit grain volume values as function of normalized porosity.

3- Amafuel et al. Rock Typing:
Amafuel et al. rock typing with average accuracy of 84% and having a reservoir with 5 different rock types. Thus, it is very applicable to be used also for unconventional reservoirs as the given case study of a shale gas reservoir.

4- FZI Group Rock Typing Method:
Flow zone indicator values group rock typing method with average accuracy of 70% and having a reservoir with 4 different rock types.

5- TOC Rock Typing Method:
Total organic carbon content rock typing as an unconventional rock typing method is based on the Rock Eval Pyrolysis that depends on the degree and ranges of the quality of petroleum potential, with average accuracy of 67% and having a reservoir with 5 different rock types.

6- Winland and Modified Winland- Zheng Rock Typing Method:
Both of Winland and modified Winland- Zheng rock typing methods with average accuracy of 41% and having a reservoir with 4 different rock types.

7- Permeability Group:
Permeability group rock typing model with the lowest average accuracy of 18% and having a reservoir with 5 different rock types.

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