Libya and the Great Challenges of Overcoming Difficulties to Exploring and Producing Shale Gas, and Tight Reservoirs (Shale Oil) Potential*

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Search and Discovery Article #10850 (2016)**
Posted July 11, 2016

*Adapted from extended abstract prepared in conjunction with oral presentation given at AAPG GEO 2016, The 12th Middle East Geosciences Conference and Exhibition March 7-10, 2016, Manama, Bahrain

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Abstract

Oil and gas are the main economic drivers for Libya, as they are the sole cash sources for the country. The biggest challenge for Libya in the future will be placing more efforts to enhance oil and gas recovery, maintain high production levels, and find more hydrocarbon sources such as shale oil and shale gas reservoirs, and generally tight oil reservoirs, to add reserves. Libya is one of main producing countries in the region with daily production rate reaching 1.6 MBOPD. Libya was placed as one of the top ten producer countries during 1970's when it produced 3.3 MBOPD. Fluctuation of production in Libya is affected by several difficulties and different regimes. The question now is: Does the Country have the capacity to achieve such production level again? Clearly this question has a wide range of answers as it depends on geosciences, engineering and investment on the technical side. It also depends on the market demands in order to manage the Country's development. An intelligent approach to answering this question needs to consider all these elements.

The size and importance of the oil and gas sector makes it essential to give these tasks high priority. The oil and gas sector will play a significant role in Libya's economy, and to achieve full potential will require profound change from "business as usual". Libya has an opportunity to start the process for change and development of the industry that can be a major agent for transformation of all walks of life. With growing demands and price increases, Libya's efforts are exerting towards the undiscovered gas potential in the deep areas of the basins. These potential sources may be better accessed if geological and geophysical knowledge, innovation, and advanced technologies are used effectively. During 1980's with increases in gas prices and consumption, gas became an attractive commodity, and with successful exploration drilling new reserves were found. This encouraged Libya to start seeking a new strategy to increase the daily rate production of gas to exceed 3 billion cubic feet per day and become one of the biggest producer in the region. In addition to expanding gas production, tight gas areas were not explored. This article is based on previous geochemical studies integrated with the results of new exploration wells indicating the presence of several thick formations of organic facies of different ages, from Triassic to Paleocene. All of these data indicate three of Libya's major hydrocarbon basins are still underexplored, with plenty of room to discover new play from the tight sandstone and gas shales.

Introduction

Libya must seek new strategies to increase daily oil and gas production. Libyan oil and gas production started more than 55 years ago. Gas was not produced in commercial quantities at the time, but mostly flared and partly used for industrial purposes and some was injected into to maintain reservoir pressures in oil fields. During 1980's with increased gas prices and consumption, gas become an attractive commodity, and with successful exploration drilling, new reserves were added. Sirte Oil Company explored many gas pools in the Sirte Basin and western Libya, and development of the gas fields such as Attahdi, Asoumoued, Sahal, and Hattiba. Agip Oil Company also discovered huge gas potential in the Sabratha Basin. Waha Oil Company had new discoveries of oil, condensate, and gas fields in the eastern part of the Sirte Basin, North Gialo, Block NC98, and Faregh fields. These discoveries increased gas reserves of Libya to 60 trillion cubic feet. New advanced technology, and 3D seismic surveys will increase the chance of finding more gas reserves in the deep troughs. According to the results of some studies, with the application of high technology in Libya, this country will join the biggest unconventional and natural gas exporters by 2020. Gas from the new deep pools has been discovered and tested by Shell and Woodside at the Jahama Platform and tests recorded 1.50 TCFG/day and 13.0 MMCFG/day respectively.

Methodology

Different methodology, technology and various software have been used to evaluate the source rocks sequences in the three major prospective sedimentary basins. Geochemical, geological, and geophysical studies are being used to determine the source rocks type quality, quantity, and maturity, and to determine source rocks thickness, richness and timing of oil and gas generation and migration. Basin modeling and other software has been used to map oil and gas generation kitchens source thickness (Figure 1).

Libyan Basins Exploration History

Northeast Libya - Cyrenaica Area

Cyrenaica occupies an area of 160,000 km^2 it is bordered to west and south by elements of the greater Sirte Basin, the Ajdabiya Trough, and on the east by the Marmarica Platform of the western desert of Egypt (Figure 2). To date more than 2.5 billion barrels of oil-in-place have been discovered in the northeast Libya. Geochemical studies indicate northeast Libya is a fairly promising area for hydrocarbon potential, due to a favorable framework of structure and stratigraphy. The area contains Paleozoic, Mesozoic and Tertiary reservoirs and traps. Northeast Libya contains large quantities of continental and marine sediments. The sandstone reservoirs are widely distributed, with adequate volumes of source rocks sufficiently deeply buried to have generated hydrocarbon, and the presence of thick sections of shale for sealing potential.

Sirte Basin

The Sirte Basin is situated in the north-central part of Libya (Figure 2) and is the largest oil producer in Africa. It formed as a series of NW-SE trending horsts and grabens (platforms and troughs) by the collapse of the Sirte Arch during Lower Cretaceous time. The Sirte Basin covers more than 500,000 square kilometers of north-central Libya with recoverable reserves of 47 billion barrels of oil and about 50 TCFG, and is the most prolific basin in Libya. Exploration activities of Sirte Basin commenced during late 1950's with the first commercial discovery in 1958 (Well A1-32). During the first half of 1960's most of the giant fields were discovered bringing the Sirte Basin among the most oil productive basins in the world.

Combining available geological, geochemical, and basin modeling studies carried out by the National Oil Corporation of Libya (NOC) and other companies, there are several thick formations of organic facies of different ages from Triassic to Paleocene. There is also the possibility of deeper source rocks which have not been penetrated yet. Various depositional and environmental conditions, as well as different thermal maturities, organic matter and richness are reported in these source rocks. Multiple source rocks have been encountered in the Sirte Basin and identified in Upper Cretaceous sediments (Rakb Group), Lower Cretaceous sediments (Nubian, Middle Shale, shaly beds within Upper and Lower Nubian Sandstone), Triassic rocks, and other younger sediments (Paleocene). The source rocks present in Sirte Basin were derived from marine and terrestrial (higher plants) organic matter which produced both type II and type III kerogen (Figure 3 and Figure 4).

The total organic carbon content of Upper Cretaceous source rocks ranges from 1% up to 6%. After extraction the remaining 3% indicates good to excellent source rock, and in the Lower Cretaceous source rocks the total organic carbon content ranges from 0.5% up to 14% before extraction, and the remaining 6% indicates excellent organic facies. The thermal maturity model ranges from immature to post-mature source rocks.

Northwest Libya - Ghadames Basin

The Ghadames Basin is one of the most important sedimentary basins for producing oil and gas in Libya. This basin is located in northwest Libya and covers more than 200,000 km^2, extending into southern Tunisia and central Algeria, with total estimated recoverable oil of 6 billion barrel of oil, proven. The Ghadames Basin will be one of the very prolific basins for the future, with undiscovered potential estimated at more than 48 billion barrel of oil-in-place.

Murzuq Basin

The Murzuq Basin is bounded on the east by the Tibisti Arch, on the west by the Tihembada Arch (which separates it from the Illizi Basin in Algeria), on the north by the Qurcal Arch (which separates it from the Ghadamis Basin), and on the south by the Libyan and Chad borders. The intra-cratonic Murzuq Basin contains a series of troughs and uplifts that dominate the basin's deposition and hydrocarbon potential. Of particular significance is the Awabari Trough in the center of the basin where a series of cored wells (F3-NC174 and H29-NC115) have been drilled that provides a most valuable data set for this resource assessment. Within this trough, the Silurian Tanezzuft Formation, particularly its lower "hot shale" interval, is the primary hydrocarbon source rock for the oil discoveries in the Murzuq Basin (Belaid et al., 2010) (Figure 4 and Figure 5). Exploration for hydrocarbons within the Murzuq Basin commenced in the late 1950's but with only limited success until 1984, when Rompetro found six oil fields, three of which were declared commercial and one of which was a giant (NC115-A-1), with total field-complex in-place reserves reported to be in excess of a billion barrels of oil. This came on-stream in December 1996 and the whole El Sharara Field complex currently produces 159,000 bo/d (September 1999). The drilling campaign by BOCO in NC 101 resulted in seven significant oil discoveries in the 1980's, but due to the PSA agreements, the discoveries were not considered commercial

In 1996 LASMO and partners discovered the Elephant Field, NC174, covering some 35 sq km and holding recoverable reserves in excess of 500 MMBO, making it the largest discovery to have been made to date in the Murzuq Basin. The Murzuq Basin is believed to contain the largest volume of undiscovered hydrocarbons in all of Libya.

Libyan Offshore Hydrocarbon Evaluation

The offshore area of Libya is divisible into three broad zones, (1) the Pelagian Block in the west, down faulted during the Miocene tectonism, (2) the Sirte Embayment, extending from Misratah to the Ajdabiya Trough, and (3) the Cyrenaican Margin.

Tectonic development of the offshore can be assigned to four main phases. Continental rifting occurred during the Late Triassic in the Sabratah Basin, the Binghazi Basin and the area from Malta to north of the Cyrenaica Ridge. During the Mid-Jurassic the rift phase developed by crustal extension with the formation of oceanic crust on the Ionian abyssal plain. Extension continued and during the Late Cretaceous the Sabratah Basin developed as a pull-apart trough. The Alpine orogeny produced intense rifting in the Pelagian and Ionian seas, resulting in the formation of the Pantelleria Rift Zone, and subsidence in both the Sabratah and Binghazi Basins. The Northeast Libyan Offshore is divided into two provinces - the Benghazi Offshore Basin and Darnah-Tobruq Basin. Its location and geologic similarities can be favorably compared with Sirte Basin to the west and in the western desert of Egypt to the east. An evaluation of hydrocarbon potential of the different geologic terrains making up the area must focus on the prerequisites of reservoirs, source and seal for the Paleozoic, Mesozoic and Tertiary hydrocarbon system.

The Benghazi Offshore Basin is largely an offshore basin located in the northeast part of Cyrenaica. This basin is formed on the remnant northwest flank of the Cyrenaica passive margin, and contains rocks of Mesozoic and Tertiary age including a thick complete section of the Cretaceous and Paleocene. This rock thin towards the northern boundary of the basin and deepens to the southwest.

The Darnah-Tobruq Basin is mostly an offshore basin located in the northeast part of the Cyrenaica region. This Basin formed on the northern edge of the Cyrenaica passive margin. It is bordered on the south by the Sirul Trough, on the west by the Al Jable al Akhar Uplift, and on the northwest by the Darnah high. The sedimentary section in the Darnah-Tobruq Basin is made up of sediments ranging in age from Mesozoic to Tertiary and the Cretaceous section is thick and complete.

Al Kufrah Basin

The Al Kufra Basin is a large 400,000 km^2, remote intra-cratonic sag basin located in southeastern Libya. The Palaeozoic structural and depositional history of the Al Kufra Basin is similar to that of the Murzuq Basin, discussed earlier. However, there is considerable uncertainty as to the presence of sufficiently organic-rich source rocks in the Kufrah. The Lower Silurian Tannezuft Formation is described as up to 130 m thick in outcrops at the basin margins (Figure 6). However, the basal section of the Tannezuft Formation containing the Silurian “hot shale” in the Murzuq Basin appears to be missing in outcrops along the northern and eastern margins of the basin (Lüning et al., 1999). In addition, the “hot shale” unit was absent in three exploration wells drilled to date, having been replaced by siltstones and sandstones in two dry exploration wells drilled in the northern part of the basin by AGIP in the late 1970’s and early 1980’s (Bellini et al., 1991). The absence of Lower Silurian shales in these two Al Kufrah Basin exploration wells (A1-NC-43 and B1-NC43) suggests that this area may have been deposited as a sandy delta during the Early Silurian, representing the westward continuation of the sandy Lower Silurian in western Egypt where the Tanezzuft basal "hot shale" is also absent.

Prospective Areas

The Hercynian tectonic event that separated the area into a series of horsts and grabens (uplifts and troughs) filled with Cambrian though Oligocene sediments. This tectonic overprint is a key factor in defining and limiting the shale gas and oil prospective areas, as discussed for each of these assessed basins of Libya (Figure 4). The regionally dominant Lower Silurian Tanezzuft basal or "hot shale" and the Upper Devonian Frasnian Shale are assessed in the Ghadamis Basin. Distinct Late Cretaceous shales, the Sirte/Rachmat and Etel are the subject of our shale resource assessment in the Sirte Basin (Figure 3 and Figure 4).The basal "hot shale" within the Silurian Tanezzuft Formation is the main shale formation assessed in the Murzuq Basin (Table 1). It is likely that future exploration will identify additional shale resources in Libyan sedimentary basins. Cretaceous shale in Sirte Basin and Silurian shale in Ghadames and Murzuq basins have favorable properties of shale gas and shale oil, and have similar characteristics to the Marcellus Shale in the USA (Table 1).

Results and Discussion

This study has compiled the results of available geological, geochemical, and basin modeling studies carried by the National Oil Corporation of Libya (NOC) and other companies, all indicating the presence of several thick formations of organic facies of different age, such as Cretaceous shales in the Sirte Basin, and Silurian and Devonian shales in the Gahdamas and Murzuq basins. The presence of good source potential in the three major prospective areas Sirte, Gahdamas and Murzuq basins has favorable properties of shale gas and shale oil. Furthermore, this potential was recorded in the past during drilling operations. Well files and final reports indicate gas kicks occurred during drilling operation within Lower Sirte Shale and Tagreift formations in wells Y1-13, 6J5, and 6J7-59 North Gialo, 4E2a-59 and 4C1-59 (Figure 7). Shale oil tested in well A1-59 in the Harash Field within the Lower Sirte Shale Formation was 500 BOPD. In well Y1-13 the gas kick occurred in the Lower Sirte Shale, and it took twenty days for the crew to control the kick. The total expected unconventional reserves is about 30 BBO of recoverable shale oil, and 90 TCFG of recoverable of shale gas; the most prospective areas of this potential are at the Jahama Platform - Sirte Basin and Atshan Saddle in western Libya (Figure 7, Figure 8, and Figure 9). This reserve is estimated based on the available geological and geochemical data, combined with proven explored reserves in the three major basins. Location, volume of hydrocarbon resources, purity and quality will play a significant role in the future investment in upstream and downstream oil and gas in Libya.

Opportunity and Challenges

Libya has an excellent opportunity to exceed the daily production rate of oil and gas if the government and decision makers start work in taking steps to explore and discover the unconventional and remaining conventional reserves. Libya is seeking a new strategy to increase the daily rate production of gas and oil to exceed 3 billion cubic feet per day and 3 million barrels of oil per day to become one of the biggest producers in the region. This task can be achieved if advanced technology is used to start producing shale gas and shale oil. Libya still has huge potential to be found, exceeding 60 BBO and 120 TCFG recoverable from both conventional and unconventional reserves. According to the last geological survey carried out by the EIA in 2013, the total estimated reserves of shale oil and shale gas as summarized in Table 3A, Table 3B, Table 4A, and Table 4B. Libya is considered one of the ten top countries with large reserves of shale oil and shale gas (Table 2).

There is still plenty of potential to discover new plays from the tight oil sandstones and gas shales. Advantages come from the diversity and richness of its basins and the relative immaturity of exploration. Serious underinvestment by the previous government provides a great opportunity for growing reserves through application of modern reservoir management techniques. Libya just needs the right skills (management and technical) and funds to be applied. Most of this potential is onshore, about 60% of this potential was explored in the past. One of the big challenges facing Libya is the absence of a strong government to secure the National and international companies to resume their activities. Technology challenges to explore and develop the oil fields and renew the infrastructure. Pollution and environmental impactions are also big challenges.

Conclusions

This shale gas and shale oil resource assessment addresses three of Libya's major hydrocarbon basins: the Ghadamis Basin in the west, the Sirte Basin in the centre, and the Murzuq Basin in the southwest of the country (Figure 4). One additional basin, the Al Kufrah Basin in the southeast, is discussed but is not quantitatively assessed due to the speculative and limited nature of the available data (ARI, 2013). We estimate that these three basins in Libya contain 942 TCF of risked shale gas-in-place, with 122 TCF as the risked, technically recoverable shale gas resource (Table 3A and Table 3B). In addition, the shale formations in these three basins contain 613 billion barrels of risked shale oil and condensate in-place, with 26.1 billion barrels as the risked, technically recoverable shale oil resource (Table 4A and Table 4B) (ARI, 2013). These figures are based on old published data and some source facies are not addressed as source potential, for instance the argillaceous Harash Formation, Tagrift Shale, Harash Argillaceous Limestone have good potential within the Intesar and Rahla fields due to low permeability the production rate not exceeding 150 BOPD. This new information increases the chances for Libya to boost the reserves of shale gas and shale oil. The three prospective basins in Libya are still underexplored and the boundary of the source rocks are not well known, offering the opportunity to penetrate new source rock in the deepest part of the basins (the deep troughs).It is believed the low porosity (tight) rocks contain significant volumes of hydrocarbons. Libya has tremendous future potential to play a significant role in the oil and gas industry in upstream and downstream investment.

Recommendations

- Initiate studies to evaluate all Libyan sedimentary basins, for the potential of unconventional hydrocarbon resources with emphasis on shale gas and tight oil.
- Study the environmental impact of producing shale oil.
- Evaluate the economic feasibility in the light of high costs of drilling and completion, also the shortage of services and know how.
- Evaluate the impact of water withdrawal required for drilling and hydraulic fracturing on our limited water resources, considering alternatives such as recycling water or using gas instead.
- New laws and regulations must be adapted to allow the exploration and exploitation of unconventional resources.

- Revise EPSA4 agreement model to accommodate exploration and development of unconventional resources terms and conditions.
- Start building a data library to store and arrange all data related to unconventional resources.
- Establish a laboratory for geochemical, petrophysical, and geotechnical analysis, where all cores and rock samples must be collected from all company's working in Libya and handle them in a better way.

Acknowledgements

I would like to express my deep thanks to the Chairman of NOC and all of NOC Management Committee for their support and efforts within the oil industry to achieve success. My deep thanks and gratitude go to the management of Waha Oil Company for making available the time and resources to execute this study. My special thanks go to the exploration department management and my colleagues for all the kind support they have given me to help complete this study and my thanks are also extended to Abdraouf El Habroush for all his help during this study. My special thanks are also extended to my father for his great stands for all my family.

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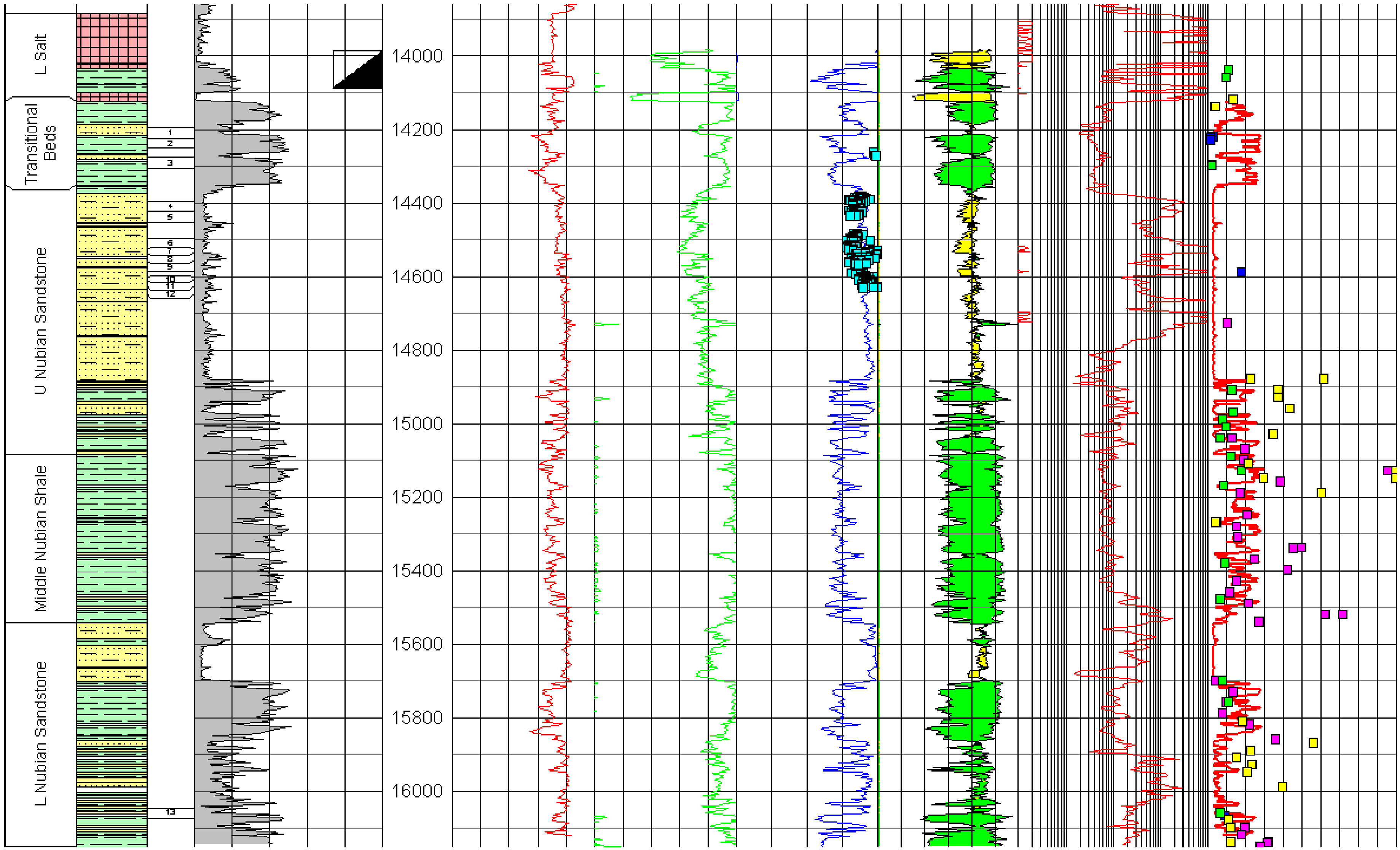


Figure 1. Shows techniques used for source rocks evaluation.

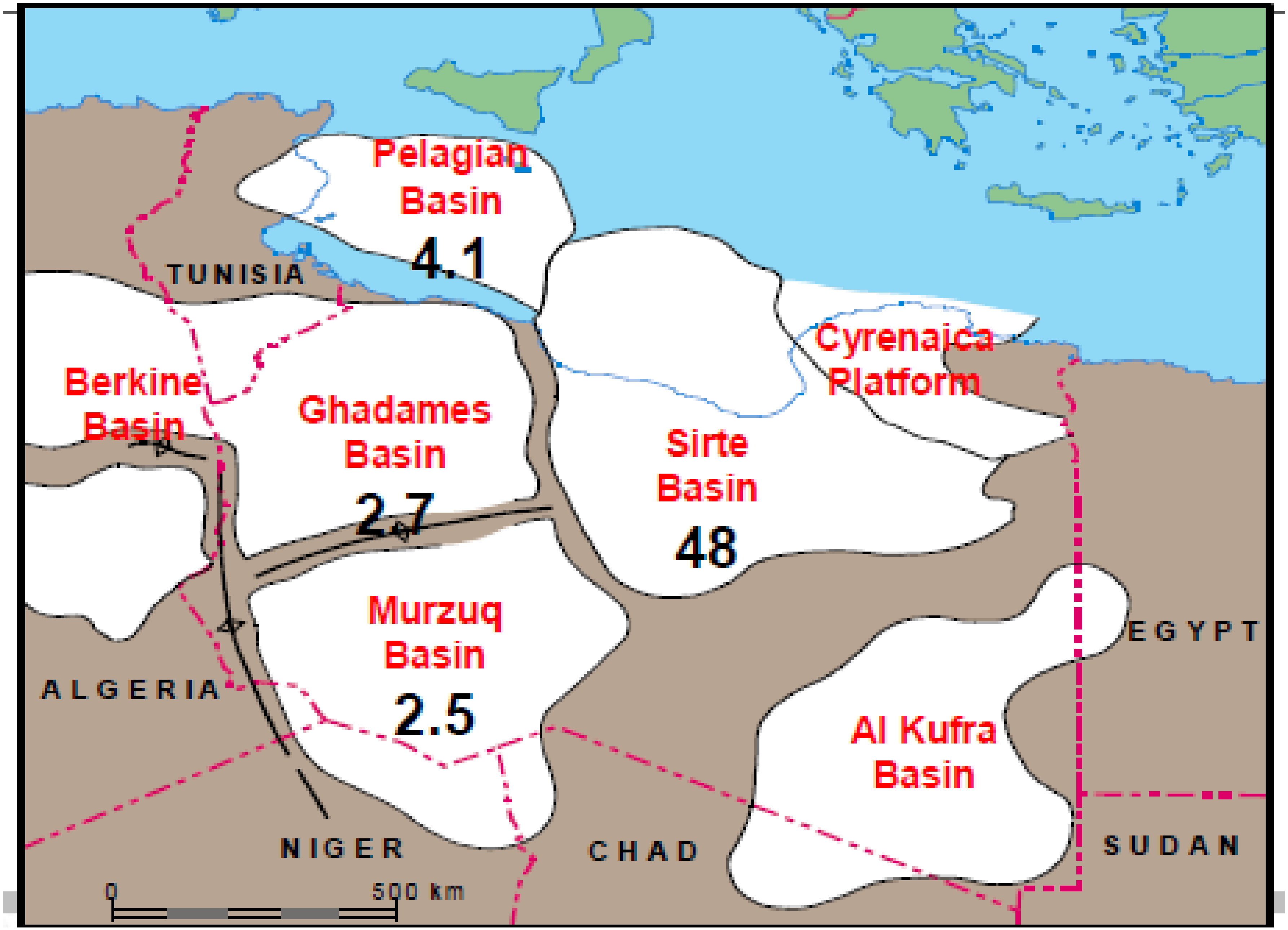


Figure 2. Map shows the location of onshore and offshore sedimentary basins in Libya and proven discovered potential.

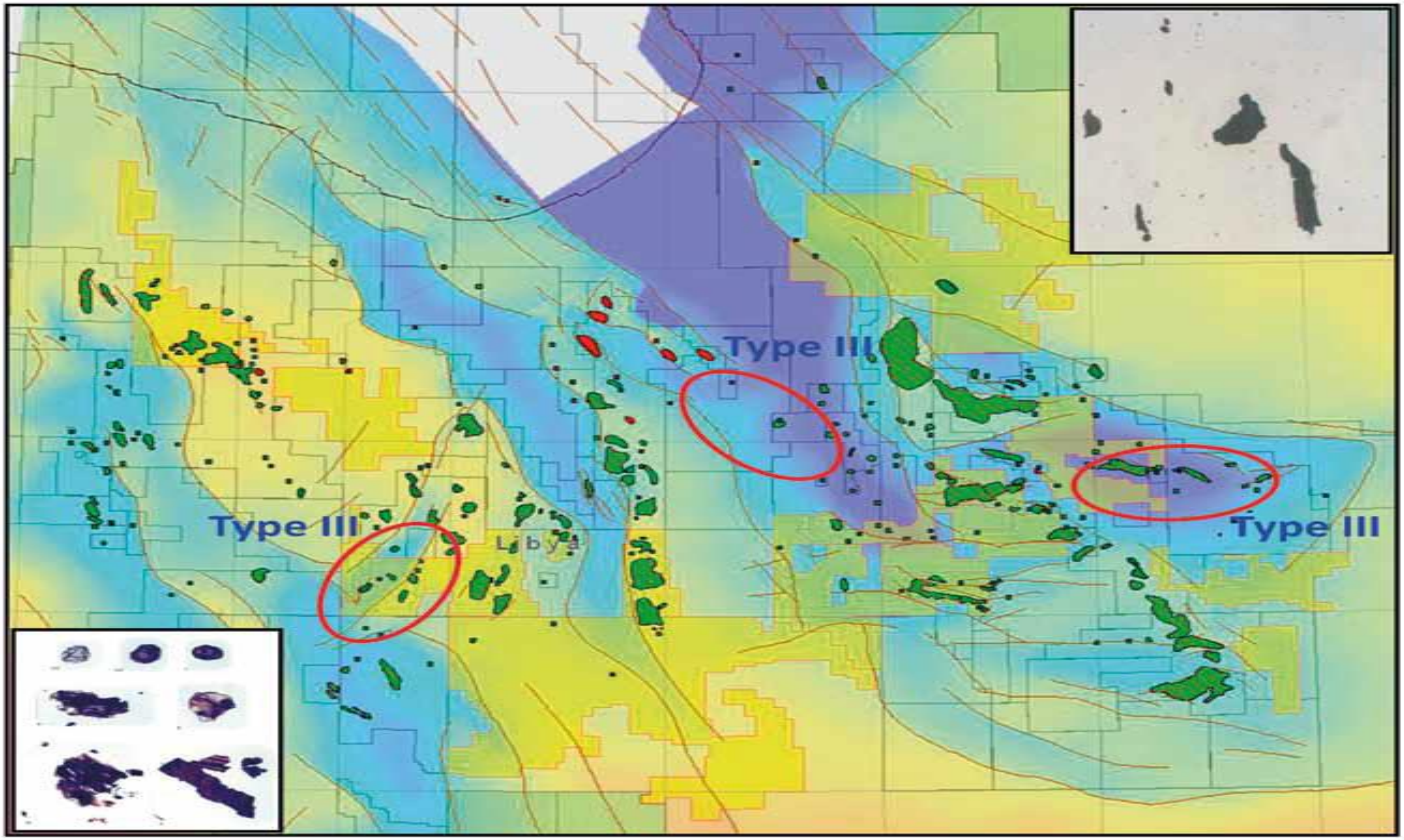


Figure 3. Map shows the distribution of organic matter, (kerogen type iii), which is typical for gas prone (Source Geology of southern Libya 2008).

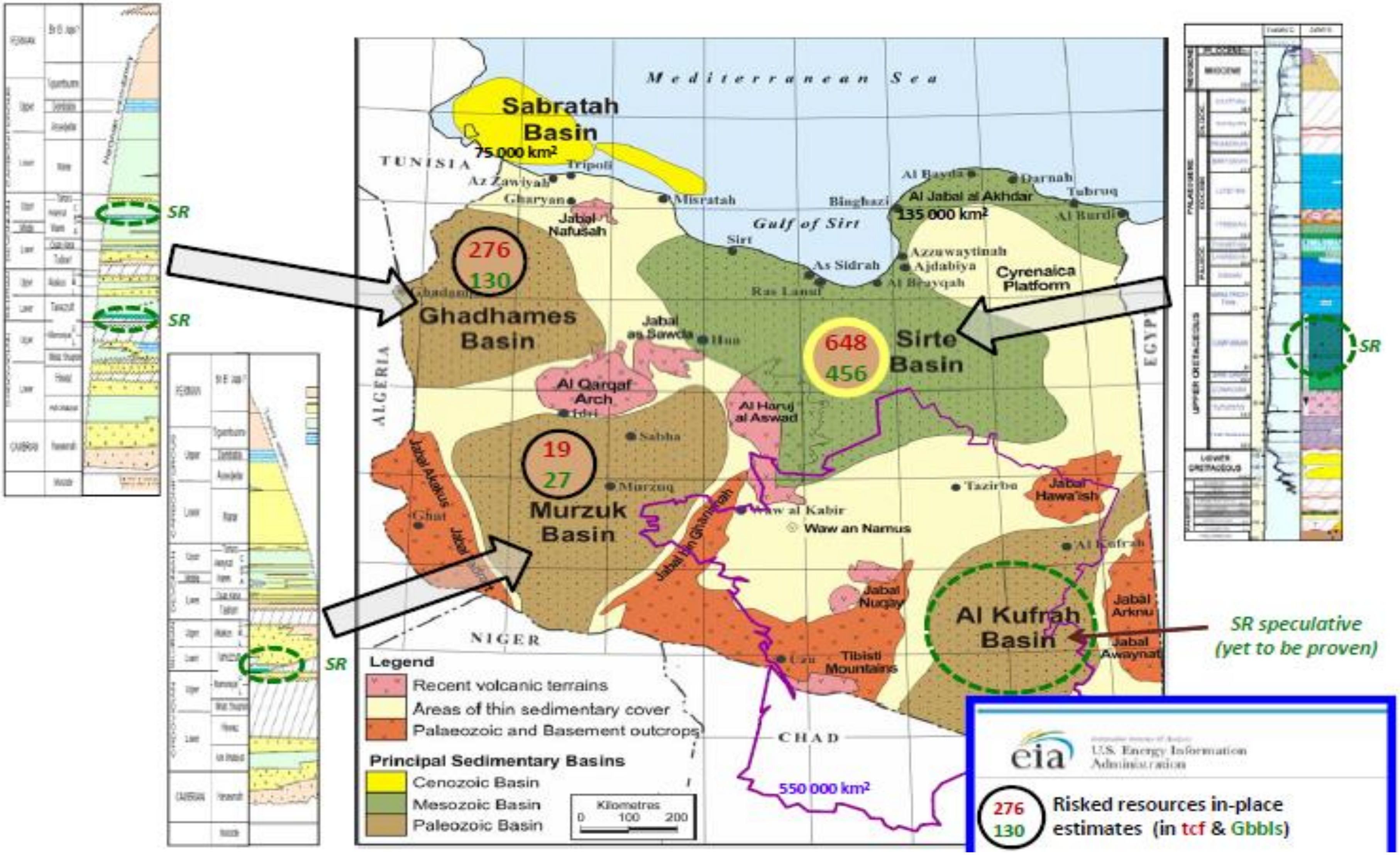


Figure 4. Map shows the prospective areas in Libya: Sirte, Ghadhames, and Murzuq (Murzuk) basins.

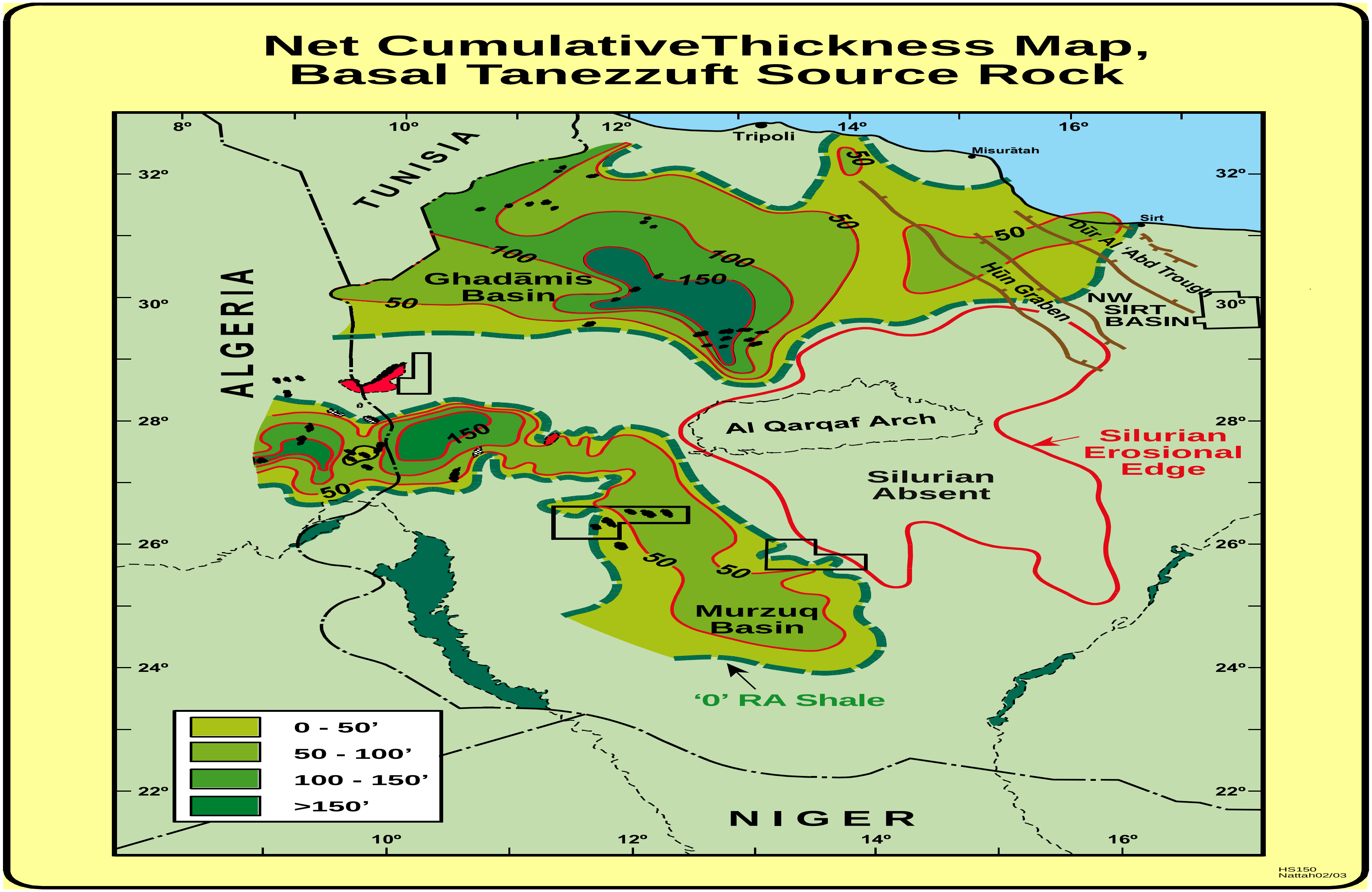


Figure 5. Map shows the net thickness of basal Tanezzuft source rock in Gahdames and Murzuq basins.

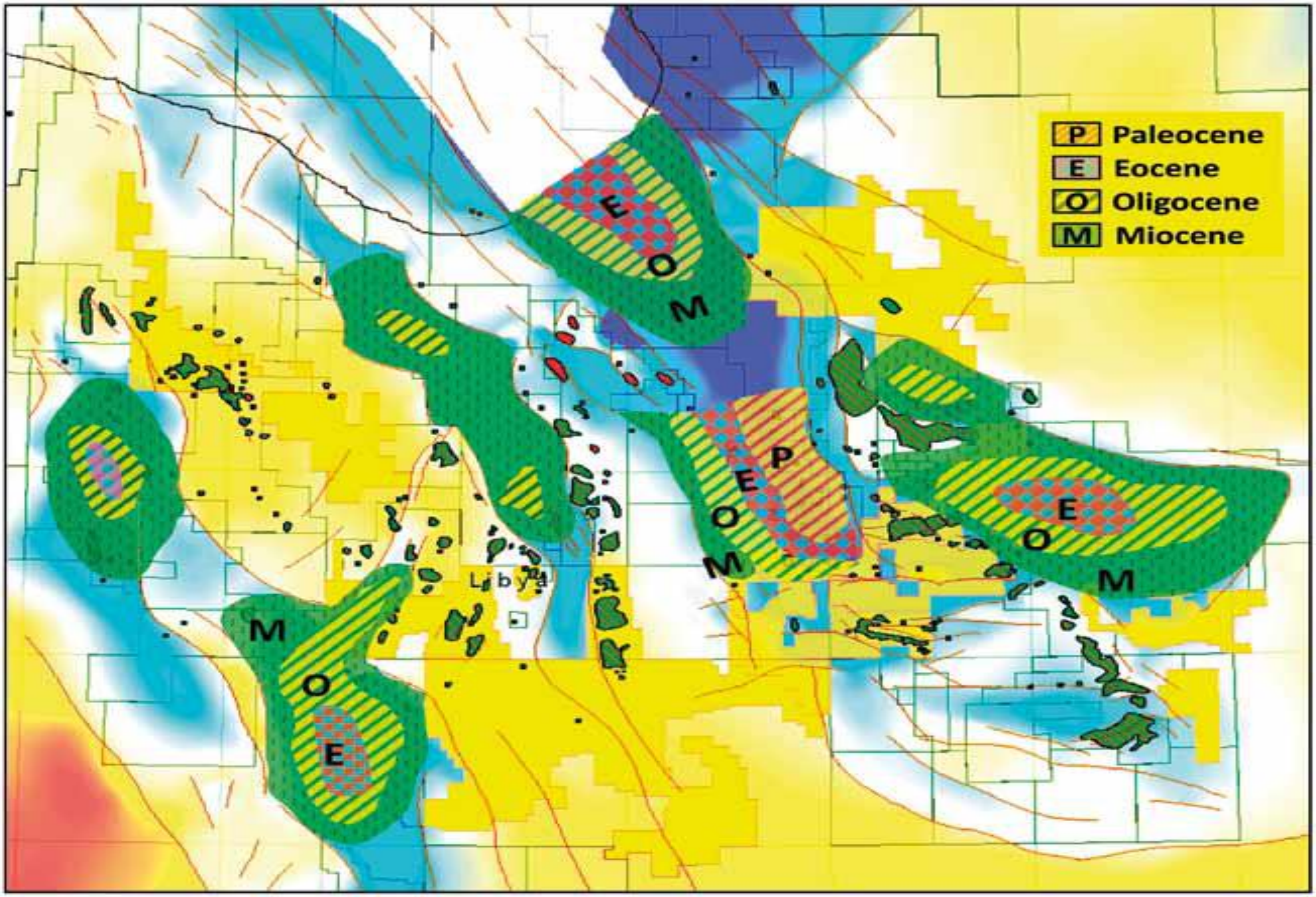


Figure 6. Map shows stages of hydrocarbon generation in Sirte Basin (Source Geology of southern Libya, 2008).

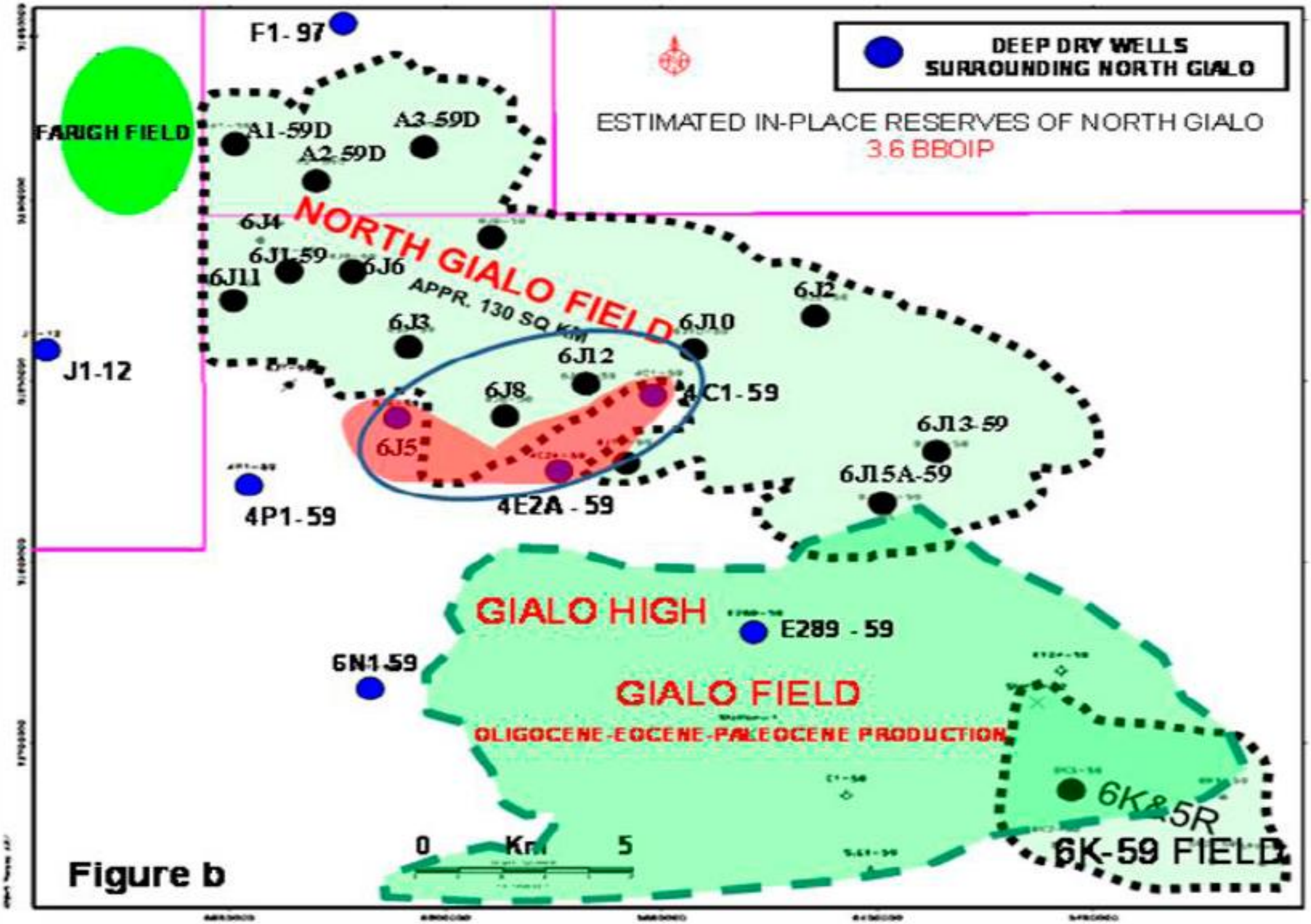
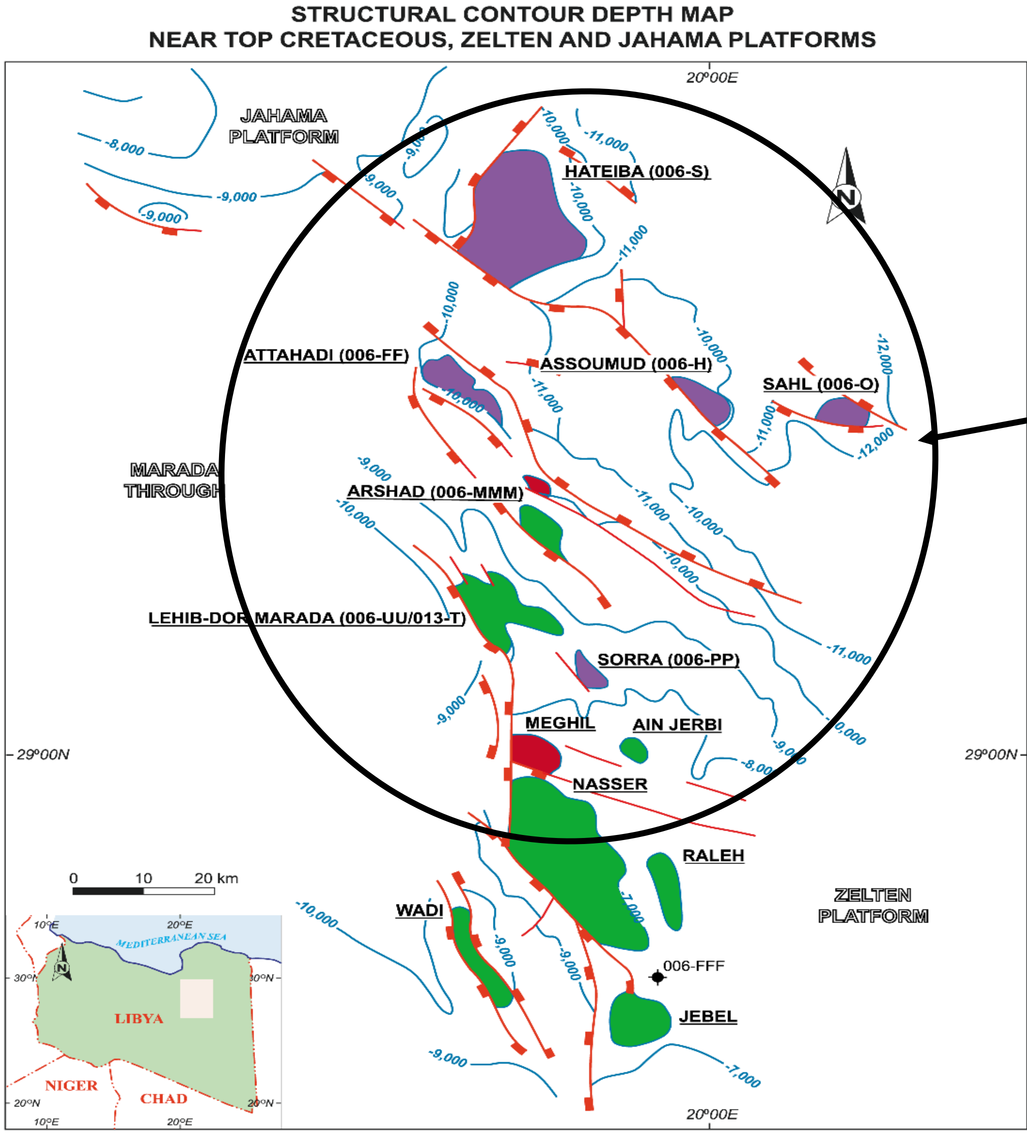


Figure 7. Map shows the high prospective area in the Sirte Basin, the North Gialo new discovery.



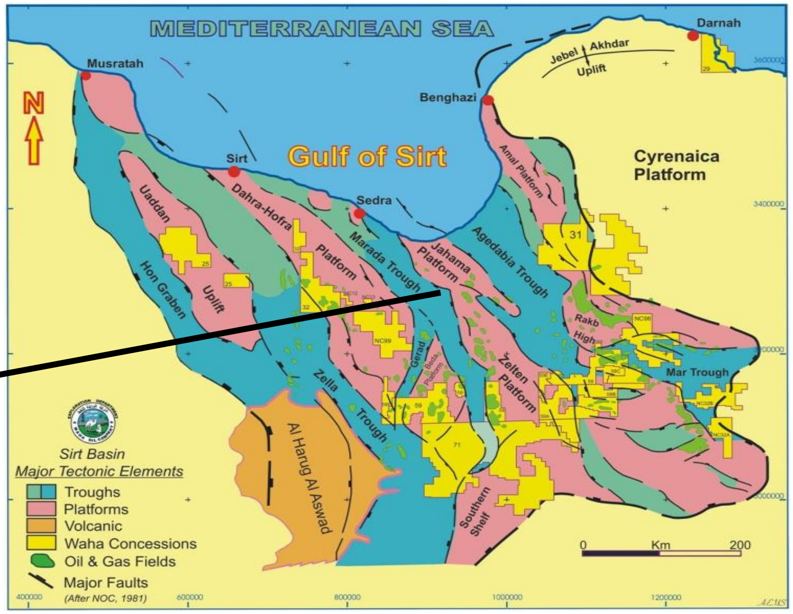


Figure 8. Map shows the prospective areas for future shale gas and shale oil potential of the Sirte Basin.

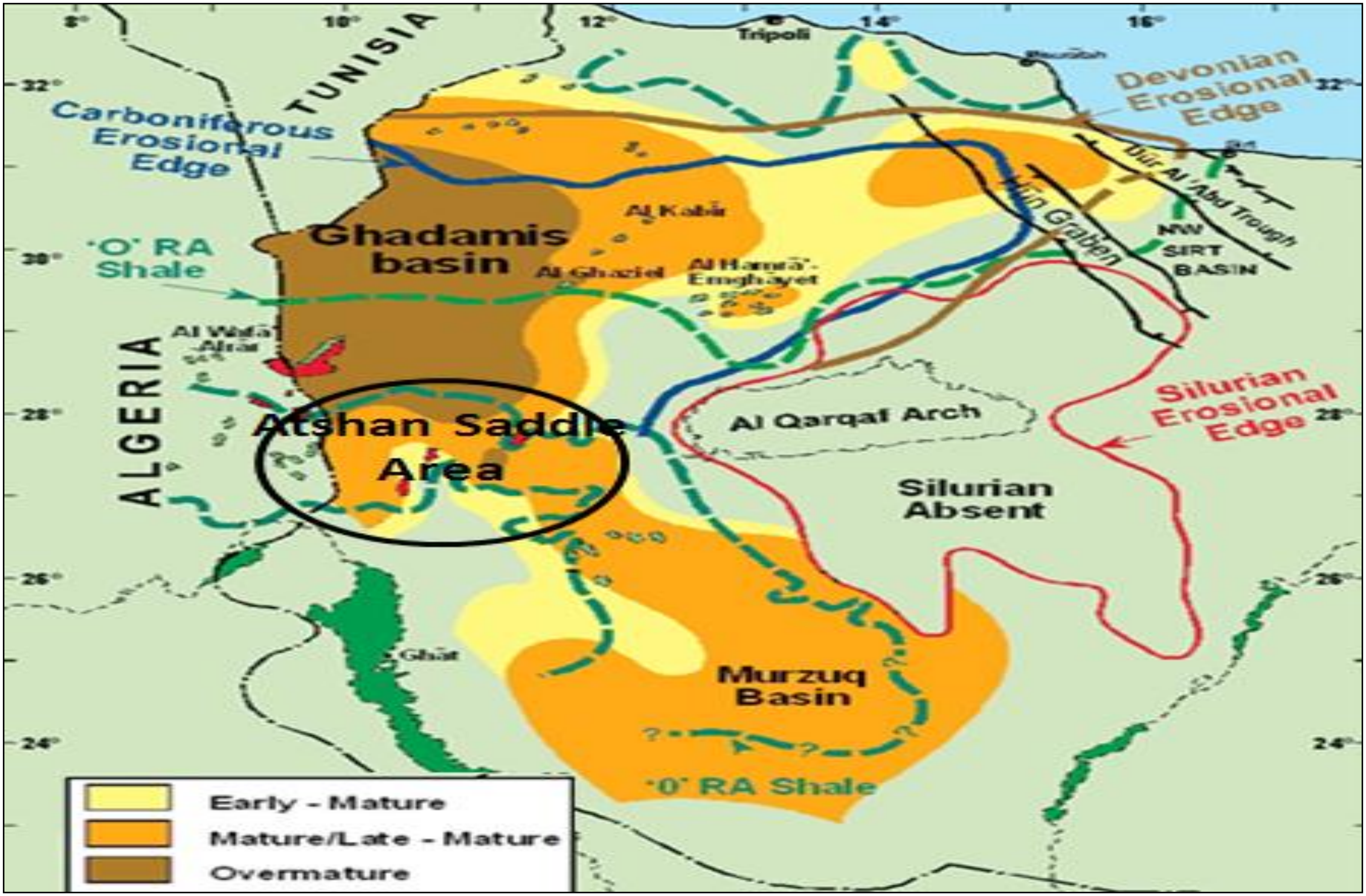


Figure 9. Map shows the prospective areas for future shale gas and shale oil potential at the Atshan Saddle in western Libya.

Shale Reservoir	**Barnett**	**Marcellus**	**Tanezzuft Hot Shale**	**Awaynat Wanin (Cues) Shale**	**Sirte Shale**
Total Organic Carbon (%TOC)	4.5	3 to 12	5.7	4.2	2.8
Kerogen Type	Type II marine	Type II marine	Type II marine	Type II marine	Type II marine
Thickness (ft)	100-600	50-200	65-165	>650	1,000-2,950
Depth (ft)	6,500-8,500	4,000-8,500	~8,000-10,000	~7,000-8000	~6,000-15,000
Basin Depositional Setting	Foreland	Foreland	Passive margin	Passive margin	Rift
Preserved basin area (square miles)	**5,000**	**95,000**	**Libyan portion (>500,000)**	**Libyan portion (>500,000)**	**193,000**

Table 1. Comparison of key characteristics of Shale Gas Plays.

Table-2, Shows. Top 10 countries with technically recoverable shale oil resources			
Rank	Country	Shale oil (billion barrels)	
1	Russia	75	
2	U.S. [1]	58	(48)
3	China	32	
4	Argentina	27	
5	Libya	26	
6	Australia	18	
7	Venezuela	13	
8	Mexico	13	
9	Pakistan	9	
10	Canada	9	
	World Total	345	(335)

[1] EIA estimates used for ranking order. ARI estimates in parentheses. *(Source: ARI, 2013)*

Table 2. Shows top 10 countries with technically recoverable shale oil resources.

Basic Data	Basin/Gross Area		Ghadames (117,000 mi^2)					
	Shale Formation		Tannezuft			Frasnian		
	Geologic Age		L. Silurian			U. Devonian		
	Depositional Environment		Marine			Marine		
Physical Extent	Prospective Area (mi^2)		16,440	3,350	2,580	1,570	370	30
	Thickness (ft)	Organically Rich	115	115	115	197	197	197
		Net	104	104	104	177	177	177
	Depth (ft)	Interval	10,000 - 11,000	10,500 - 11,500	11,000 - 14,500	8,000 - 10,000	9,000 - 10,000	11,000 - 12,000
		Average	10,500	11,000	13,000	8,500	9,500	11,500
Reservoir Properties	Reservoir Pressure		Mod. Overpress.	Mod. Overpress.	Mod. Overpress.	Mod. Overpress.	Mod. Overpress.	Mod. Overpress.
	Average TOC (wt. %)		5.7%	5.7%	5.7%	6.0%	6.0%	6.0%
	Thermal Maturity (% Ro)		0.85%	1.15%	1.60%	0.85%	1.15%	1.35%
	Clay Content		Medium	Medium	Medium	Medium	Medium	Medium
Resource	Gas Phase		Assoc. Gas	Wet Gas	Dry Gas	Assoc. Gas	Wet Gas	Dry Gas
	GIP Concentration (Bcf/mi^2)		11.8	43.4	54.5	25.4	79.8	93.1
	Risked GIP (Tcf)		96.9	72.7	70.3	19.9	14.8	1.4
	Risked Recoverable (Tcf)		9.7	14.5	17.6	2.0	3.0	0.3

Table 3A. Shale gas reservoir properties and resources of Libya (Source: ARI, 2013)

	Basin/Gross Area		Sirte (172,000 mi^2)		Murzuq (97,000 mi^2)
Basic Data	Shale Formation		Sirte/Rachmat	Etel Fm	Tannezuft
	Geologic Age		U. Cretaceous	U. Cretaceous	L. Silurian
	Depositional Environment		Marine	Marine	Marine
Physical Extent	Prospective Area (mi^2)		35,240	19,920	5,670
	Thickness (ft)	Organically Rich	2,000	600	67
		Net	200	120	60
	Depth (ft)	Interval	10,000 - 12,000	11,000 - 16,400	3,300 - 10,000
		Average	11,000	13,500	6,500
Reservoir Properties	Reservoir Pressure		Normal	Normal	Mod. Overpress.
	Average TOC (wt. %)		2.8%	3.6%	7.0%
	Thermal Maturity (% Ro)		0.85%	1.15%	0.90%
	Clay Content		Medium	Medium	Medium
Resource	Gas Phase		Assoc. Gas	Wet Gas	Assoc. Gas
	GIP Concentration (Bcf/mi^2)		24.8	37.4	6.5
	Risked GIP (Tcf)		349.8	297.9	18.6
	Risked Recoverable (Tcf)		28.0	44.7	1.9

Table 3B. Shale gas reservoir properties and resources of Libya (Source: ARI, 2013)

Basic Data	Basin/Gross Area		Ghadames ($117,000\ mi^2$)			
	Shale Formation		Tannezuft		Frasnian	
	Geologic Age		L. Silurian		U. Devonian	
	Depositional Environment		Marine		Marine	
Physical Extent	Prospective Area (mi^2)		16,440	3,350	1,570	370
	Thickness (ft)	Organically Rich	115	115	197	197
		Net	104	104	177	177
	Depth (ft)	Interval	10,000 - 11,000	10,500 - 11,500	8,000 - 10,000	9,000 - 10,000
		Average	10,500	11,000	8,500	9,500
Reservoir Properties	Reservoir Pressure		Mod. Overpress.	Mod. Overpress.	Mod. Overpress.	Mod. Overpress.
	Average TOC (wt. %)		5.7%	5.7%	6.0%	6.0%
	Thermal Maturity (% Ro)		0.85%	1.15%	0.85%	1.15%
	Clay Content		Medium	Medium	Medium	Medium
Resource	Oil Phase		Oil	Condensate	Oil	Condensate
	OIP Concentration ($MMbbl/mi^2$)		12.0	3.1	31.3	7.0
	Risked OIP (B bbl)		98.8	5.1	24.6	1.3
	Risked Recoverable (B bbl)		4.94	0.26	1.23	0.06

Table 4A. Shale oil reservoir properties and resources of Libya (Source: ARI, 2013)

	Basin/Gross Area		Sirte (172,000 mi²)		Murzuq (97,000 mi²)
Basic Data	Shale Formation		Sirte/Rachmat	Etel Fm	Tannezuft
	Geologic Age		U. Cretaceous	U. Cretaceous	L. Silurian
	Depositional Environment		Marine	Marine	Marine
Physical Extent	Prospective Area (mi^2)		35,240	19,920	5,670
	Thickness (ft)	Organically Rich	2,000	600	67
		Net	200	120	60
	Depth (ft)	Interval	10,000 - 12,000	11,000 - 16,400	3,300 - 10,000
		Average	11,000	13,500	6,500
Reservoir Properties	Reservoir Pressure		Normal	Normal	Mod. Overpress.
	Average TOC (wt. %)		2.8%	3.6%	7.0%
	Thermal Maturity (% Ro)		0.85%	1.15%	0.90%
	Clay Content		Medium	Medium	Medium
Resource	Oil Phase		Oil	Condensate	Oil
	OIP Concentration ($MMbbl/mi^2$)		28.8	6.3	9.5
	Risked OIP (B bbl)		405.9	50.5	26.9
	Risked Recoverable (B bbl)		16.24	2.02	1.34

Table 4B. Shale oil reservoir properties and resources of Libya (Source: ARI, 2013)