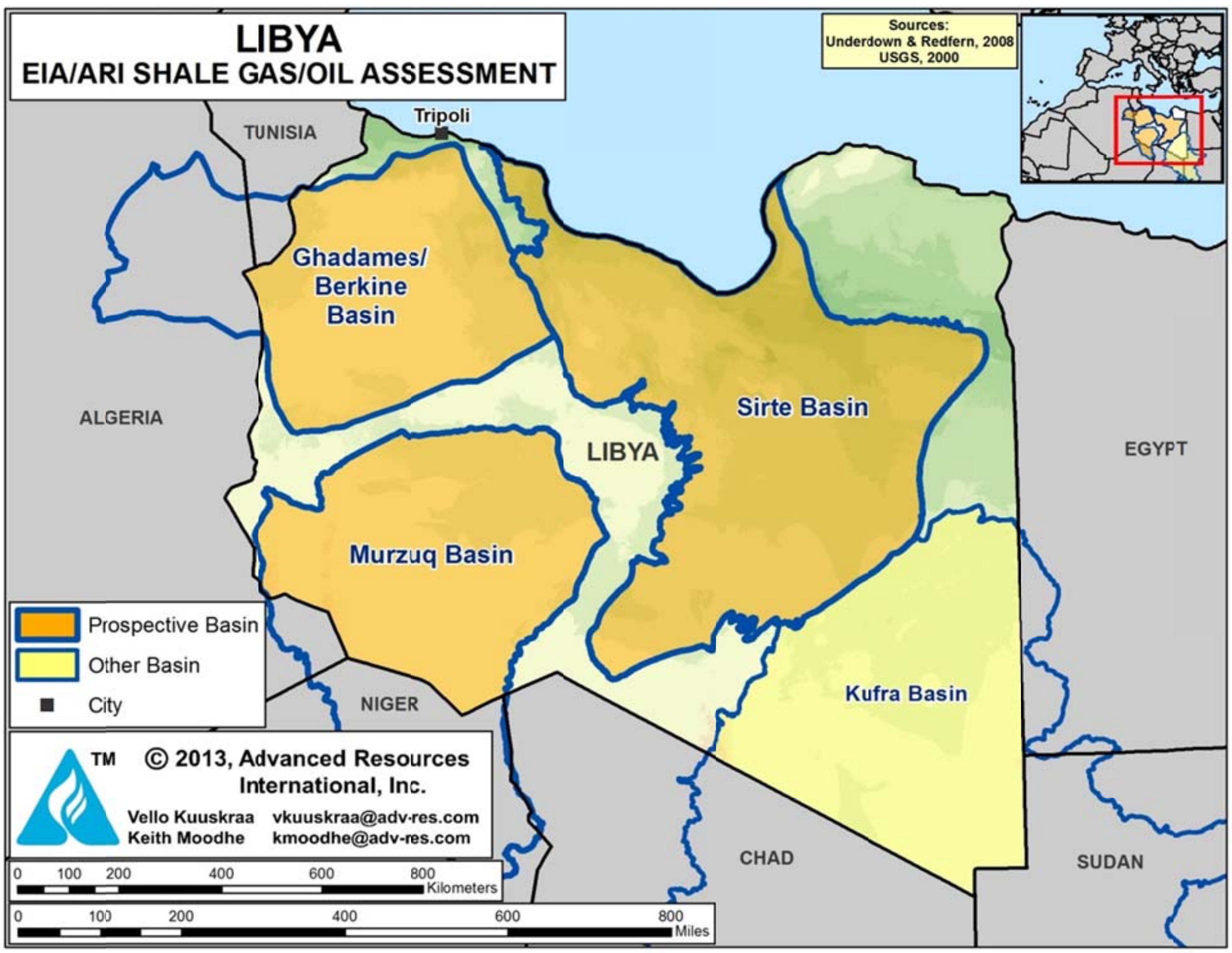
# XVII. LIBYA

## SUMMARY

This shale gas and shale oil resource assessment addresses three of Libya's major hydrocarbon basins: the Ghadames (Berkine) Basin in the west, the Sirte Basin in the center, and the Murzuq Basin in the southwest of the country, Figure XVII-1. One additional basin, the Kufra Basin in the southeast, is discussed but is not quantitatively assessed due to the speculative and limited nature of the available data.

Figure XVII-1. Shale Gas and Shale Oil Basins of Libya




Source: 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, Tables XVII-1A and 1B. In addition, the shale formations in these three basins also 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, Tables XVII-2A and 2B.

Table XVII-1A. Shale Gas Reservoir Properties and Resources of Libya.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 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 XVII-1B. Shale Gas Reservoir Properties and Resources of Libya.

| | | | | | |
|---|---|---|---|---|---|
| Basic Data | Basin/Gross Area | | Sirte (172,000 mi$^2$) | | Murzuq (97,000 mi$^2$) |
| | 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 XVII-2A. Shale Oil Reservoir Properties and Resources of Libya.

| | | | | | | |
|---|---|---|---|---|---|---|
| Basic Data | Basin/Gross Area | | Ghadames (117,000 mi²) | | | |
| | Shale Formation | | Tannezuft | | Frasnian | |
| | Geologic Age | | L. Silurian | | U. Devonian | |
| | Depositional Environment | | Marine | | Marine | |
| Physical Extent | Prospective Area (mi²) | | 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/mi²) | | 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 XVII-2B. Shale Oil Reservoir Properties and Resources of Libya.

| | | | | | |
|---|---|---|---|---|---|
| Basic Data | Basin/Gross Area | | Sirte (172,000 mi²) | | Murzuq (97,000 mi²) |
| | Shale Formation | | Sirte/Rachmat | Etel Fm | Tannezuft |
| | Geologic Age | | U. Cretaceous | U. Cretaceous | L. Silurian |
| | Depositional Environment | | Marine | Marine | Marine |
| Physical Extent | Prospective Area (mi²) | | 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/mi²) | | 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 |

## INTRODUCTION

Libya is one of the important hydrocarbon producing countries of North Africa, with a successful history of oil and gas exploration, particularly in the Sirte Basin. The geologic setting of Libya's sedimentary basins is complex, having been formed by a series of tectonic events, the Hercynian 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.

The regionally dominant Lower Silurian Tannezuft basal or "hot shale" and the Upper Devonian Frasnian Shale are assessed in the Ghadames (Berkine) Basin. Two distinct Late Cretaceous shales -- Sirte/Rachmat and Etel -- are the subject of our shale resource assessment in the Sirte Basin. The basal "hot shale" within the Silurian Tannezuft Formation is the main shale formation assessed in the Murzuq Basin.

While our shale resource assessment has targeted three of Libya's most prospective basins and their shale source rocks, it is likely that future exploration will identify additional shale resources in other basins and formations.

# 1. GHADAMES (BERKINE) BASIN

## 1.1 Introduction and Geologic Setting

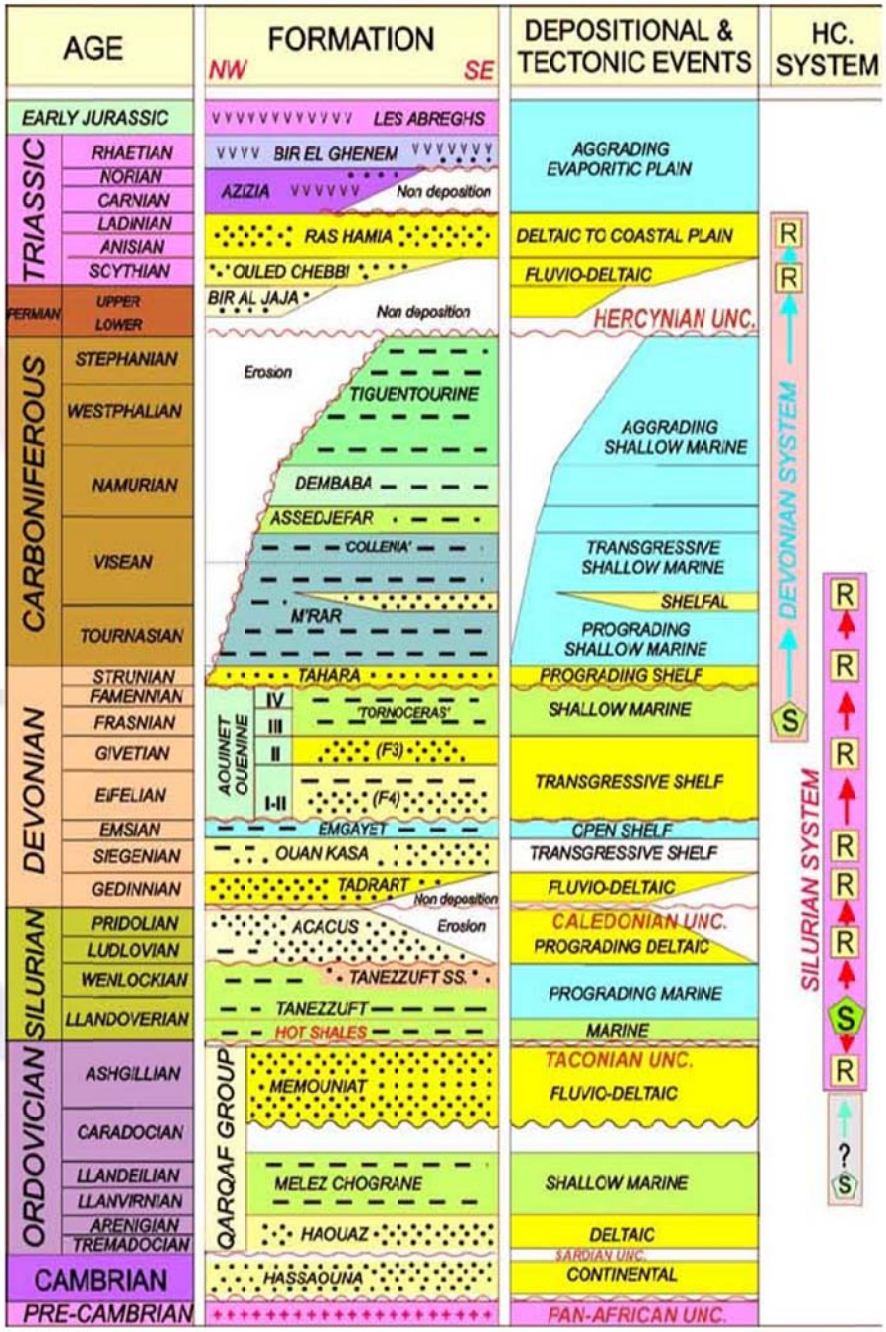
The Ghadames (Berkine) Basin is a large intra-cratonic basin underlying eastern Algeria and southern Tunisia. It encompasses an 84,000-mi$^2$ area in northwestern Libya and hosts two significant shale formations, the Lower Silurian Tannezuft and the Upper Devonian Frasnian, Figure XVII-2.[1]

In Libya's portion of the Ghadames Basin, the Silurian Tannezuft Formation contains a basal organic-rich marine shale ("hot shale") that increases in maturity toward the basin center. We have mapped a 22,370-mi$^2$ higher quality area for the Tannezuft "hot shale" in this basin, comprising separate dry gas, wet gas/condensate, and oil-prone windows. The southern, northern and eastern boundaries of the Tannezuft Shale prospective area are defined by uplifts, the erosional limits of the Silurian, and by thermal maturity. (Due to limited thermal maturity data for the eastern portion of the prospective area, we relied on the ring of discovered oil fields as the eastern boundary.) The western boundaries of the prospective area is defined by the Libya, Tunisia and Algerian border.

The central, dry-gas portion of the 2,580-mi$^2$ Tannezuft Shale prospective area in the Ghadames Basin has a thermal maturity ($R_o$) ranging from 1.3% to over 2%. The wet gas/condensate prospective area covers 3,350 mi$^2$ and has a $R_o$ between 1.0% and 1.3%. The remainder of the prospective area of 16,440 mi$^2$ is in the oil window, with a $R_o$ of 0.7% to 1.3%, Figure XVII-3.

The Upper Devonian Frasnian Shale is deposited above the Tannezuft Formation. The Frasnian Shale is more limited in area and is thermally less mature. We have mapped a 1,970-mi$^2$ higher quality prospective area for the Frasnian Shale in the Ghadames Basin of Libya. The eastern, northern and southern boundaries of the Frasnian Shale prospective area in this basin are set by the minimum thermal maturity criterion of 0.7% $R_o$. The western boundary of the prospective area is the Tunisia, Algeria, and Libyan border.

Figure XVII-2. Ghadames Basin Stratigraphic Column




Source: Seddiq Hussein, 2004.

The northern, eastern and southern outer ring of the Frasnian Shale prospective area in the Ghadames Basin, encompassing an area of 1,570 $mi^2$, is in the oil window with $R_o$ between 0.7% and 1.0%. The central, quite small 30-$mi^2$ portion of the Frasnian Shale prospective area is in the dry gas window, with $R_o$ of 1.3% to over 2%. In between is the 370-$mi^2$ wet gas and condensate area for the Frasnian Shale, with $R_o$ between 1.0% and 1.3%, Figure XVII-4.

## 1.2 Reservoir Properties (Prospective Area)

**Silurian Tannezuft Formation.** The depth of the gas prospective area of the Silurian Tannezuft Shale in the Ghadames (Berkine) Basin of Libya ranges from 10,000 ft along the northern and eastern edge of the basin to 14,500 ft toward the basin center, averaging about 13,000 ft in the dry gas area, 11,000 ft in the wet gas area, and 10,500 ft in the oil area. The lower organic-rich basal shale unit has a net thickness of 104 ft. The TOC of the basal Tannezuft Shale averages 5.7%.[2]

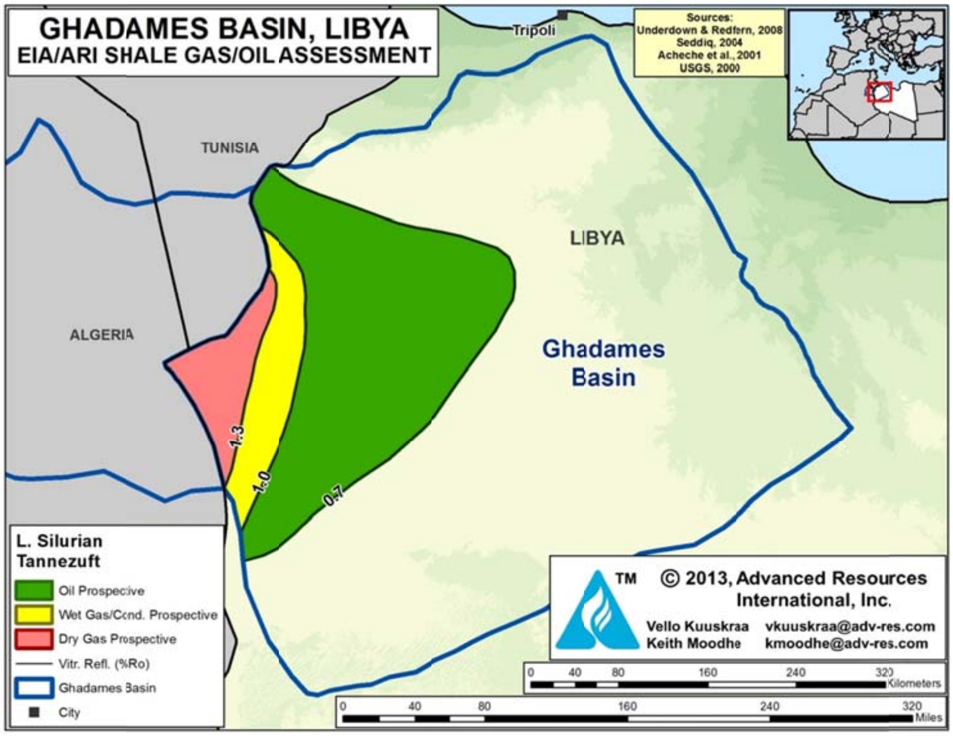
**Upper Devonian Frasnian Formation.** The depth of the prospective area of the overlying Upper Devonian Frasnian Shale in the Ghadames (Berkine) Basin of Libya ranges from 8,000 to 12,000 ft, averaging 8,500 ft in the oil-prone area; 9,500 ft in the wet gas/condensate area; and 11,500 ft in the dry gas area. The organic-rich portion of the Frasnian Shale has an average net thickness of 177 ft. The Frasnian Shale has TOC values ranging from 3% to 10%, with an average of 6%.[3]

## 1.3 Resource Assessments

**Silurian Tannezuft Shale.** The Tannezuft Shale, within its 2,580-$mi^2$ dry gas prospective area, has a resource concentration of 54 Bcf/$mi^2$. Within its larger 3,350-$mi^2$ wet gas and condensate prospective area, the Tannezuft Shale of the Ghadames (Berkine) Basin has resource concentrations of 43 Bcf/$mi^2$ of wet gas and 3 million barrels/$mi^2$ of condensate. The resource concentration in the 16,440 $mi^2$ oil prospective area is 12 million barrels/$mi^2$.

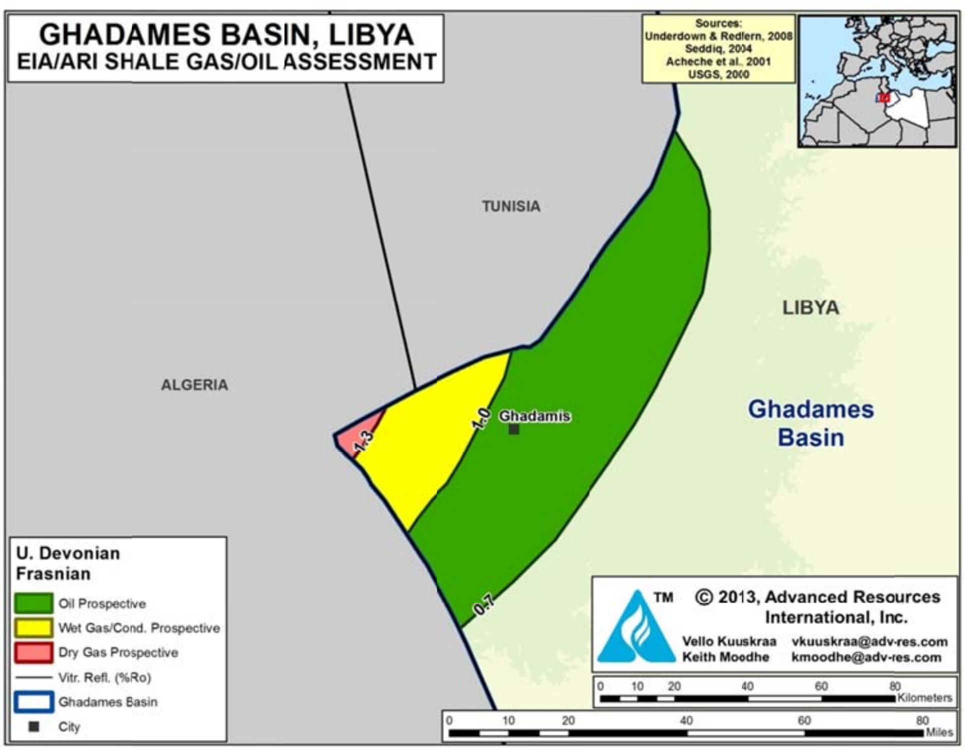
The risked resource in-place for the prospective areas of the Tannezuft Shale is 104 billion barrels of shale oil/condensate and 240 Tcf of wet and dry shale gas. Given concerns with presence of clays but otherwise favorable reservoir properties, we estimate a risked, technically recoverable shale oil/condensate resource of 5.2 billion barrels and 42 Tcf of wet and dry shale gas.

Figure XVII-3. Ghadames Basin Silurian Tannezuft Shale Outline and Thermal Maturity




Source: ARI, 2013

Figure XVII-4. Ghadames Basin Upper Devonian Frasnian Shale Outline and Thermal Maturity




Source: ARI, 2013

**Upper Devonian Frasnian Shale.** The Frasnian Shale has resource concentrations of 31 million barrels/mi$^2$ for oil (plus associated gas) in the 1,570-mi$^2$ oil window, 7 million barrels/mi$^2$ of condensate and 8 Bcf/mi$^2$ of wet gas in the 370-mi$^2$ wet gas/condensate window, and 93 Bcf/mi$^2$ of dry gas in the 30-mi$^2$ dry gas window.

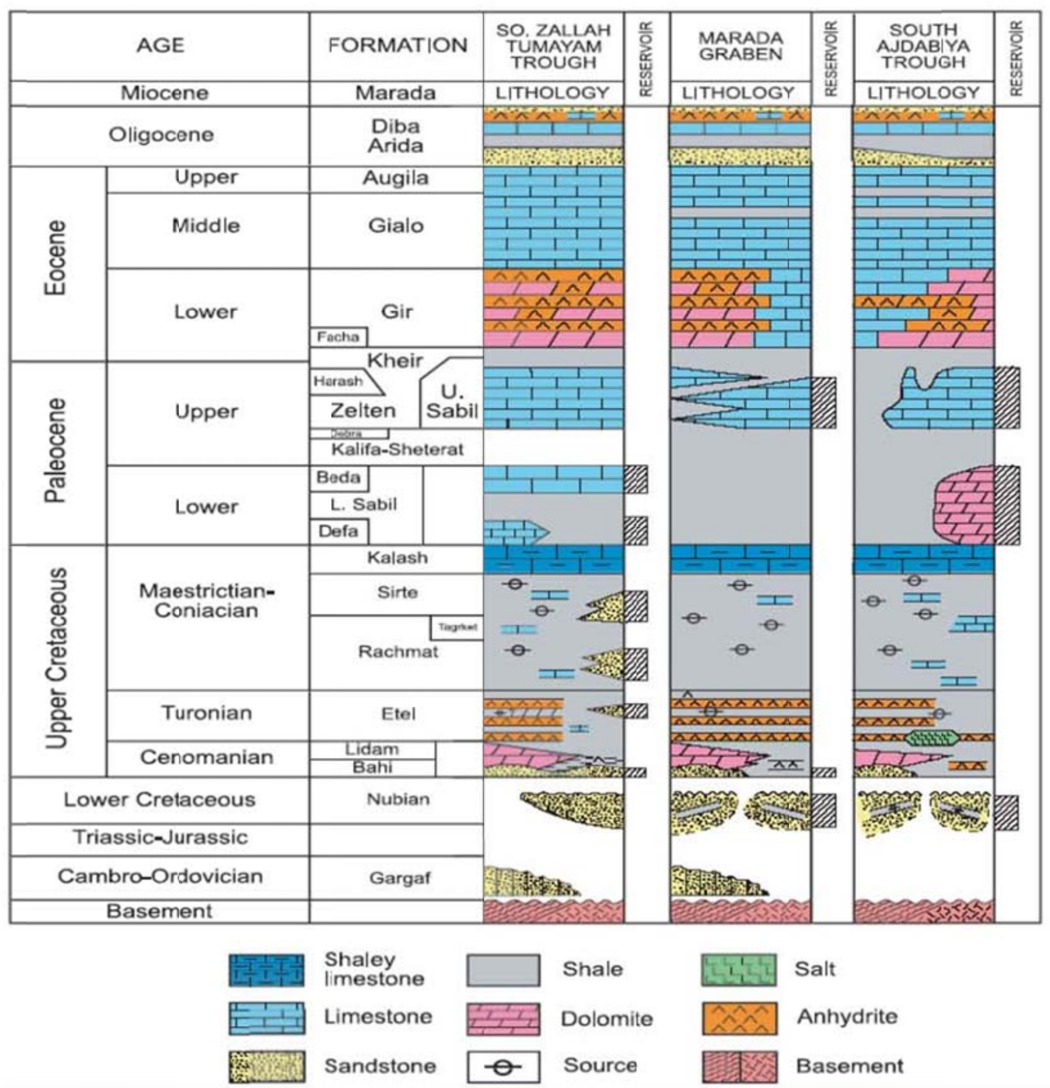
The risked resource in-place for the prospective areas is 23 billion barrels of oil/condensate and 33 Tcf of wet/dry shale gas, with risked, recoverable shale oil of 1.2 billion barrels and 4 Tcf of wet/dry shale gas.

## 2. SIRTE BASIN

### Introduction and Geologic Setting

The Sirte Basin, covering an area of 172,000 $mi^2$ in central Libya, is the most prolific hydrocarbon basin in North Africa. The Sirte Basin contains sixteen giant oil and gas fields (defined as fields containing more than 500 million barrels of oil equivalent. To date, the Sirte Basin has yielded 45 billion barrels of oil and 33 Tcf of natural gas discoveries (SEPM Strata, 2013). The Upper Cretaceous Sirte/Rachmat and Etel shales are the principal source rocks for these hydrocarbon discoveries and are the two organic-rich shale formations addressed by this resource study, Figure XVII-5.[1]

Figure XVII-5. Sirte Basin Stratigraphic Column

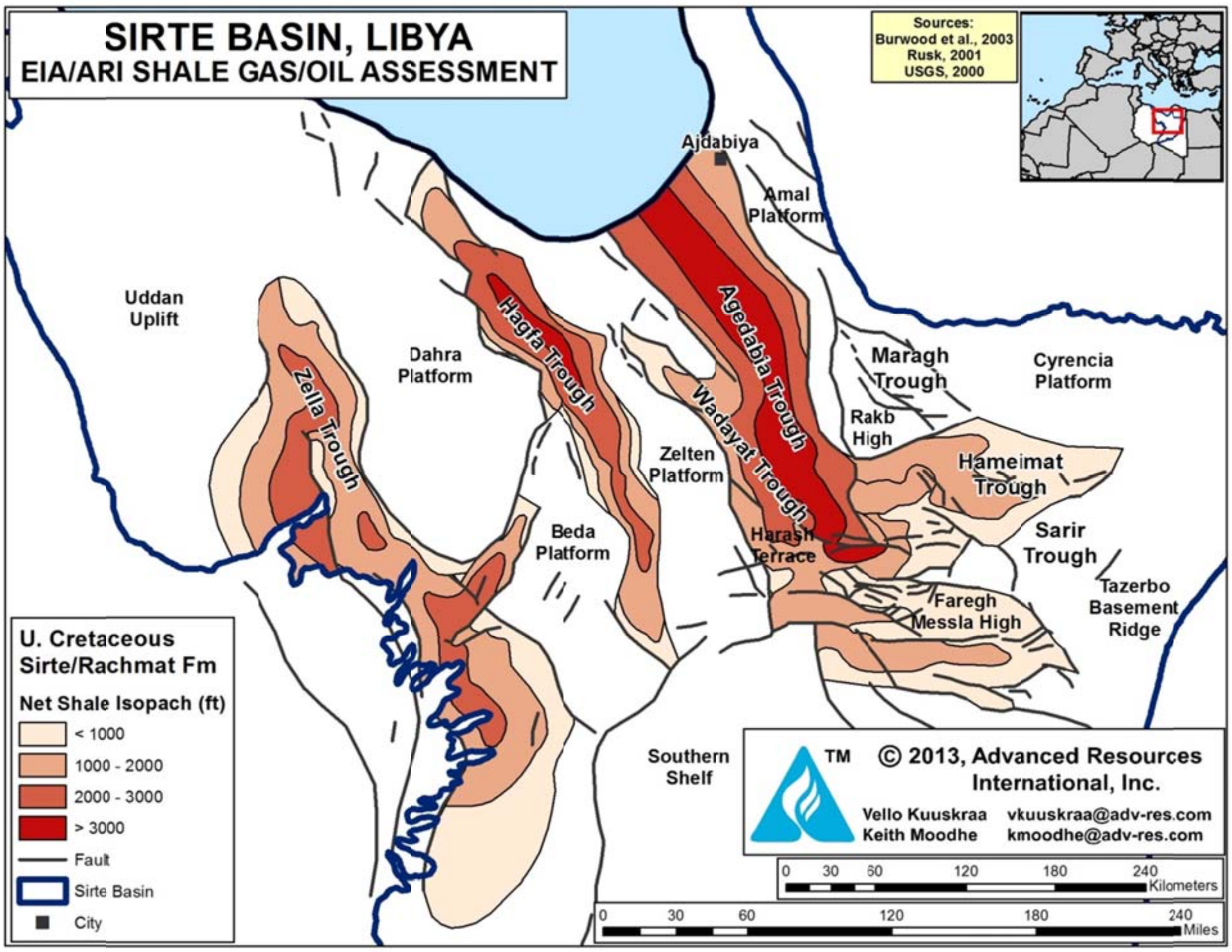



Source: Seddiq Hussein, 2004

## 2.1 Geologic Setting

The Sirte Basin consists of a series of horst and graben structures trending northwest to southeast including the Hameimat, Agedabia, Wadayat, Hagfa and Zella, as shown in Figure XVII-6. These troughs contain the two main shale formations evaluated by this study - - the Upper Cretaceous Sirte/Rachmat Shale and the underlying Upper Cretaceous Etel Shale. We have mapped an oil-prospective area totaling 35,240 mi$^2$ for the Sirte/Rachmat Shale in these five troughs, similarly, we have mapped a 19,920-mi$^2$ wet gas/condensate area for the areally more limited Etel Shale in these five troughs.

Figure XVII-6. Sirte Basin Net Shale Isopach for the Sirte/Rachmat Shale

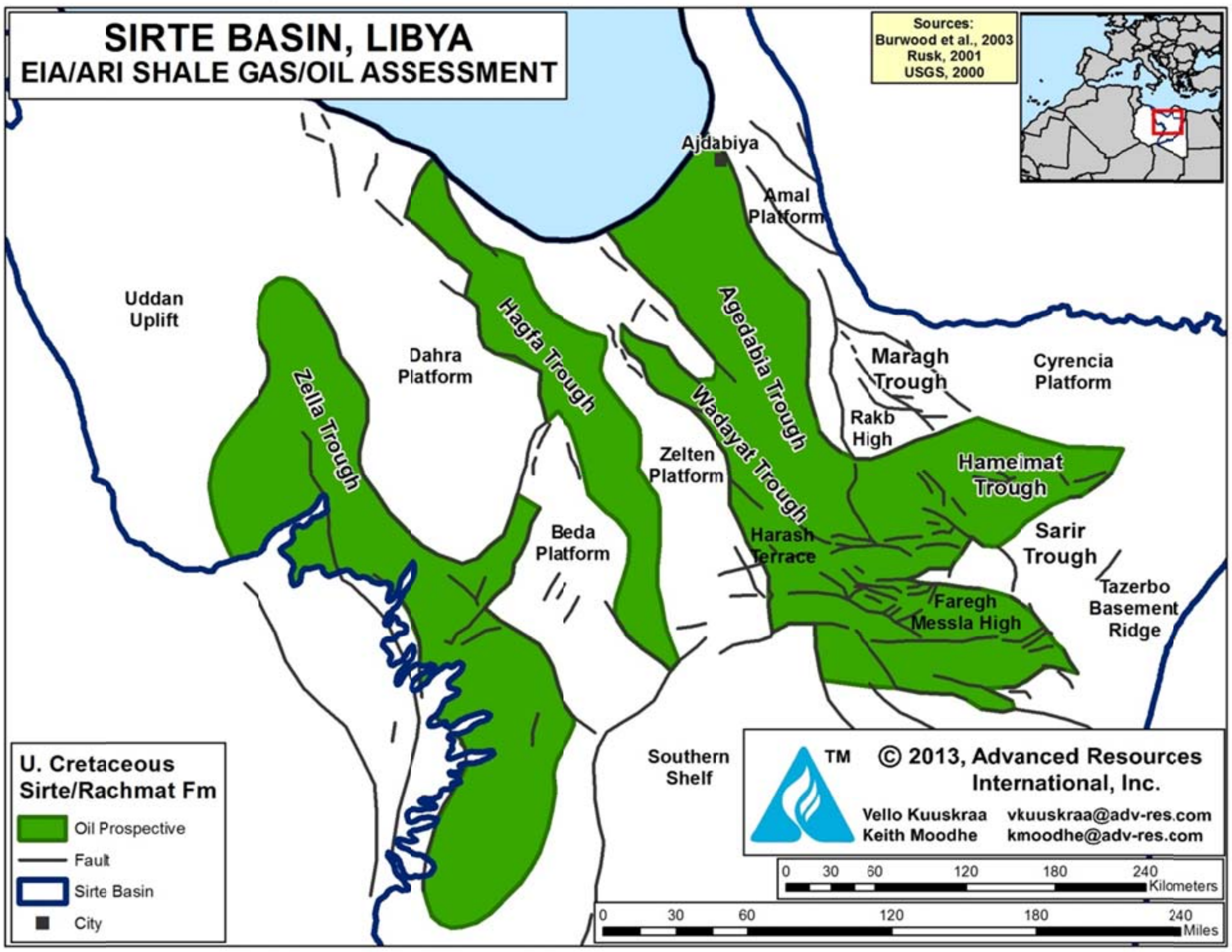



Source: ARI, 2013

## 2.2 Reservoir Properties (Prospective Area)

***Sirte/Rachmat Shale.*** Within the oil-prospective area of the Sirte Basin, the Sirte/Rachmat Shale is present in a series of troughs at depths of 10,000 to 12,000 ft, averaging 11,000 ft, Figure VXII-7. The total Sirte/Rachmat Formation has a gross thickness of 2,000 ft with a net organic-rich shale section of 200 ft. The TOC of the organic–rich shale interval averages 2.8% and the shale is in the oil window ($R_o$ of 0.7% to 1.0%).

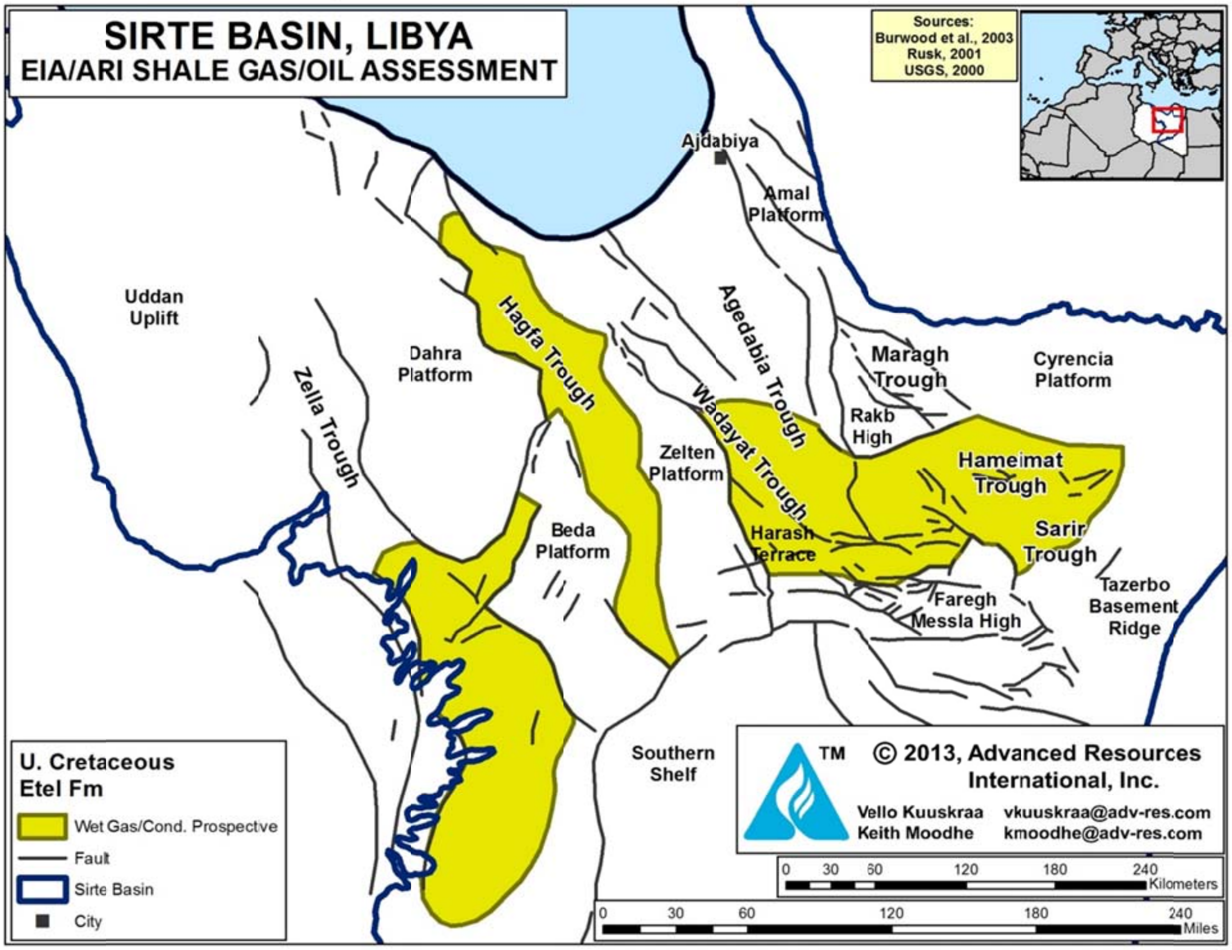
Figure XVII-7. Sirte Basin, Sirte/Rachmat Shale Prospective Area




Source: ARI, 2013

***Etel Shale.*** The Etel Shale's 19,920-mi$^2$ prospective area underlies the Sirte/Rachmat Shale at depths of 11,000 to 16,400 ft, averaging 13,500 ft, Figure XVIII-8. The Etel Formation is about 600 ft thick, of which 120 net ft is organic-rich shale. The TOC of the organic-rich shale is high at 3.6%. The thermal maturity ($R_o$) of 1.0% to 1.3% places the Etel Shale in the wet gas/condensate window.

Figure XVII-8. Sirte Basin, Etel Shale Prospective Area




Source: ARI, 2013

## 2.3 Resource Assessment

***Sirte/Rachmat Shale.*** The Upper Cretaceous Sirte/Rachmat Shale, within its 35,240-mi$^2$ prospective area for oil, has an oil concentration of 29 million barrels/mi$^2$, plus associated gas. The risked shale oil in-place is estimated at 406 billion barrels, with 16.2 billion barrels as risked, technically recoverable. In addition, we estimate a risked associated shale gas in-place of 350 Tcf, with 28 Tcf as the risked, technically recoverable shale gas resource.

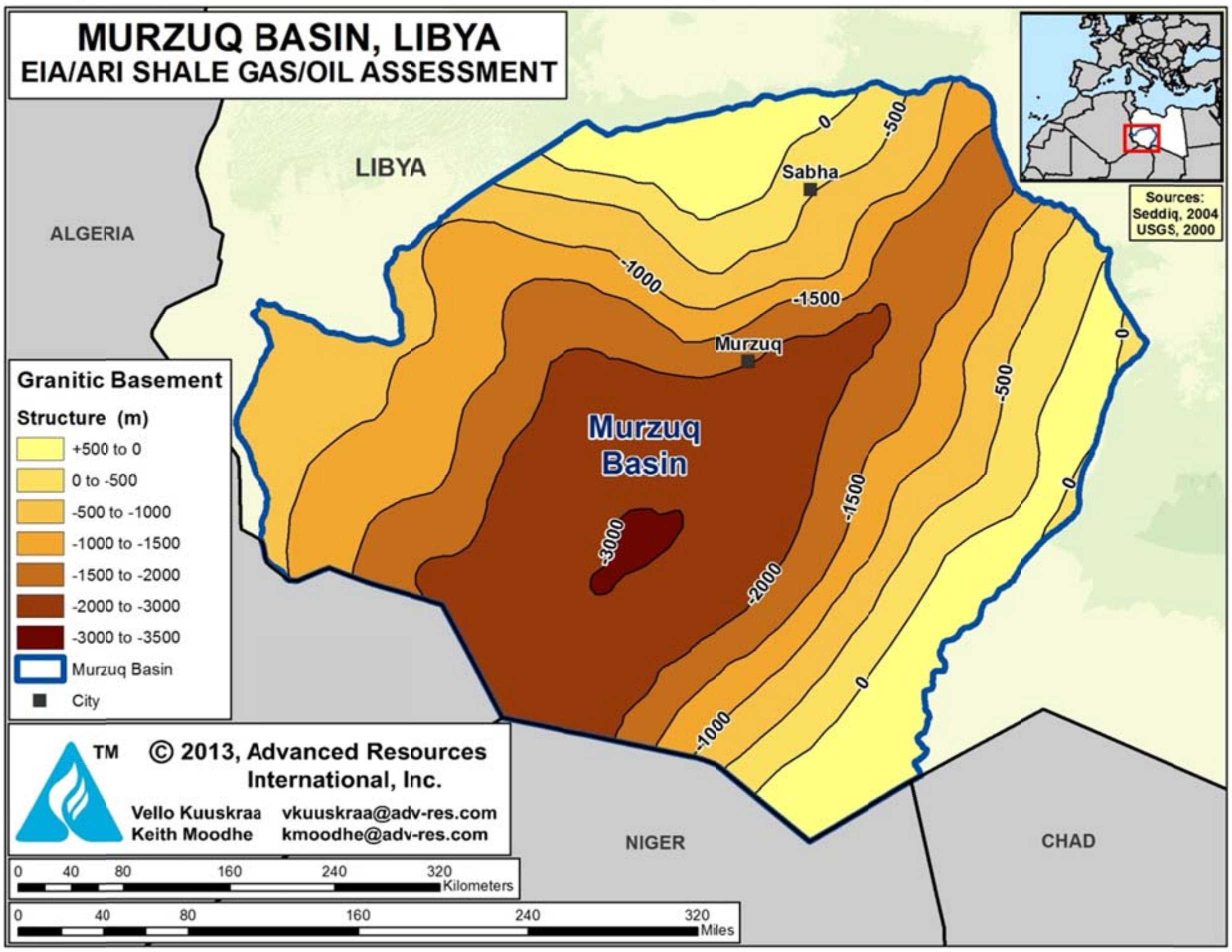
***Etel Shale.*** The Upper Cretaceous Etel Shale has a prospective area of 19,920 mi$^2$ for wet gas and condensate. The Etel Shale has resource concentrations of 6 million barrels of oil and 37 Bcf of wet gas per square mile. With risked resources in-place of 51 billion barrels of oil/condensate and 298 Tcf of wet gas, the risked, technically recoverable shale oil and gas resources are estimated at 2.0 billion barrels of shale oil/condensate and 45 Tcf of shale gas.

## 3. MURZUQ BASIN

### Introduction

The Murzuq Basin extends over a large 97,000-mi$^2$ area in the southwestern portion of Libya (extending southward into the Republic of Chad), Figure XVII-9. With its remote location, the Murzuq Basin remained undiscovered and unproven for hydrocarbons until the 1980s. Since then, four large discoveries, including the giant Elephant field plus numerous smaller fields, account for 5.4 billion barrels of discovered oil in-place, with 1.75 billion barrels estimated as recoverable.

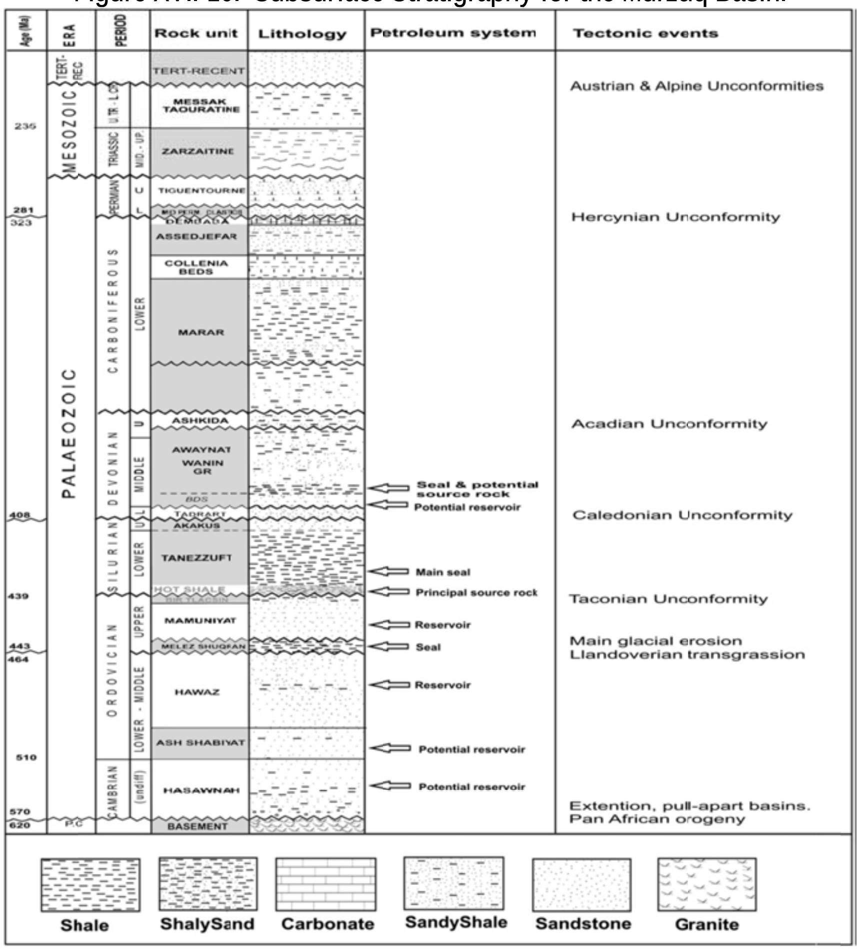
Figure XVII-9. Basin Outline and Structural Contour Map (Granitic Basement) for the Murzuq Basin




Source: ARI, 2013

The primary shale source rock addressed in the Murzuq Basin resource study is the Lower Silurian Tannezuft Formation, notably the “hot shale” interval at the base of the formation, Figure XVII-10.[4] Another potential source rock in this basin, not further assessed due to lack of data and concern with respect to thermal maturity, is the Middle Devonian Awaynat Formation in the deep center of the basin.

Figure XVII-10. Subsurface Stratigraphy for the Murzuq Basin.

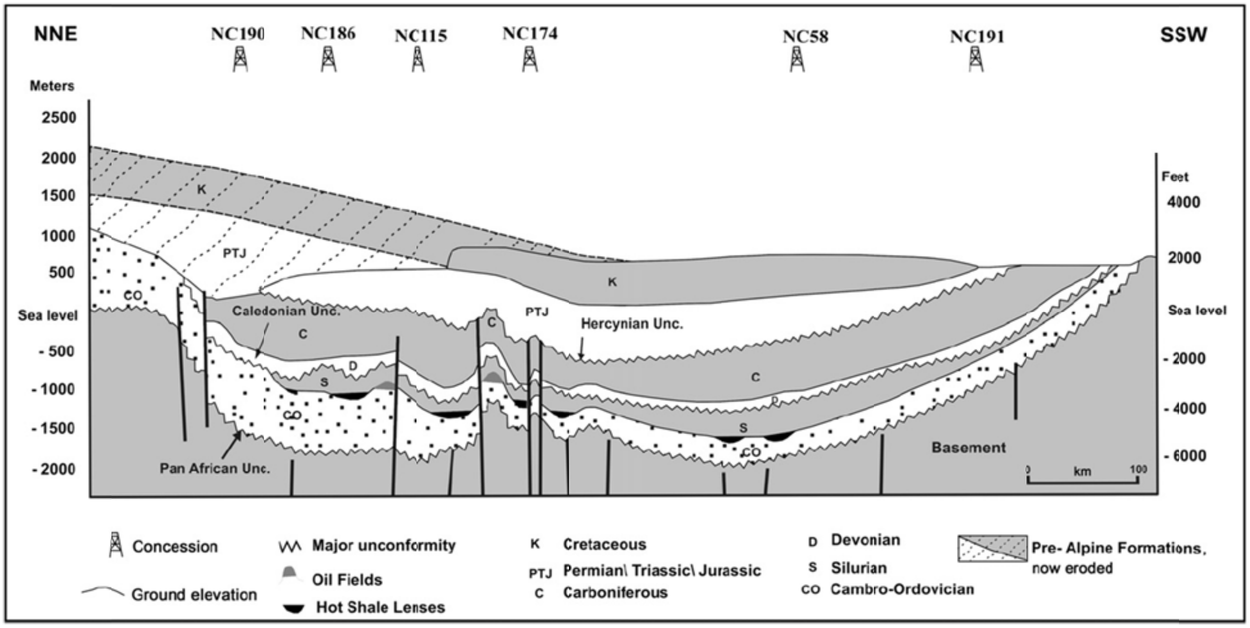



Source: Belaid at al., 2010

## 3.1 Geologic Setting

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 Ghadames Basin), and on the south by the Libya and Chad borders. Figure XVII-11[4] provides a generalized cross-section across the northern portion of the Murzuq Basin.

Figure XVII-11. Cross-Section for Murzuq Basin



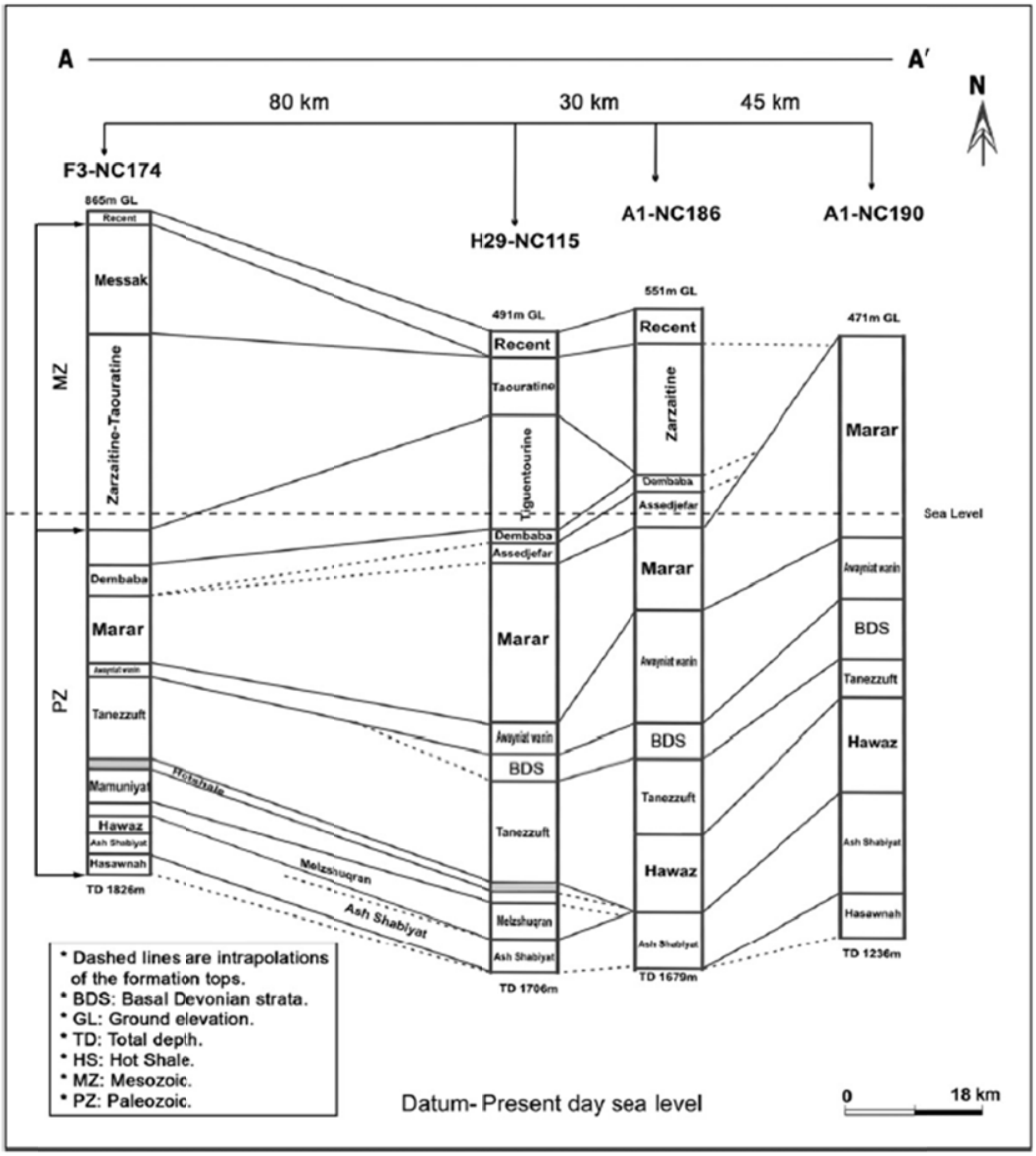

Source: Belaid at al., 2010

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 provide a most valuable data set for this resource assessment. Within this trough, the Silurian Tannezuft Formation, particularly its lower "hot shale" interval, is the primary hydrocarbon source rock for the oil discoveries in the Murzuq Basin. The presence of this shale interval is illustrated by the cross-section on Figure XVII-12,[4] with the cross-section location provided on Figure XVII-13.[4]

## 3.2 Reservoir Properties (Prospective Area).

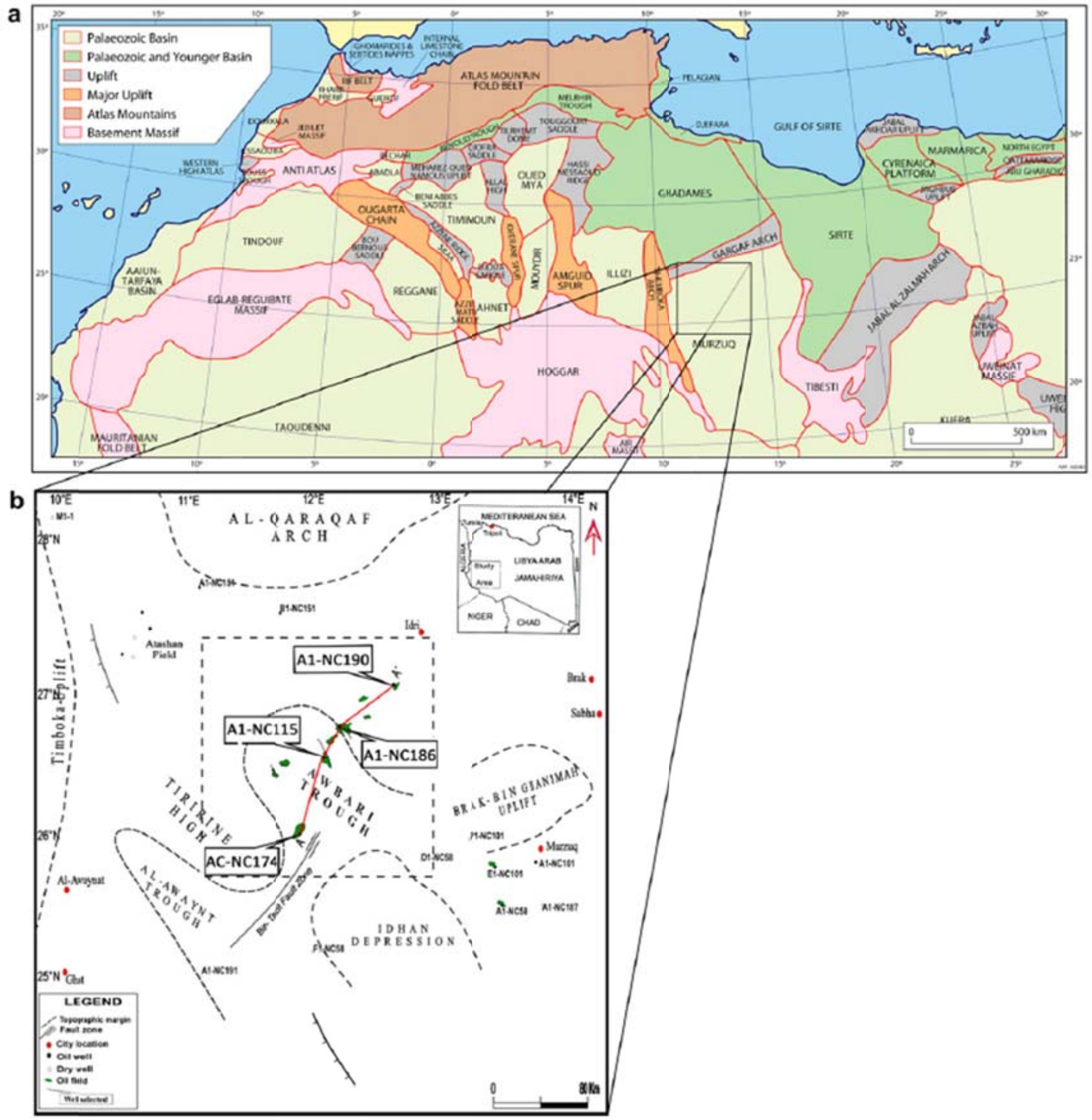
***Lower Silurian Tannezuft Shale.*** The Silurian Tannezuft Formation (early Llandoverian) consists of dark gray to black graptolitic shales with intervals of siltstone and fine-grained sandstone deposited in a marine environment.[5]

Figure XVII-12. General Stratigraphy and Cross Section (A-A') for Four Murzuq Basin Study Wells
(See Figure XVIII-13 for Cross-Section Locations)




Source: Belaid et al., 2010

Figure XVII-13. Awabari Trough of the Murzuq Basin




Source: Belaid at al., 2010



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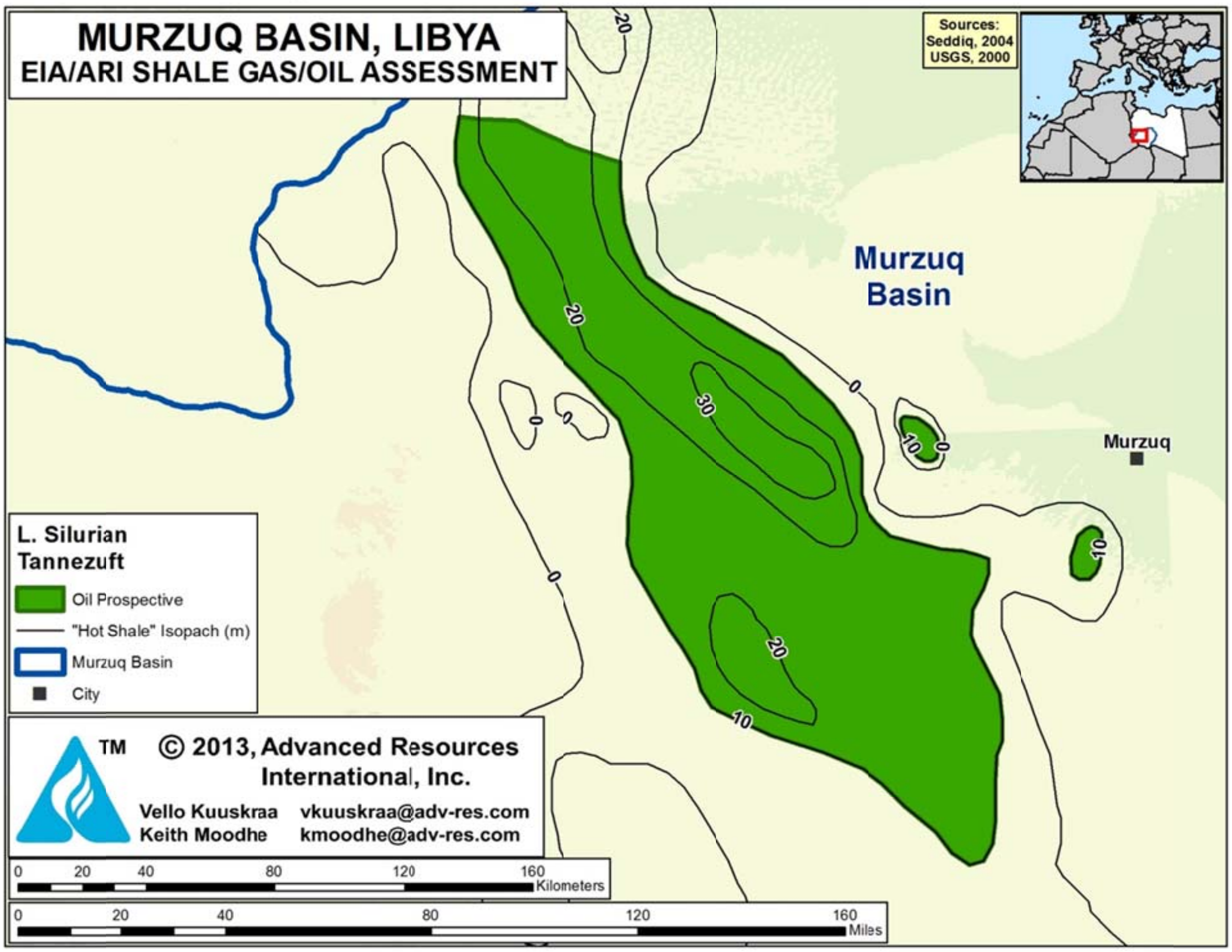
We have mapped a 5,670-mi$^2$ oil-prospective area in the center of the Murzuq Basin, Figure XVII-14. The depth of the Tannezuft "hot shale" in the prospective area of the Murzuq Basin ranges from 3,300 ft on the flanks to 10,000 ft in the central part of the basin.[6] The outcrops of the Tannezuft Formation in the uplifts surrounding the basin provide useful information on formation thickness and other properties. While the overall Tannezuft Formation can be up to 1,000 ft thick, only the basal "hot shale" unit, with thickness ranging from 30 to 100 ft has been included in our resource assessment.

Figure XVII-14. Shale Prospective Area of the Murzuq Basin.




Source: ARI, 2013

- In the NC-115 license area, 146 m of core was taken from 22 wells, all of which penetrated the Tannezuft Formation. Here the basal Tannezuft shale serves as both a seal as well as the source rock for the productive Mamuniyat sandstone formation in the license area. In this area, the "hot shale" exists as a north to south belt with limited width, ranging in thickness up to 35 m, with the thickest development in the southeastern portion of the prospective area. The TOC of the "hot shale" ranges from 3.2% to 23.1% (average 9.9%) and the shale has a thermal maturity of $R_o$ 0.83% to 0.95% in well A1-NC115, placing the shale in the late oil maturity window. The maturity of the shale is believed to increase toward the southern portion of the prospective area.[4]

- Core analysis from a second well, F3-NC174, recorded TOC values that ranged from 3.7% to 4.7% (average 4.0%), with thermal maturity of 0.7 $R_o$.[4]
- A detailed analysis of the E1-NC174 well, drilled in 1997, provides further information on the properties of Tannezuft "hot shale" in the Awabari Trough. The core data shows the presence of Type II (oil prone) kerogen with TOC values of up to 13%. The "hot shale" existed over an interval from 7,244 to 7,267 ft, with leaner but still organic-rich intervals above and below the "hot shale" interval, Figure XVII-15.[7]

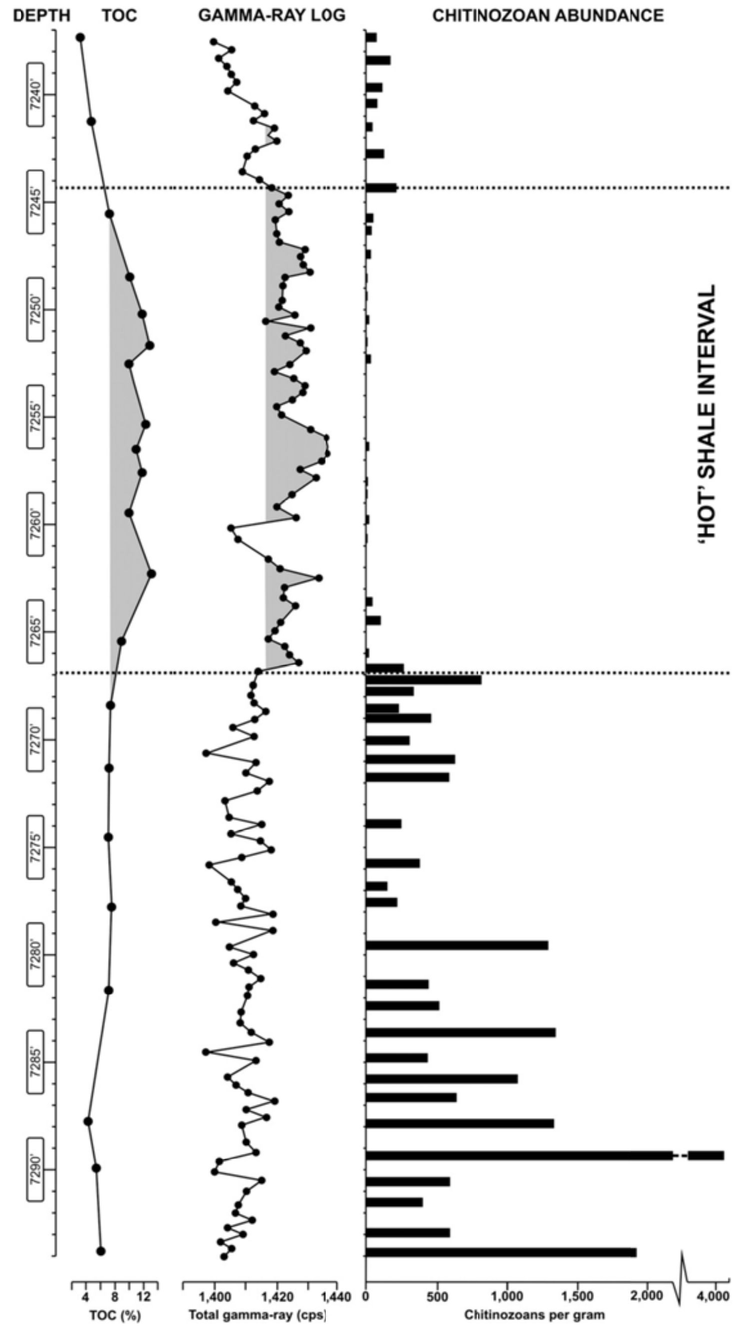
***Upper Silurian Tannezuft Shale.*** An in-depth geochemical investigation was performed recently on a series of representative shale samples from the Upper Silurian Tannezuft Formation of the Murzuq Basin.[5] The purpose of this study was to establish the source rock quality of the extensive Silurian Tannezuft "cool shales" at the top of the Silurian section. (Geochemical analysis of the Upper Silurian Shale in Jordan, as reported in our separate Jordan chapter, indicated the potential for prospective organic-rich shale within the Upper Silurian in addition to the organic-rich shale in the Lower Silurian.)

The rock samples from this upper interval were mainly Type III kerogen (gas prone) with some contribution of mixed Type II and III kerogen (gas/oil prone) from marine/terrigenous sources, Figure XVIII-16.[5] The rock samples showed an early to intermediate stage of thermal maturity with Tmax values of 435° to 445°C, indicating the source rock was in the early to middle oil window ($R_o$ of 0.6% to 0.9%) The organic content of the samples was characterized as poor to fair, with TOC values ranging from 0.4% to 1.28%, indicating a mixed oxic to sub-oxic depositional environment.

While the overall Tannezuft Shale Formation in the Murzuq Basin is on the order of 300 m thick, it appears that only the basal ("hot shale") unit of the Silurian Tannezuft Formation is sufficiently organic-rich to be included in our shale resource assessment.

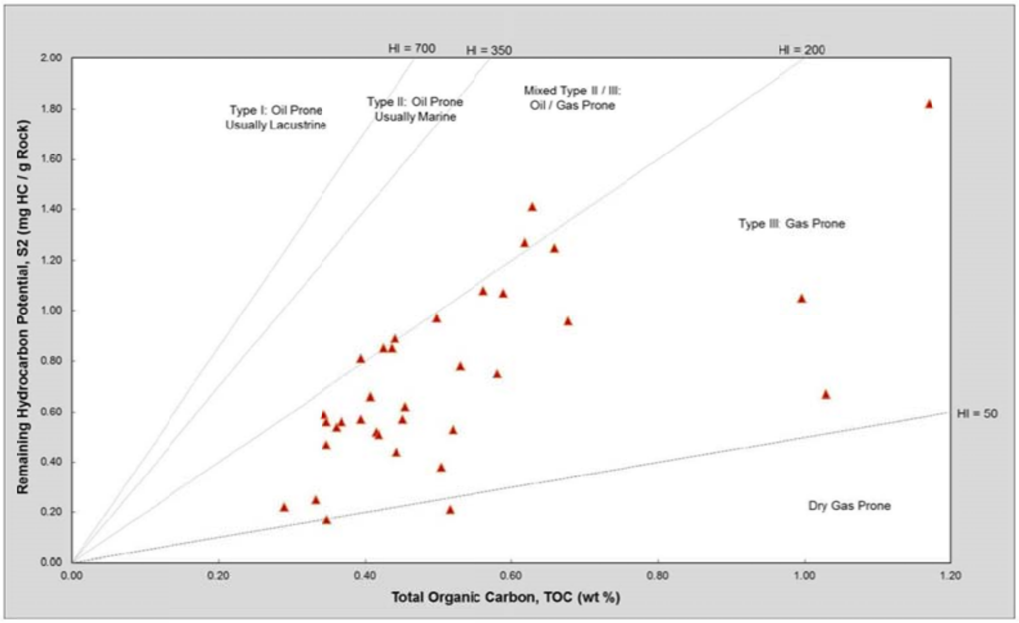
***Devonian Awaynat Wanin Formation.*** The Middle-Late Devonian Awaynat Wanin Formation is also considered a potential shale source rock in the Murzuq Basin. However, only limited information exists for this unit. To date, only the Silurian Tannezuft-Mamuniyat has been established as an effective petroleum system.[8]

Figure XVII-15. TOC Values within the E1-NC174 Core.
Modified from Luning et al. 2003.




Source: Butcher, 2013.

Figure XVII-16. Cross Plot Between S2 mg HC/g Rock and %TOC for Tannezuft Formation, Field A, NC-115, Murzuq Basin.
Modified from GeoMark Research, LTD (2009).




Source: Hodairi, T. and Philp, P., 2011.

## 3.3 Resource Assessment

The Tannezuft "hot shale", within the 5,670-mi$^2$ prospective area of the Murzuq Basin, has a resource concentration of 10 million barrels/mi$^2$ of oil plus associated gas. The risked shale oil resource in-place is estimated at 27 billion barrels of shale oil plus 19 Tcf of associated shale gas, with 1.3 billion barrels of shale oil and 2 Tcf of associated shale gas as the risked, technically recoverable resource.

## 4. KUFRA BASIN

### Introduction

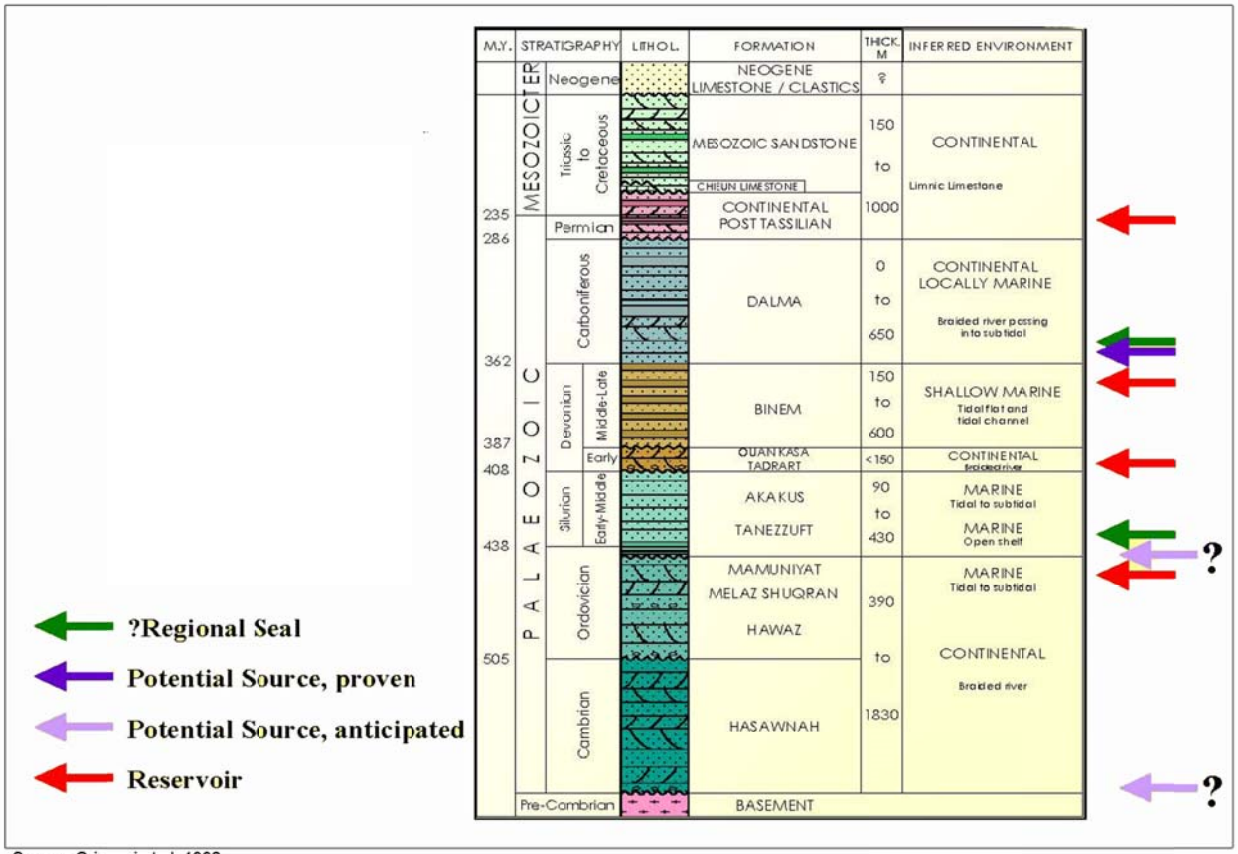
The Kufra Basin is a large 400,000-km$^2$, remote intra-cratonic sag basin located in southeastern Libya. The Paleozoic structural and deposition history of the Kufra Basin is similar to that of the Murzuq Basin, discussed earlier in this chapter. However, there is considerable uncertainty as to the presence of sufficiently organic-rich source rocks in this basin.

The Lower Silurian Tannezuft Formation is described as up to 130 m thick in outcrops at the basin margins, Figure XVII-17.[9] 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.[10]

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 1970s and early 1980s (Bellini, 1991). The absence of lower Silurian shales in these two Kufra 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 Tannezuft basal "hot shale" is also absent, Figure XVII-18.[10] Since then, one additional exploration well drilled in 1997 has noted the absence of the lower Silurian "hot shale" in the Kufra Basin.

Lower Silurian, organic-rich shales may be present in the western part of the Kufra Basin.[11] However, the areal distribution of this shale unit is laterally highly variable with Silurian basal "hot shale" occurrences deposited as linear features and patches, surrounded by areas in which the basal "hot shale" is absent.[10]

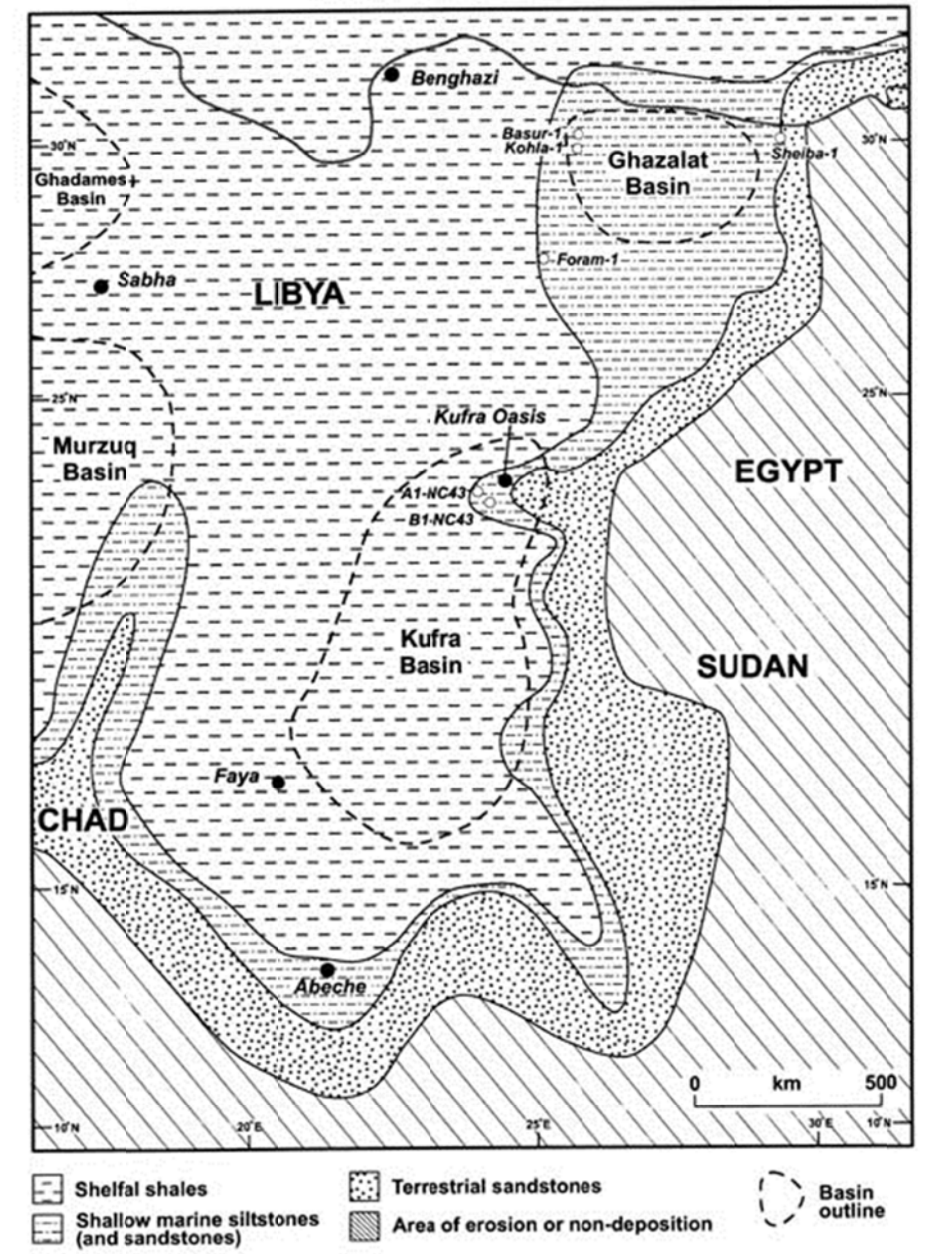
Figure XVII-17. Stratigraphic Column of the Kufra Basin




Source: Grignani et al. 1992

Figure XVII-18. Early Silurian Paleogeography of the Kufra Basin

Based on Keeley, 1989; Semtner et al., 1997; Selley, 1997b; Keeley & Masoud, 1998 and Luning, 1999.




Source: Luning et al. 1999

## RECENT ACTIVITY

Libya's oil and gas exploration, including the assessment of its shale oil and gas resources came to a halt during the uprising that overthrew the government of Muammar Gaddafi. However, in late 2012, the Chairman of Libya's National Oil Company, Mr. Nuri Berruien, announced that the company is examining options for exploring its unconventional oil and gas resources. One option discussed by Chairman Berruien is to internally evaluate the unconventional resources and then bring in international companies with expertise in unconventional resource exploration and development.[12]

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