Independent Statistics & Analysis
U.S. Energy Information Administration

Technically Recoverable Shale Oil and Shale Gas Resources:

United Arab Emirates

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Executive Summary

Introduction

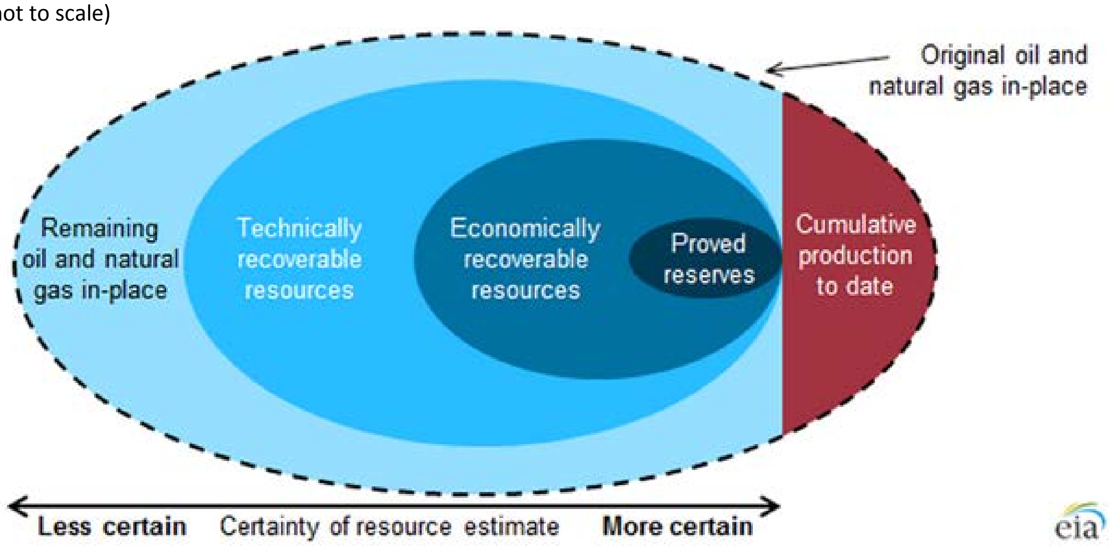
Although the shale resource estimates presented in this report will likely change over time as additional information becomes available, it is evident that shale resources that were until recently not included in technically recoverable resources constitute a substantial share of overall global technically recoverable oil and natural gas resources. This chapter is a supplement to the 2013 EIA world shale report Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States.

Resource categories

When considering the market implications of abundant shale resources, it is important to distinguish between a technically recoverable resource, which is the focus of this supplement as in the 2013 report, and an economically recoverable resource. Technically recoverable resources represent the volumes of oil and natural gas that could be produced with current technology, regardless of oil and natural gas prices and production costs. Economically recoverable resources are resources that can be profitably produced under current market conditions. The economic recoverability of oil and gas resources depends on three factors: the costs of drilling and completing wells, the amount of oil or natural gas produced from an average well over its lifetime, and the prices received for oil and gas production. Recent experience with shale gas and tight oil in the United States and other countries suggests that economic recoverability can be significantly influenced by above-the-ground factors as well as by geology. Key positive above-the-ground advantages in the United States and Canada that may not apply in other locations include private ownership of subsurface rights that provide a strong incentive for development; availability of many independent operators and supporting contractors with critical expertise and suitable drilling rigs and, preexisting gathering and pipeline infrastructure; and the availability of water resources for use in hydraulic fracturing. See Figure 1.

Figure 1. Stylized representation of oil and natural gas resource categorizations

(not to scale)



Source: U.S. Energy Information Administration
Note: Resource categories are not drawn to scale relative to the actual size of each resource category. The graphic shown above is applicable only to oil and natural gas resources.

Crude oil and natural gas resources are the estimated oil and natural gas volumes that might be produced at some time in the future. The volumes of oil and natural gas that ultimately will be produced cannot be known ahead of time. Resource estimates change as extraction technologies improve, as markets evolve, and as oil and natural gas are produced. Consequently, the oil and gas industry, researchers, and government agencies spend considerable time and effort defining and quantifying oil and natural gas resources.

For many purposes, oil and natural gas resources are usefully classified into four categories:

- Remaining oil and gas in-place (original oil and gas in-place minus cumulative production at a specific date)
- Technically recoverable resources
- Economically recoverable resources
- Proved reserves

The oil and natural gas volumes reported for each resource category are estimates based on a combination of facts and assumptions regarding the geophysical characteristics of the rocks, the fluids trapped within those rocks, the capability of extraction technologies, and the prices received and costs paid to produce oil and natural gas. The uncertainty in estimated volumes declines across the resource categories (see figure above) based on the relative mix of facts and assumptions used to create these resource estimates. Oil and gas in-place estimates are based on fewer facts and more assumptions, while proved reserves are based mostly on facts and fewer assumptions.

Remaining oil and natural gas in-place (original oil and gas in-place minus cumulative production). The volume of oil and natural gas within a formation before the start of production is the original oil and gas in-place. As oil and natural gas are produced, the volumes that remain trapped within the rocks are the remaining oil and gas in-place, which has the largest volume and is the most uncertain of the four resource categories.

Technically recoverable resources. The next largest volume resource category is technically recoverable resources, which includes all the oil and gas that can be produced based on current technology, industry practice, and geologic knowledge. As technology develops, as industry practices improve, and as the understanding of the geology increases, the estimated volumes of technically recoverable resources also expand.

The geophysical characteristics of the rock (e.g., resistance to fluid flow) and the physical properties of the hydrocarbons (e.g., viscosity) prevent oil and gas extraction technology from producing 100% of the original oil and gas in-place.

Economically recoverable resources. The portion of technically recoverable resources that can be profitably produced is called economically recoverable oil and gas resources. The volume of economically recoverable resources is determined by both oil and natural gas prices and by the capital and operating costs that would be incurred during production. As oil and gas prices increase or decrease, the volume of the economically recoverable resources increases or decreases, respectively. Similarly, increasing or decreasing capital and operating costs result in economically recoverable resource volumes shrinking or growing.

U.S. government agencies, including EIA, report estimates of technically recoverable resources (rather than economically recoverable resources) because any particular estimate of economically recoverable resources is tied to a specific set of prices and costs. This makes it difficult to compare estimates made by other parties using different price and cost assumptions. Also, because prices and costs can change over relatively short periods, an estimate of economically recoverable resources that is based on the prevailing prices and costs at a particular time can quickly become obsolete.

Proved reserves. The most certain oil and gas resource category, but with the smallest volume, is proved oil and gas reserves. Proved reserves are volumes of oil and natural gas that geologic and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions. Proved reserves generally increase when new production wells are drilled and decrease when existing wells are produced. Like economically recoverable resources, proved reserves shrink or grow as prices and costs change. The U.S. Securities and Exchange Commission regulates the reporting of company financial assets, including those proved oil and gas reserve assets reported by public oil and gas companies.

Each year EIA updates its report of proved U.S. oil and natural gas reserves and its estimates of unproved technically recoverable resources for shale gas, tight gas, and tight oil resources. These reserve and resource estimates are used in developing EIA's Annual Energy Outlook projections for oil and natural gas production.

- Proved oil and gas reserves are reported in EIA's U.S. Crude Oil and Natural Gas Proved Reserves.
- Unproved technically recoverable oil and gas resource estimates are reported in EIA's Assumptions report of the Annual Energy Outlook. Unproved technically recoverable oil and gas resources equal total technically recoverable resources minus the proved oil and gas reserves.

Over time, oil and natural gas resource volumes are reclassified, going from one resource category into another category, as production technology develops and markets evolve.

Additional information regarding oil and natural gas resource categorization is available from the Society of Petroleum Engineers and the United Nations.

Methodology

The shale formations assessed in this supplement as in the previous report were selected for a combination of factors that included the availability of data, country-level natural gas import dependence, observed large shale formations, and observations of activities by companies and governments directed at shale resource development. Shale formations were excluded from the analysis if one of the following conditions is true: (1) the geophysical characteristics of the shale formation are unknown; (2) the average total carbon content is less than 2 percent; (3) the vertical depth is less than 1,000 meters (3,300 feet) or greater than 5,000 meters (16,500 feet), or (4) relatively large undeveloped oil or natural gas resources.

The consultant relied on publicly available data from technical literature and studies on each of the selected international shale gas formations to first provide an estimate of the "risked oil and natural gas in-place," and then to estimate the unproved technically recoverable oil and natural gas resource for that shale formation. This methodology is intended to make the best use of sometimes scant data in order to perform initial assessments of this type.

The risked oil and natural gas in-place estimates are derived by first estimating the volume of in-place resources for a prospective formation within a basin, and then factoring in the formation's success factor and recovery factor. The success factor represents the probability that a portion of the formation is expected to have attractive oil and natural gas flow rates. The recovery factor takes into consideration the capability of current technology to produce oil and natural gas from formations with similar geophysical characteristics. Foreign shale oil recovery rates are developed by matching a shale formation's geophysical characteristics to U.S. shale oil analogs. The resulting estimate is referred to as both the risked oil and natural gas in-place and the technically recoverable resource. The specific tasks carried out to implement the assessment include:

1. Conduct a preliminary review of the basin and select the shale formations to be assessed.
2. Determine the areal extent of the shale formations within the basin and estimate its overall thickness, in addition to other parameters.
3. Determine the prospective area deemed likely to be suitable for development based on depth, rock quality, and application of expert judgment.
4. Estimate the natural gas in-place as a combination of *free gas*[1] and *adsorbed gas*[2] that is contained within the prospective area. Estimate the oil in-place based on pore space oil volumes.
5. Establish and apply a composite success factor made up of two parts. The first part is a formation success probability factor that takes into account the results from current shale oil and shale gas activity as an indicator of how much is known or unknown about the shale formation. The second part is a prospective area success factor that takes into account a set of factors (e.g., geologic complexity and lack of access) that could limit portions of the prospective area from development.
6. For shale oil, identify those U.S. shales that best match the geophysical characteristics of the foreign shale oil formation to estimate the oil in-place recovery factor.[3] For shale gas, determine the recovery factor based on geologic complexity, pore size, formation pressure, and clay content, the latter of which determines a formation's ability to be hydraulically fractured. The gas phase of each formation includes dry natural gas, associated natural gas, or wet natural gas. Therefore, estimates of shale gas resources in this report implicitly include the light wet hydrocarbons that are typically coproduced with natural gas.
7. Technically recoverable resources[4] represent the volumes of oil and natural gas that could be produced with current technology, regardless of oil and natural gas prices and production costs. Technically recoverable resources are determined by multiplying the risked in-place oil or natural gas by a recovery factor.

Based on U.S. shale production experience, the recovery factors used in this supplement as in the previous report for shale gas generally ranged from 20 percent to 30 percent, with values as low as 15 percent and as high as 35 percent being applied in exceptional cases. Because of oil's viscosity and capillary forces, oil does not flow through rock fractures as easily as natural gas. Consequently, the recovery factors for shale oil are typically lower than they are for shale gas, ranging from 3 percent to 7 percent of the oil in-place with exceptional cases being as high as 10 percent or as low as 1 percent. The consultant selected the recovery factor based on U.S. shale production recovery rates, given a range of factors including mineralogy, geologic complexity, and a number of other factors that affect the response of the geologic formation to the application of best practice shale gas recovery technology. Because most shale oil and shale gas wells are only a few years old, there is still considerable uncertainty as to the expected life of U.S. shale wells and their ultimate recovery. The recovery rates used in this analysis are based on an extrapolation of shale well production over 30 years. Because a shale's geophysical characteristics vary significantly throughout the formation and analog matching is never exact, a shale formation's resource potential cannot be fully determined until extensive well production tests are conducted across the formation.

[1] Free gas is natural gas that is trapped in the pore spaces of the shale. Free gas can be the dominant source of natural gas for the deeper shales.

[2] Adsorbed gas is natural gas that adheres to the surface of the shale, primarily the organic matter of the shale, due to the forces of the chemical bonds in both the substrate and the natural gas that cause them to attract. Adsorbed gas can be the dominant source of natural gas for the shallower and higher organically rich shales.

[3] The recovery factor pertains to percent of the original oil or natural gas in-place that is produced over the life of a production well.

[4] Referred to as risked recoverable resources in the consultant report.

Key exclusions

In addition to the key distinction between technically recoverable resources and economically recoverable resources that has been already discussed at some length, there are a number of additional factors outside of the scope of this report that must be considered in using its findings as a basis for projections of future production. In addition, several other exclusions were made for this supplement as in the previous report to simplify how the assessments were made and to keep the work to a level consistent with the available funding.

Some of the key exclusions for this supplement as in the previous report include:

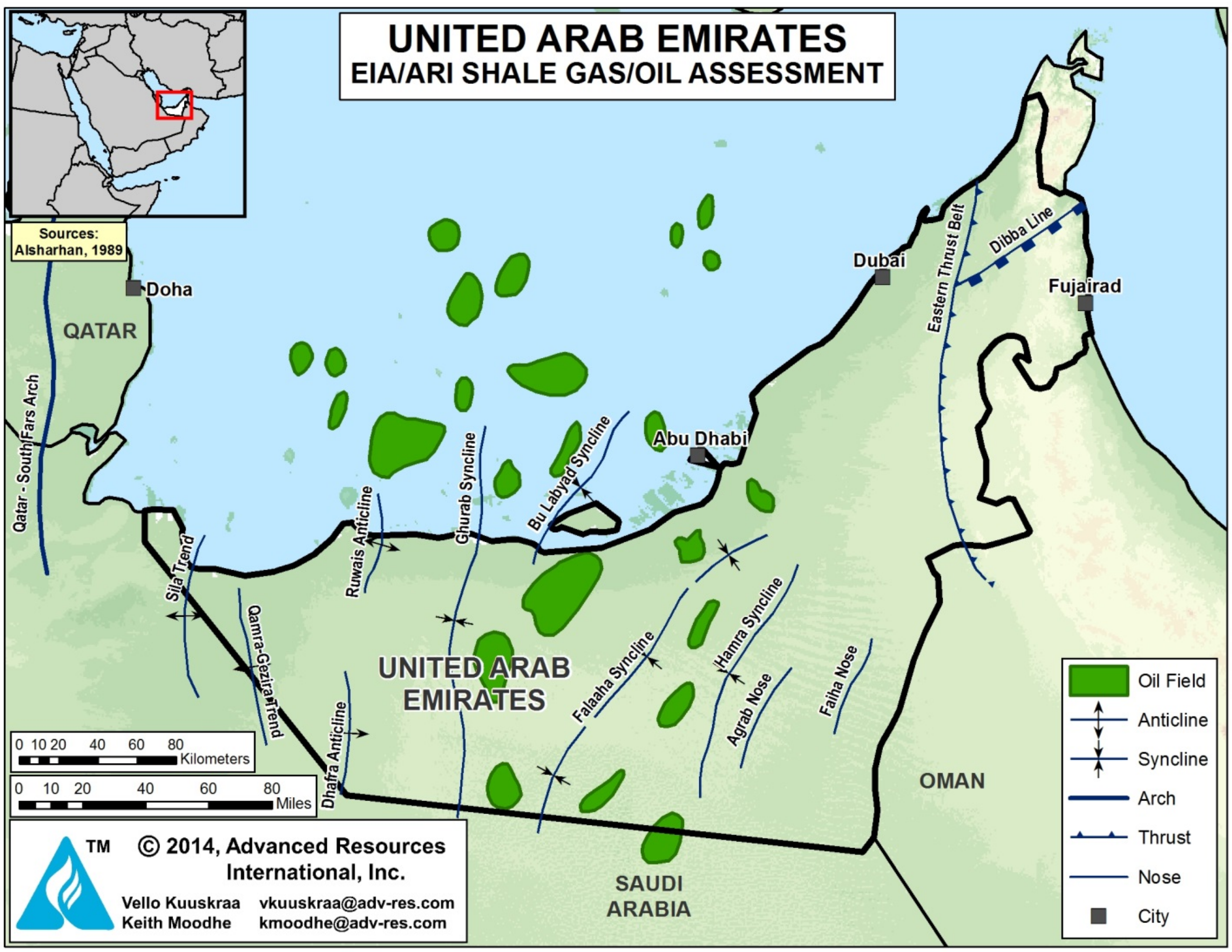
1. **Tight oil produced from low permeability sandstone and carbonate formations** that can often be found adjacent to shale oil formations. Assessing those formations was beyond the scope of this supplement as in the previous report.
2. **Coalbed methane and tight natural gas** and other natural gas resources that may exist within these countries were also excluded from the assessment.
3. **Assessed formations without a resource estimate**, which resulted when data were judged to be inadequate to provide a useful estimate. Including additional shale formations would likely increase the estimated resource.
4. **Countries outside the scope of the report**, the inclusion of which would likely add to estimated resources in shale formations. It is acknowledged that potentially productive shales exist in most of the countries in the Middle East and the Caspian region, including those holding substantial non-shale oil and natural gas resources.
5. **Offshore portions of assessed shale oil** and shale gas formations were excluded, as were shale oil and shale gas formations situated entirely offshore.

UNITED ARAB EMIRATES

SUMMARY

The United Arab Emirates (UAE) holds a significant number of major oil and gas fields in the Rub' Al-Khali Basin in both its onshore and offshore areas, Figure 1. These oil and gas fields have been sourced by three main shale and tight source rocks assessed by this study. These are: (1) the Lower Silurian Qusaiba Shale, (2) the Upper Jurassic Diyab organic-rich "tight" carbonate, and (3) the Middle Cretaceous Shilaif Formation.

Figure 1. Structural Features and Major Oil Fields, United Arab Emirates



Our assessment is that these three shale/tight formations contain 376 billion barrels of risked shale/tight oil in-place, with 22.6 billion barrels as the risked, technically recoverable oil resource, Table 1. In addition, we estimate 828 Tcf of risked, shale gas in-place, with 205 Tcf as the risked, technically recoverable resource, Table 2.

Table 1. Shale Oil Reservoir Properties and Resources of United Arab Emirates

Basic Data	Basin/Gross Area		Rub' Al-Khali/U.A.E (25,000 mi^2)	
	Shale Formation		Diyab	Shilaif
	Geologic Age		U. Jurassic	M. Cretaceous
	Depositional Environment		Marine	Marine
Physical Extent	Prospective Area (mi^2)		1,300	9,670
	Thickness (ft)	Organically Rich	150	660
		Net	135	330
	Depth (ft)	Interval	9,500 - 13,000	3,500 - 11,000
		Average	11,000	6,500
Reservoir Properties	Reservoir Pressure		Normal	Normal
	Average TOC (wt. %)		3.0%	4.0%
	Thermal Maturity (% Ro)		1.15%	0.70%
	Clay Content		Medium	Medium
Resource	Oil Phase		Condensate	Oil
	OIP Concentration (MMbbl/mi^2)		10.3	58.5
	Risked OIP (B bbl)		8.7	367.4
	Risked Recoverable (B bbl)		0.52	22.04

Source: ARI, 2014.

Table 2. Shale Gas Reservoir Properties and Resources of United Arab Emirates

Basic Data	Basin/Gross Area		Rub' Al-Khali/U.A.E. (25,000 mi^2)			
	Shale Formation		Qusaiba	Diyab		Shilaif
	Geologic Age		Silurian	U. Jurassic		M. Cretaceous
	Depositional Environment		Marine	Marine		Marine
Physical Extent	Prospective Area (mi^2)		13,020	1,300	8,980	9,670
	Thickness (ft)	Organically Rich	80	150	180	660
		Net	80	135	162	330
	Depth (ft)	Interval	14,000 - 16,400	9,500 - 13,000	12,000 - 14,000	3,500 - 11,000
		Average	15,000	11,000	13,000	6,500
Reservoir Properties	Reservoir Pressure		Mod. Overpress.	Normal	Normal	Normal
	Average TOC (wt. %)		4.0%	3.0%	3.0%	4.0%
	Thermal Maturity (% Ro)		2.80%	1.15%	1.50%	0.70%
	Clay Content		Medium	Medium	Medium	Medium
Resource	Gas Phase		Dry Gas	Wet Gas	Dry Gas	Assoc. Gas
	GIP Concentration (Bcf/mi^2)		38.1	16.7	70.1	25.0
	Risked GIP (Tcf)		247.8	14.1	409.4	157.0
	Risked Recoverable (Tcf)		62.0	1.7	122.8	18.8

Source: ARI, 2014.

INTRODUCTION

The United Arab Emirates (UAE), a federation of seven emirates - - Abu Dhabi, Ajman, Dubai, Fujairah, Ras al-Khaimah, Sharjah, and Umm al-Quwain - - is the world's eighth largest oil producer, providing 2.8 million barrels per day of crude oil production in 2012 (3.2 million barrels per day of total oil production (crude oil plus condensate).

Crude oil production has steadily increased in the past ten years from 2.1 million barrels per day in 2002 to 2.8 million barrels per day in 2012, from nearly 98 billion barrels of proved crude oil reserves. While recent exploration has yielded few significant discoveries of crude oil, UAE has placed great emphasis on improving the recovery efficiencies at its existing oil fields for maintaining its remaining recoverable reserves.

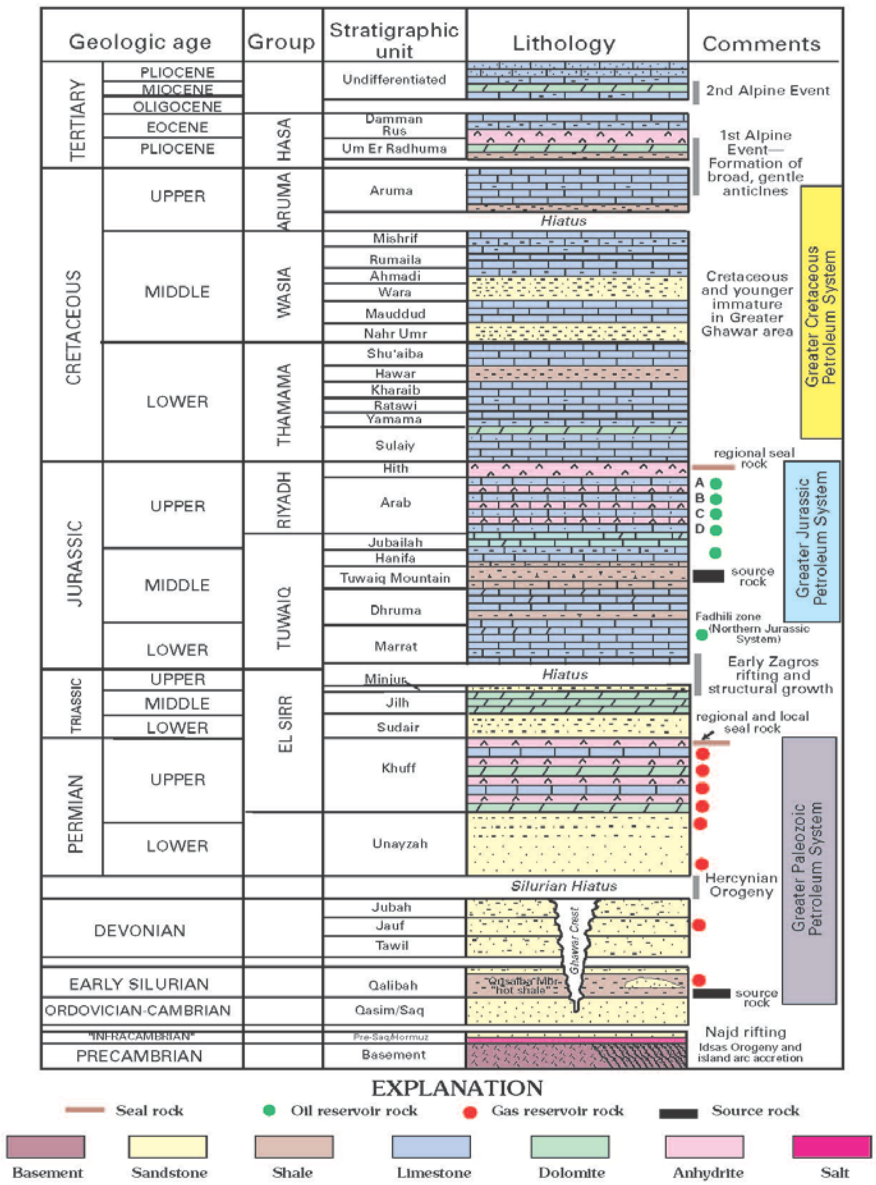
Natural gas provides a more complicated picture. Even with large volumes of proved reserves, 215 Tcf as of the end of 2012, UAE has become a net importer of natural gas. One reason is that the UAE re-injects a major portion of its gross gas production into its oil fields to improve oil recovery efficiency. The second is the rapid growth of electricity demand by UAE that relies on natural gas-fired power plants. The third is the high sulfur content of much of UAE's conventional gas requiring more sophisticated, expensive technologies for its production and use.

The UAE contains a series of organic-rich source rocks ranging from the deep, mature Lower Silurian Qusaiba Shale to the shallower, less mature Middle Cretaceous Shilaif tight oil formation with several source rocks in between. This chapter on the shale gas and oil resources of the UAE assesses the three major shale/tight source-rock formations:

- The organic-rich Lower Silurian Qusaiba Shale of the Qalibah Formation, one of the most prolific source rocks of the Arabian Peninsula.
- The Upper Jurassic Diyab Formation, a dark gray lime mudstone and calcareous shale in western Abu Dhabi.
- The Middle Cretaceous Shilaif (also called Khatiyah) Formation in central UAE.

Figure 2 provides a stratigraphic column for the Eastern Arabian Peninsula, highlighting the major shale/tight oil source rocks addressed by this resource assessment. The figure identifies the Lower Silurian Qusaiba "hot shale" and identifies Upper Jurassic Jubailah (equivalent to the Diyab in UAE) as major source rocks. In addition, the Middle Cretaceous Shilaif/Khatiyah, while a major source rock in the UAE, is considered to be immature in the Greater Ghawar area of Saudi Arabia.

Figure 2. Stratigraphic Columns for Eastern Arabian Peninsula



Source: Pollastro, 2003 (USGS Bulletin 2202-H)

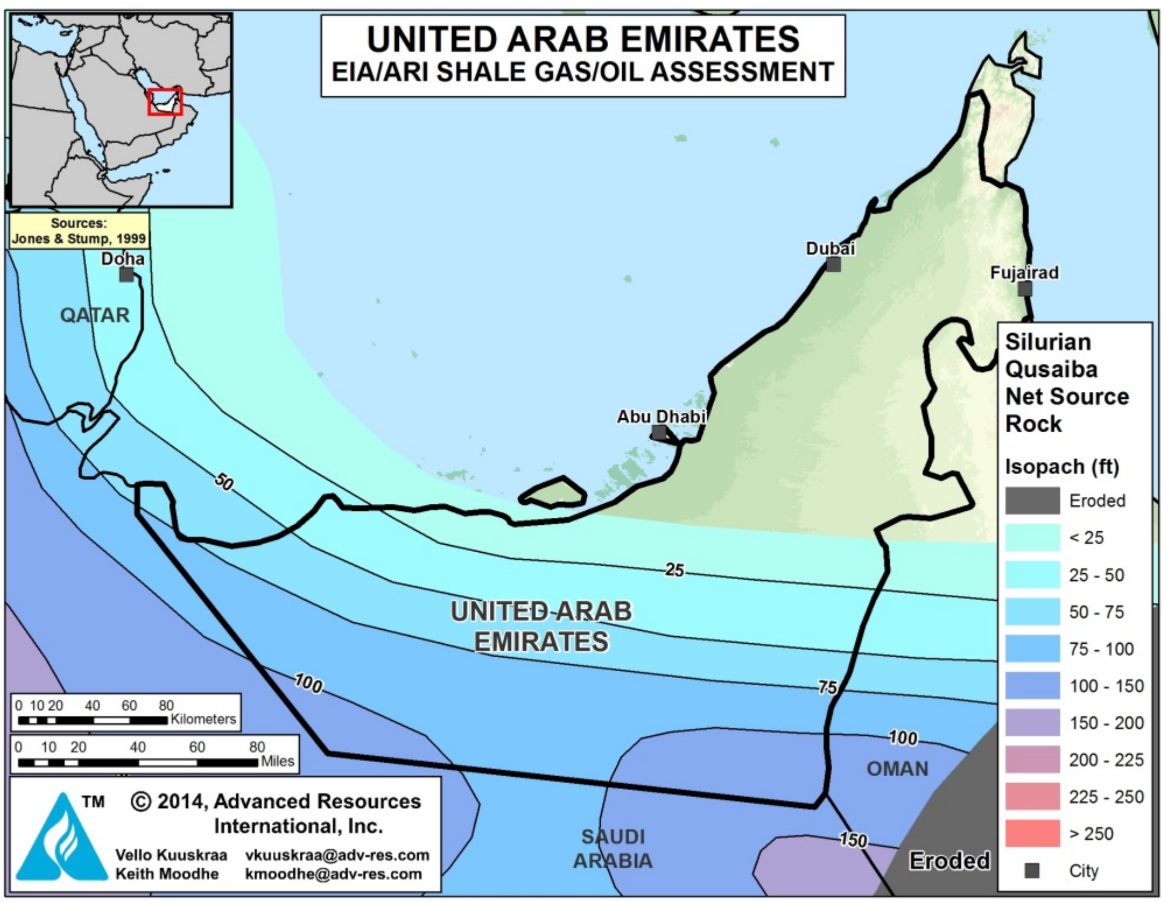
1. QUSAIBA SHALE

1.1 Introduction and Geologic Setting

The Lower Silurian Qusaiba organically rich "hot shale" is a major source rock, extending from North Africa into the Middle East. Our prior shale/tight oil and gas resource assessments have mapped the presence of the Lower Silurian "hot shale" in Jordan and Oman, and we also note its extensive presence in Saudi Arabia.

Recent depositional studies of the Lower Silurian Qusaiba Shale indicate that the areal extent of this prolific source rock is much greater than previously thought in the Arabian Peninsula. New information indicates that the Qusaiba Shale extends eastward from its depocenter in Saudi Arabia into the United Arab Emirates, Figure 3.

Figure 3. Extent of Silurian Qusaiba Source Rock in UAE

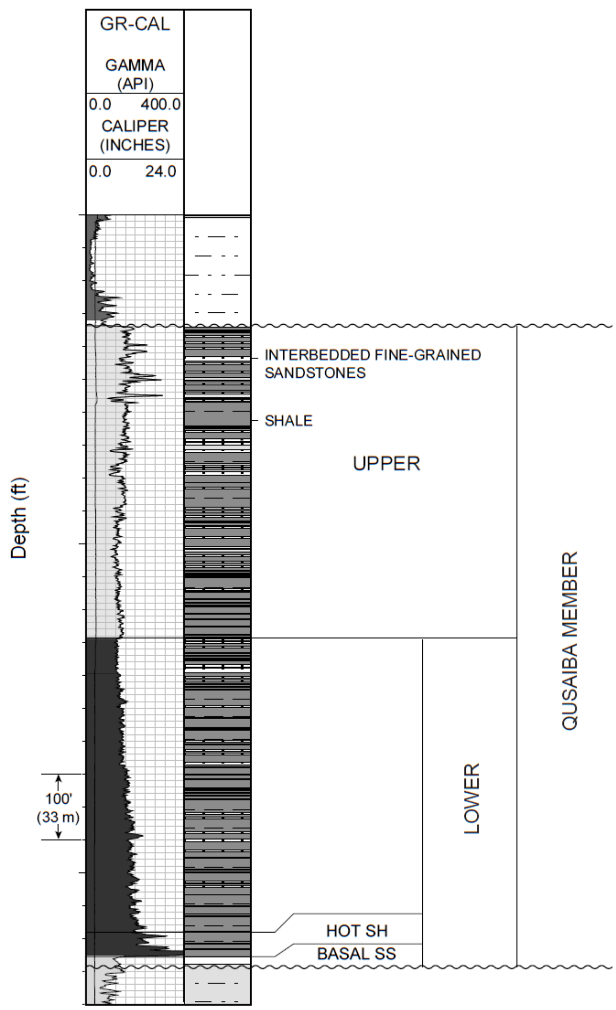


Source: ARI, 2014

The Qusaiba Shale is composed mostly of claystone and shale with interbeds of siltstone and sandstone. A major depocenter of the shale is in southern Saudi Arabia, now shown to extend into Oman and UAE.

The Qusaiba Shale is located at the base of the Qalibah Formation, Figure 4. The organic-rich basal Qusaiba Shale member (the "hot shale") was deposited in anoxic marine conditions and holds Type II oil prone kerogen, although kinetic modeling indicates that the shale is more gas prone than would be expected from typical Type II marine kerogen. Overlying the "basal" "hot shale" is a thick column of lean, lower clay content shale that, under favorable conditions, may serve as a secondary reservoir for wet and dry gas that may have been expulsed from the basal "hot shale".

Figure 4. Silurian Qusaiba Stratigraphic Column

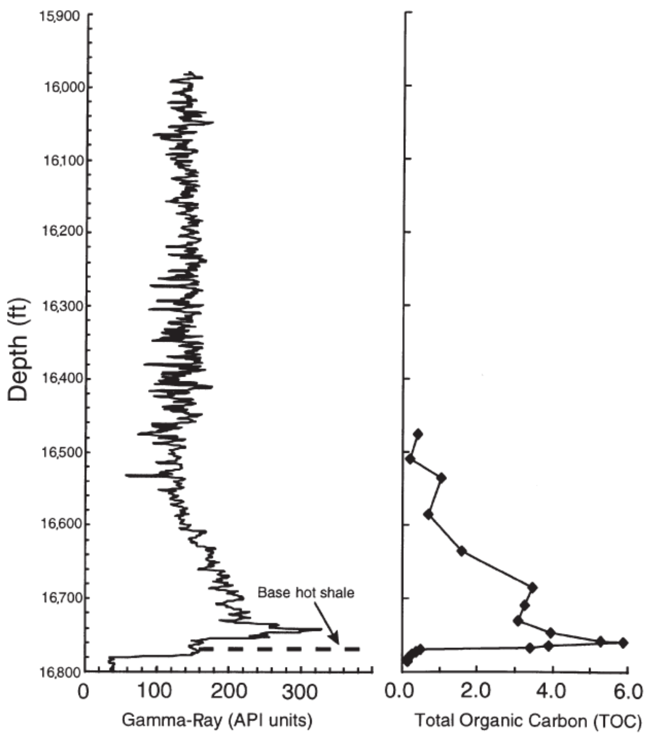


Source: Jones and Stump, 1991

1.2 Reservoir Properties (Prospective Area)

The Qusaiba Shale is deeply buried in central UAE, with a depth that ranges from 14,000 to 16,400 ft (average depth of 15,000 ft). The shale ranges in thickness from 25 ft in northern onshore UAE to 150 ft in south central UAE, averaging 80 ft in central and southern UAE. The TOC of the "hot shale" of the base of the Lower Qusaiba, measured as a gamma-ray response of over 150 API units, ranges from 2% to 6%, averaging 3%, Figure 5. Based on analog data from other Silurian "hot shale" deposits, the Qusaiba Shale in UAE is assessed to be moderately overpressured and have a medium clay content.

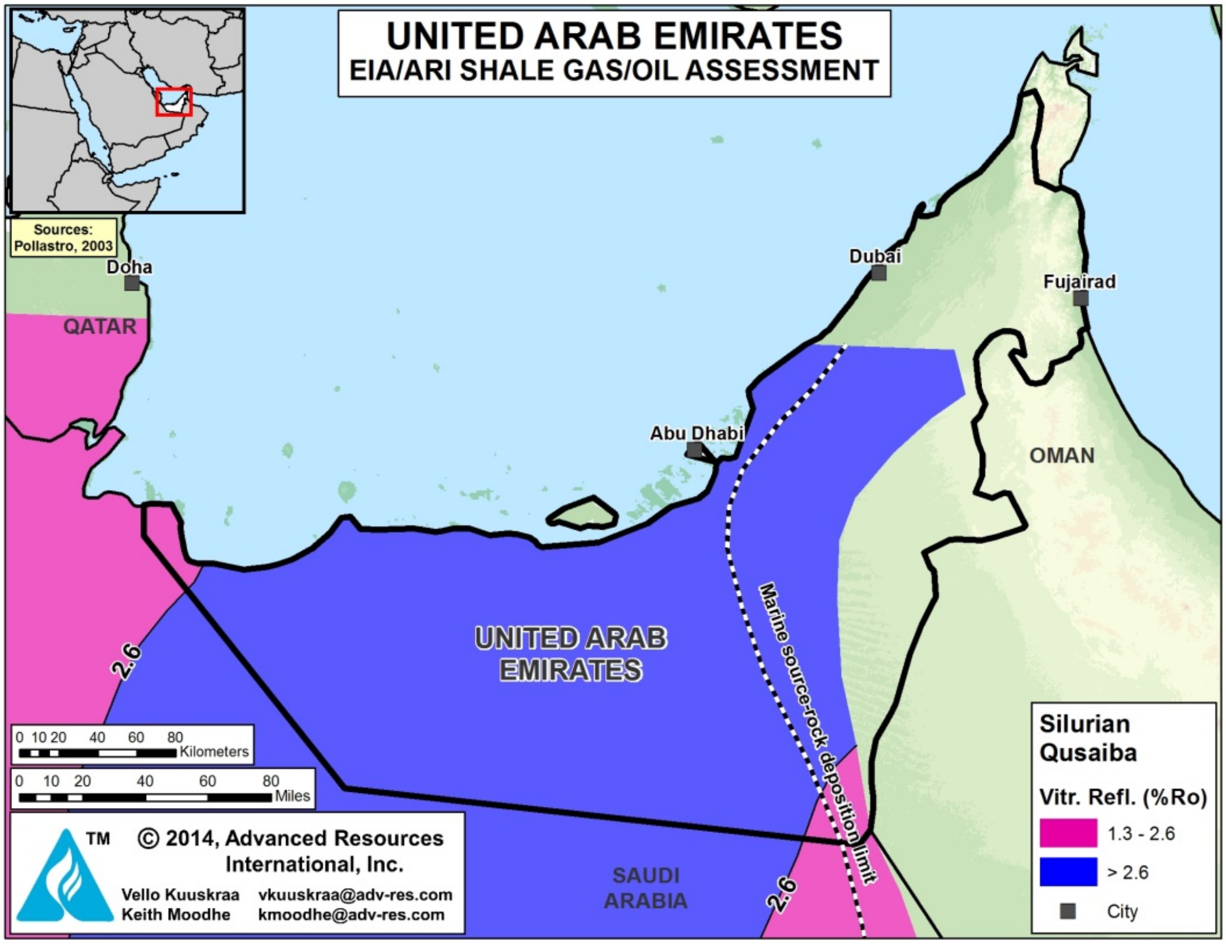
Figure 5. Silurian Qusaiba TOC Well Log



Source: Jones and Stump, 1991

The Qusaiba Shale in the UAE is primarily in the dry gas to overmature window, with a Ro of 1.3 to 2.6%. Two small areas in the northeast and southwest of the UAE are thermally highly mature, having an Ro of over 2.6%, Figure 6.

Figure 6. Silurian Qusaiba Thermal Maturity and Vitrinite Reflectance



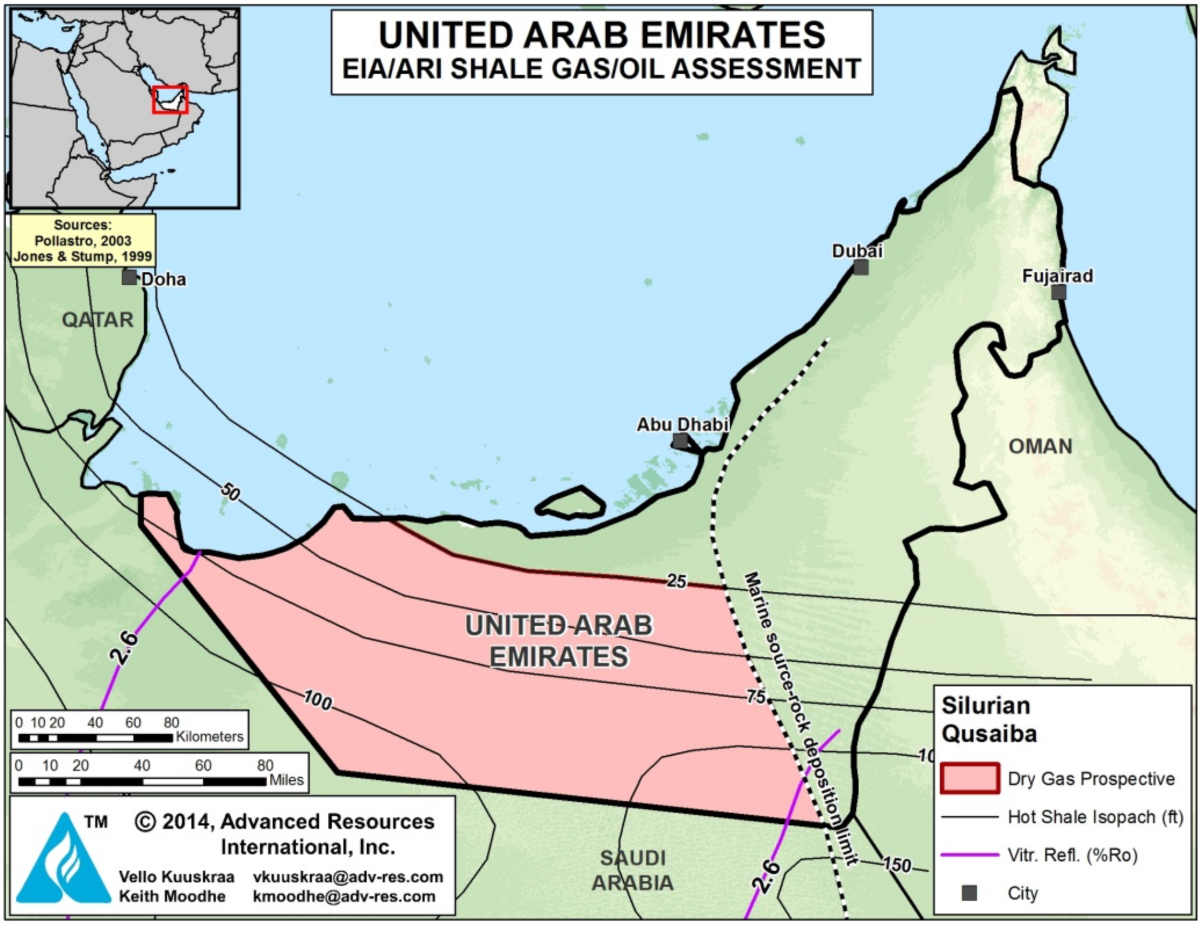
Source: ARI, 2014

1.3 Resource Assessment (Prospective Area)

The Qusaiba "hot shale" covers a prospective area of about 13,020 mi^2 in onshore UAE, Figure 7. The onshore prospective area is bounded on the east by the limit of marine source-rock deposition, on the west and south by the UAE and Saudi Arabia border, and one the north by the offshore/onshore boundary.

Within the 13,020 mi^2 area prospective for dry gas, the Qusaiba Shale has a resource concentration of 38 Bcf/mi^2. The risked resource in-place for the onshore prospective area of the Qusaiba "hot shale" is estimated at 248 Tcf. Based on moderately favorable reservoir properties, we estimate a risked, technically recoverable dry gas resource of 62 Tcf.

Figure 7. Prospective Area for Silurian Qusaiba "Hot Shale" in the UAE



Source: ARI, 2014

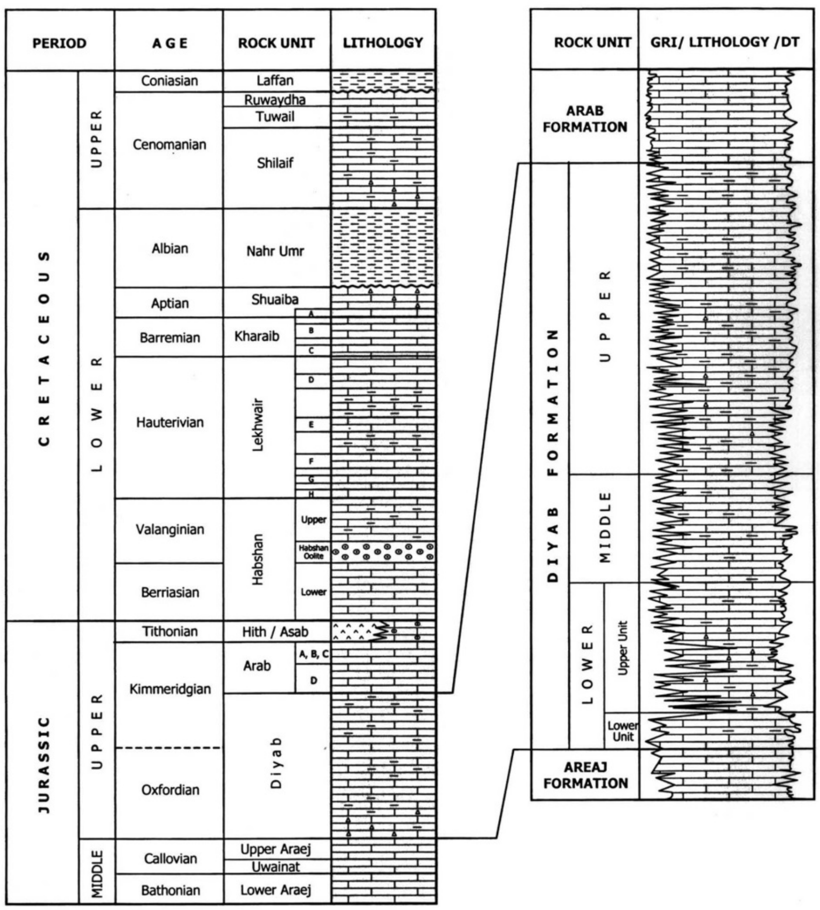
2. DIYAB FORMATION

2.1 Introduction and Geologic Setting

The Upper Jurassic Diyab Formation is the source rock for some of the most prolific reservoirs in the world. The Diyab Formation consists of argillaceous lime mudstones rich in organic matter in central UAE and grades into low organic matter packstones and grainstones in eastern UAE.

The organic-rich source rock within the Diyab Formation is contained in the Upper Unit of the Lower Member of the Diyab Formation and is characterized by a high gamma-ray response, Figure 8. The organic-rich Lower Member of the Diyab Formation exists in the western portion of onshore UAE, extending into the offshore.

Figure 8. Lower Cretaceous and Upper Jurassic Lithostratigraphy in Abu Dhabi, UAE



Source: Al-Suwaidi et al., 2000.

The organic content of the Lower Member of the Diyab Formation is mostly Type II amorphous kerogen plus degraded marine sapropelic kerogen deposited in an anoxic marine setting.

2.2 Reservoir Properties (Prospective Area)

The depth of the Lower Member (Upper Unit) of the Diyab Formation in the onshore prospective area ranges from 9,500 to 13,000 ft, averaging 11,000 feet. We have used the overlying Upper Jurassic Arab D Formation to estimate the depth of the Lower Member of the Diyab Formation, Figure 9.

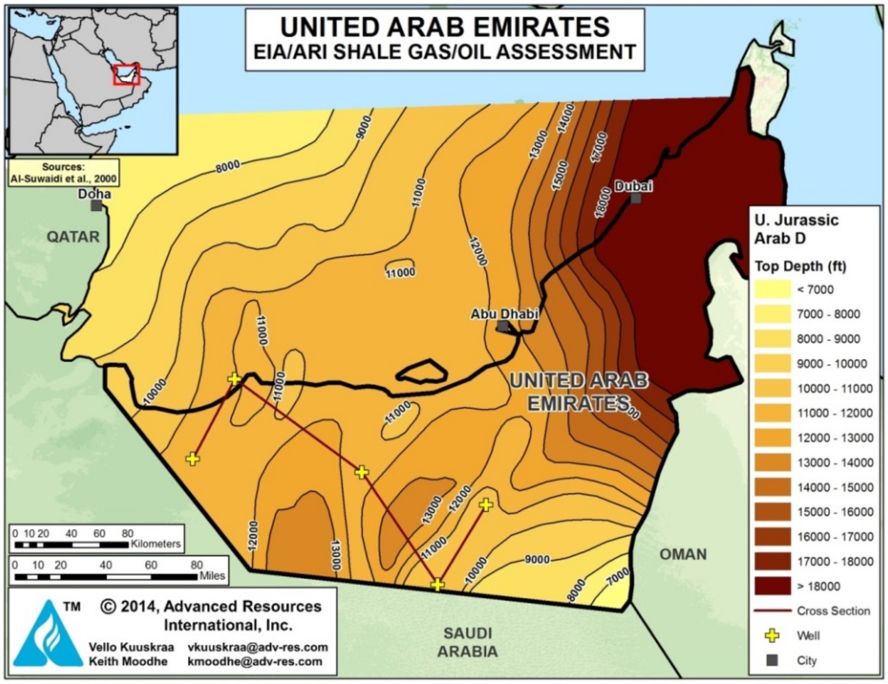
The organic-rich gross interval of the Lower Member ranges from 50 to 200 feet in the western UAE onshore prospective area and has an average net pay of about 135 feet, Figure 10. We have selected one south-to-east cross-section to illustrate the deposition and thickness of the Diyab Formation, Figure 11.

Prior research indicates that the original organic content and source rock potential of the Lower Member of the Diyab Formation was considerably higher than measured today. In addition, we have restricted our resource assessment to only the higher TOC Upper Unit of the Lower Member of the Diyab Formation. We estimated that the prospective area has adjusted TOC values that range from 2 to 3%, Figure 12. Figure 13 provides a 5-well cross-section with TOC values posted for the Upper Unit of the Lower Member of the Diyab Formation.

The Upper Unit of the Lower Member of the Diyab Formation contains two hydrocarbon windows - - dry gas (Ro > 1.3%) in the deeper, central portion of the deposit and wet gas/condensate (Ro of 0.7 to 1.3%) in the shallower, northern and southeastern portions of the deposit, Figure 14. The formation becomes immature (Ro of <0.7%) in the offshore.

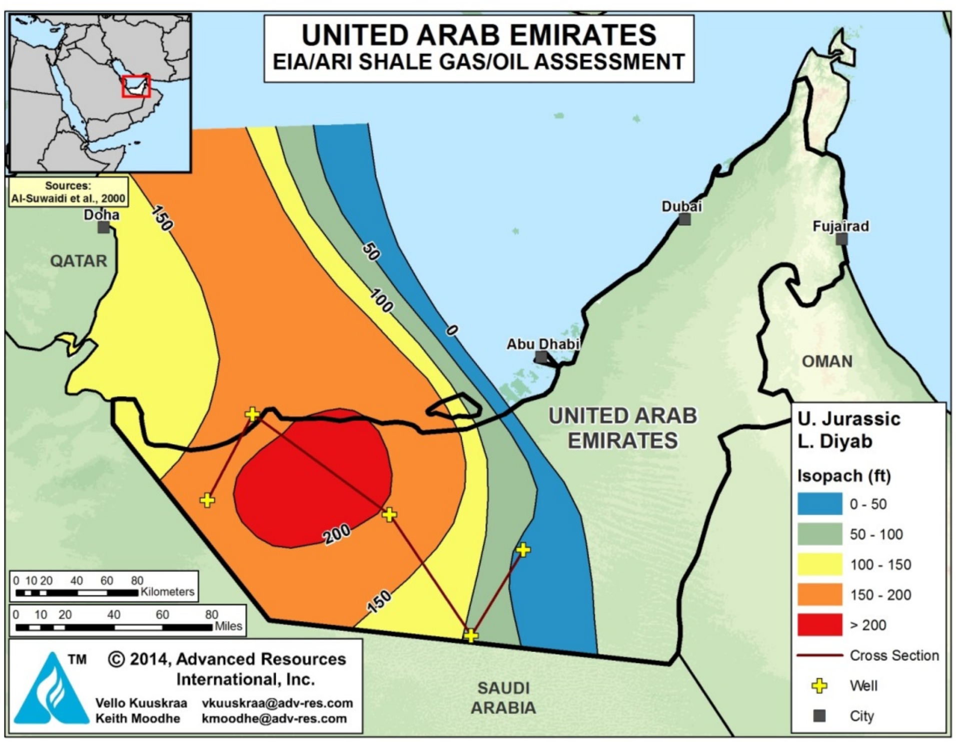
The temperature gradient in the Diyab Formation ranges from 1.5 ^{o}F to 2.5 ^{o}F per 100 feet. We assume the formation to be at hydrostatic pressure.

Figure 9. Depth of Upper Jurassic Arab D Formation



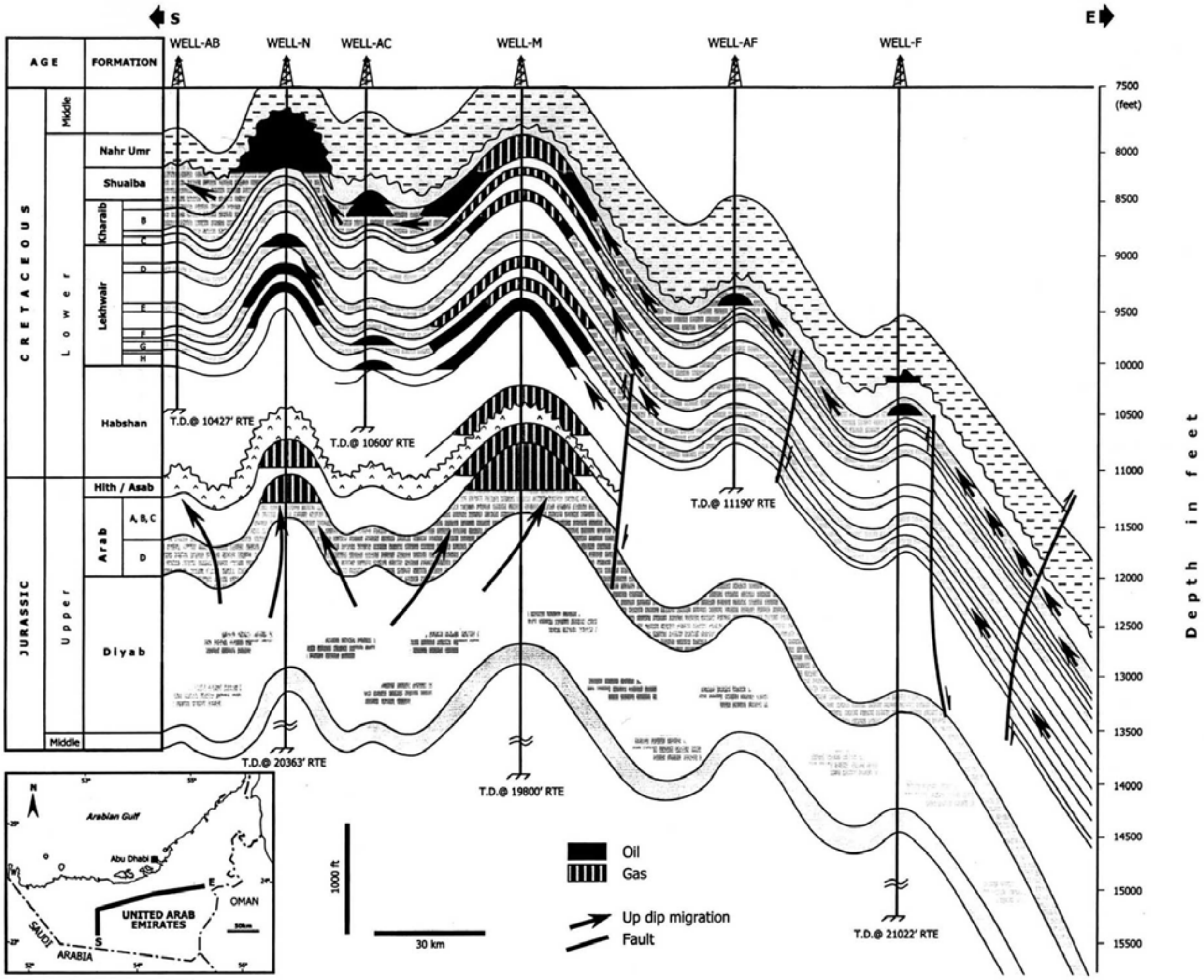
Source: ARI, 2014

Figure 10. Isopach of the Lower Member (Upper Unit) of the Diyab Formation



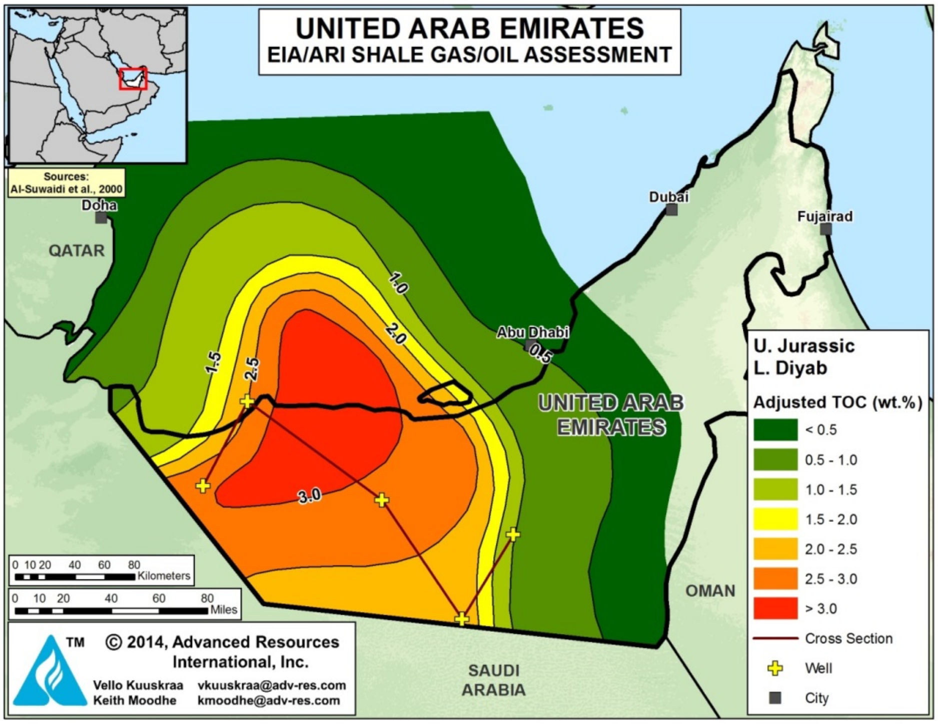
Source: ARI, 2014

Figure 11. Structural S-to-E Cross-Section for Onshore Abu Dhabi/UAE



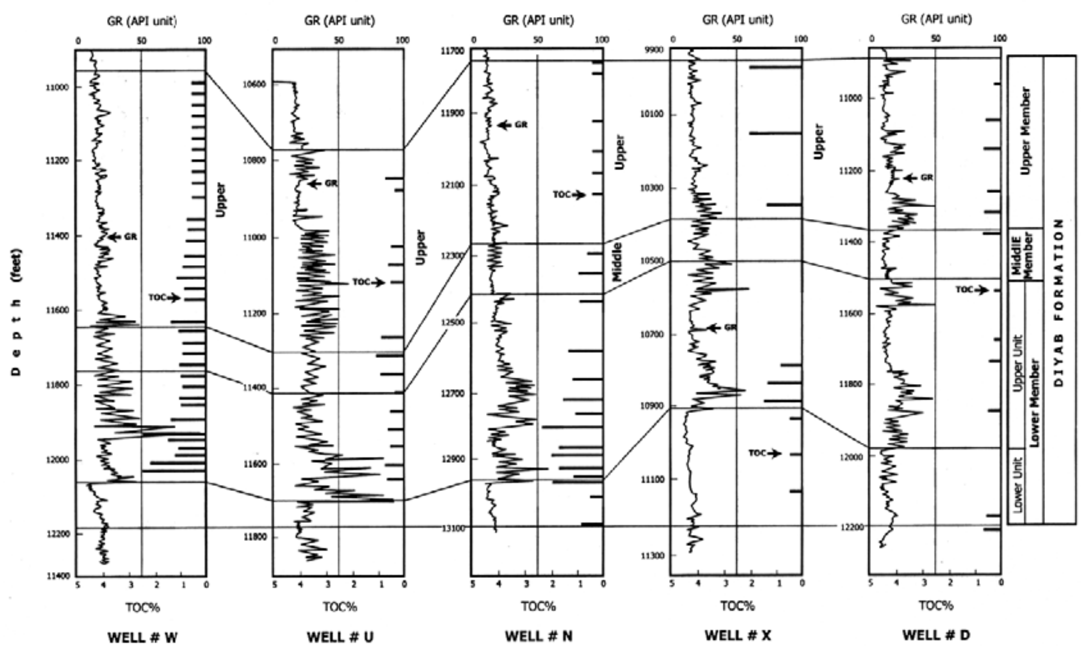
Source: Al-Suwaidi et al., 2000.

Figure 12. TOC Values (Adjusted) for the Upper Unit of the Lower Member of the Diyab Formation



Source: ARI, 2014

Figure 13. UAE U Jurassic Diyab Well Correlation Cross-Section



Source: Al-Suwaidi et al., 2000.

Advanced Resources International, Inc.

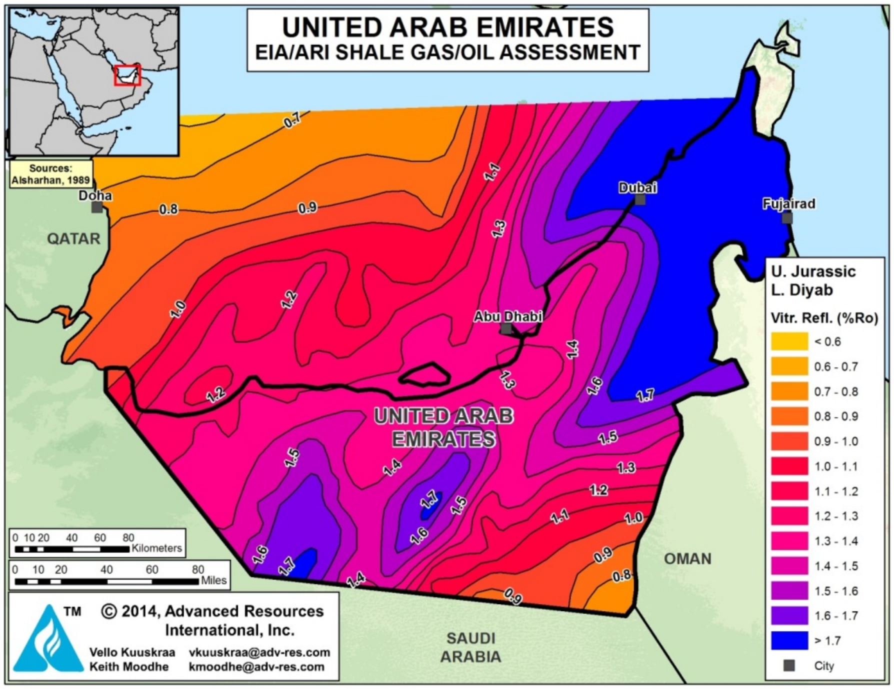
2.3 Resource Assessment

The prospective area of the onshore portion of the Lower Diyab Formation is limited on the east by the thinning of the formation, on the south and west by the Saudi Arabia border, and on the north by the onshore/offshore boundary, Figure 15.

Within the 8,980 mi^2 prospective area for dry gas, the Lower Member (Upper Unit) of the Diyab Formation has a resource concentration of 70 Bcf per mi^2. The risked resource in-place for the prospective area of the Lower Member of the Diyab Formation is estimated at 409 Tcf. Based on moderately favorable reservoir properties, we estimate a risked, technically recoverable shale gas resource of 123 Tcf.

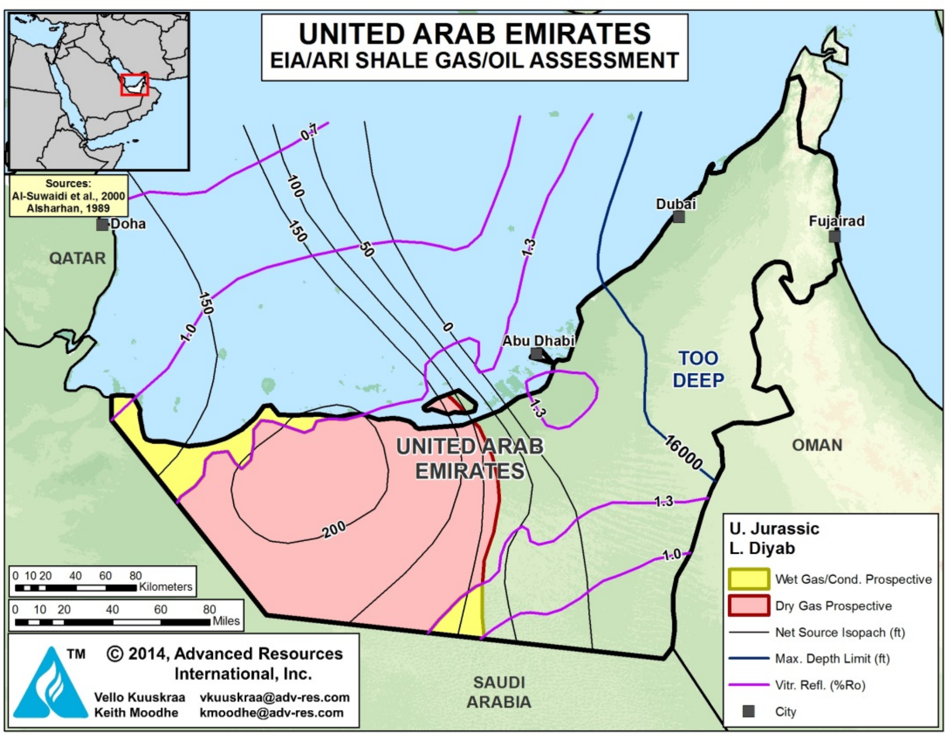
Within the 1,300 mi^2 prospective area for wet gas/condensate, the Lower Member of the Diyab Formation has a resource concentration of 17 Bcf/mi^2 for wet gas and 11 million barrels/mi^2 for oil/condensate. The risked resources in-place for the wet gas/condensate prospective areas of the Lower Member of the Diyab Formation are estimated at 14 Tcf of wet gas and 9 billion barrels of oil/condensate. Based on moderately favorable reservoir properties, we estimate risked, technically recoverable resources of 2 Tcf for wet gas and 0.5 billion barrels for oil/condensate.

Figure 14. Vitrinite Reflectance of the Lower Member of the Diyab Formation



Source: ARI, 2014

Figure 15. Prospective Areas of the Lower Member of the Diyab Formation



Source: ARI, 2014

3. SHILAIF FORMATION

3.1 Introduction and Geologic Setting

The Middle Cretaceous Shilaif Formation, part of the larger Wasia Group that also contains the productive Mishrif and Simsima reservoirs, extends across much of the UAE. The Shilaif Formation (called Khatiyah in Dubai) is a laminated, locally bituminous carbonaceous marl and pelagic lime mudstone that serves as the source rock for the major Mishrif and Simsima reservoirs of the UAE. The formation is judged to have accumulated in an anoxic basinal setting with conditions favorable for accumulations and preservation of organic matter.

3.2 Reservoir Properties (Prospective Area)

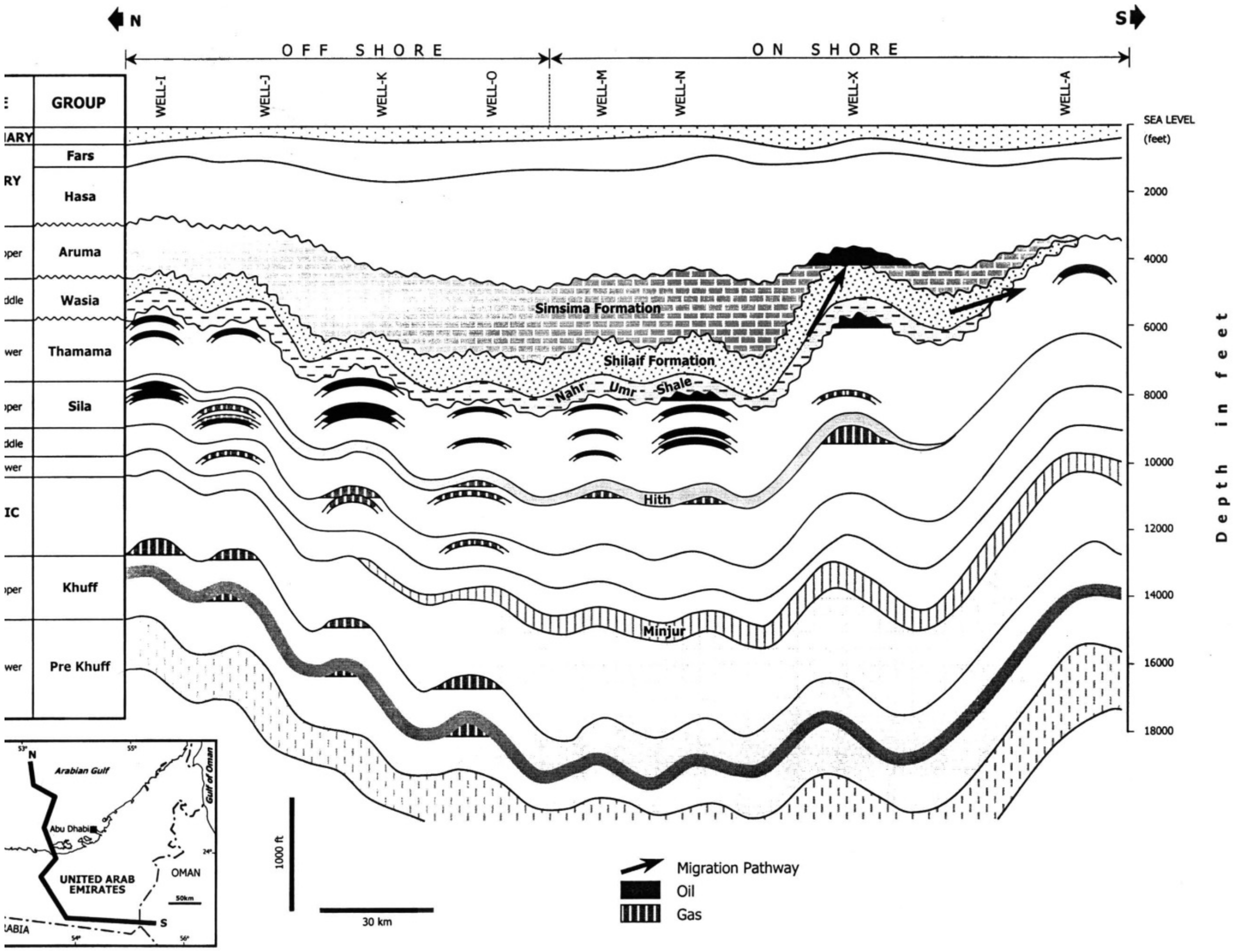
The depth of the Shilaif Formation in the onshore prospective area ranges from 3,500 to 11,000 ft, averaging 6,500 ft. The onshore portion of the north-to-southeast cross-section, Figure 16, and the east-to-west cross-section, Figure 17, provides data on the depth of the Shilaif Formation in central UAE. The figures show the shallowing of the formation to the south and its truncation in the east, Figure 16. (The location of the north-to-southeast cross-section and the east-to-west cross-section are shown in Figure 18.

The gross thickness of the Shilaif Formation in the prospective area is estimated at 660 ft. Applying a net-to-gross ratio of 50%, we estimate a 330 ft net organic-rich interval. Figure 19 is a west-to-east cross-section for the Middle Cretaceous section in the offshore UAE that provides information on the presence and continuity of the Shilaif Formation.

The Shilaif Formation has TOC values that range from 1 to 6%, with some intervals having TOC values of up to 15%. The organics are composed primarily of oil-prone sapropelic material. The Shilaif Formation has good to excellent source-rock potential, with pyrolysis yields in central UAE of 15 to 35 kg/tonne, Figure 20.

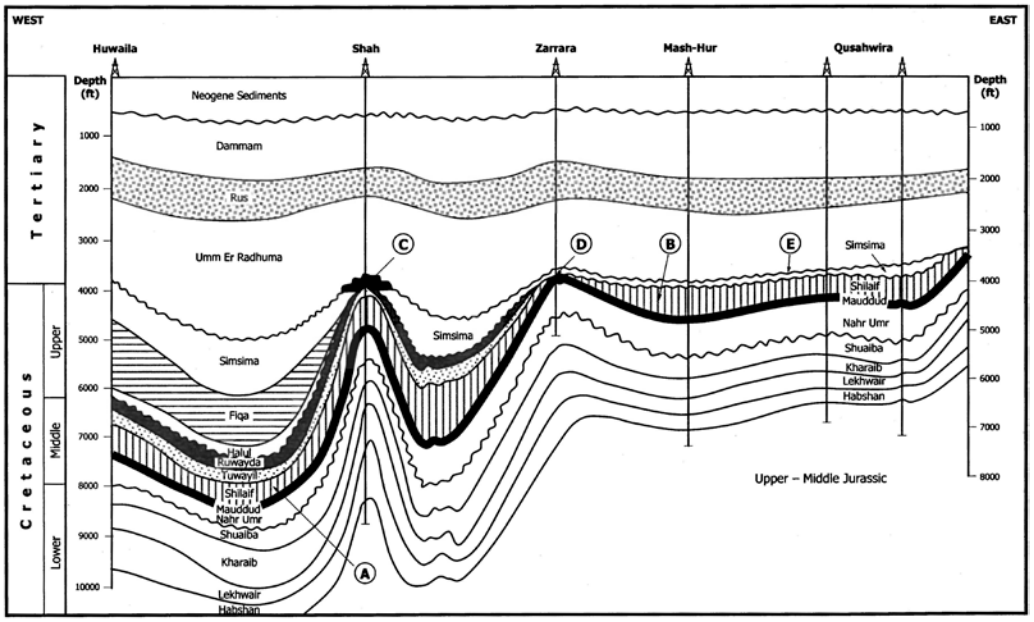
The thermal maturity of the Shilaif Formation is immature in much of the offshore, becoming increasingly mature in onshore central and north-eastern UAE where subsidence provided deeper burial, Figure 21. For establishing the hydrocarbon-generating thresholds for the Shilaif Formation, we have followed the criteria set forth in the article “Petroleum Geology of the United Arab Emirates” (A.S. Alsharhan) using 0.6% to 0.8% Ro as the oil window. We assume that the formation is normally pressured and has a thermal gradient of 1.5^{o}F to 2.5^{o}F per 100 ft.

Figure 16. North-to-South Structural Cross-Section for Shilaif Formation, UAE



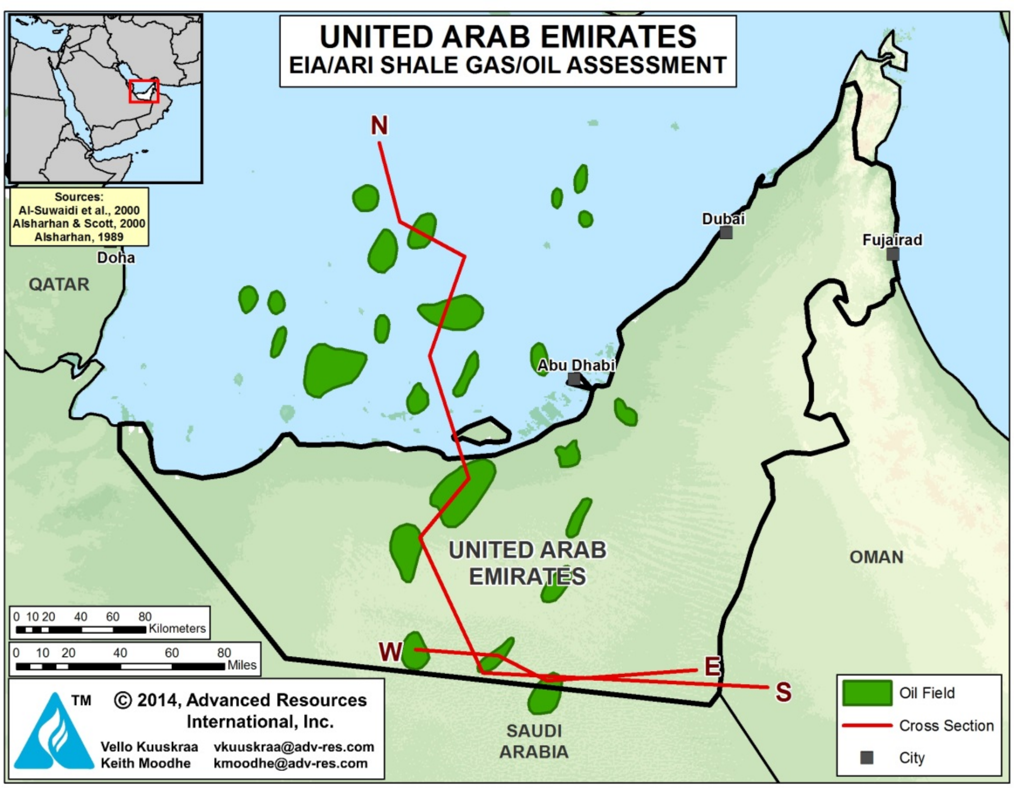
Source: Al-Suwaidi et al., 2000.

Figure 17. West-to-East Structural Cross-Section for Shilaif Formation, UAE



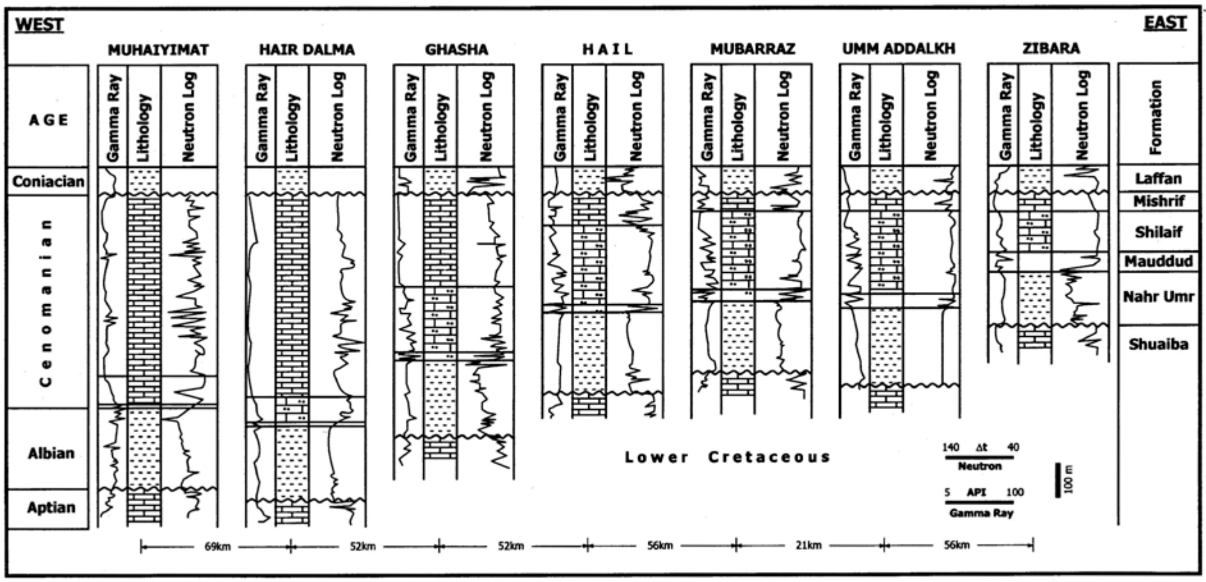
Cretaceous Reservoirs modified from Loutfi and El-Bishlawy, 1986.
Source: Alsharhan and Scott, 2000

Figure 18. United Arab Emirates' Shale Gas and Shale Oil Basins with Cross-Sections



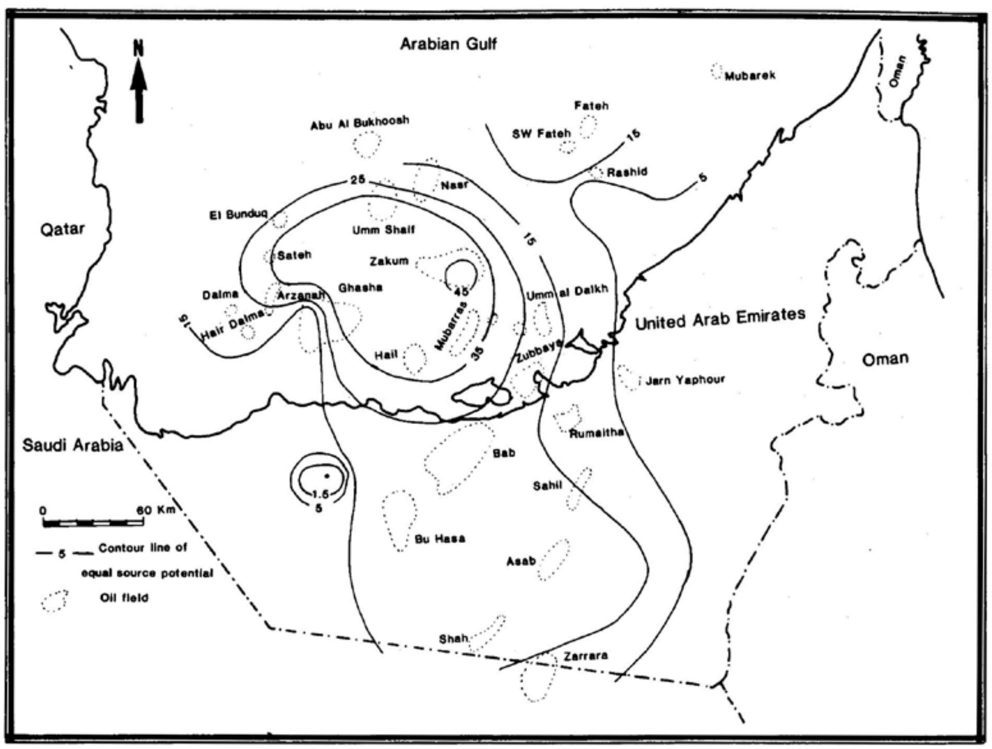
Source: ARI, 2014

Figure 19. Lithostratigraphy and Log Characteristics of Middle Cretaceous Strata in Offshore Abu Dhabi



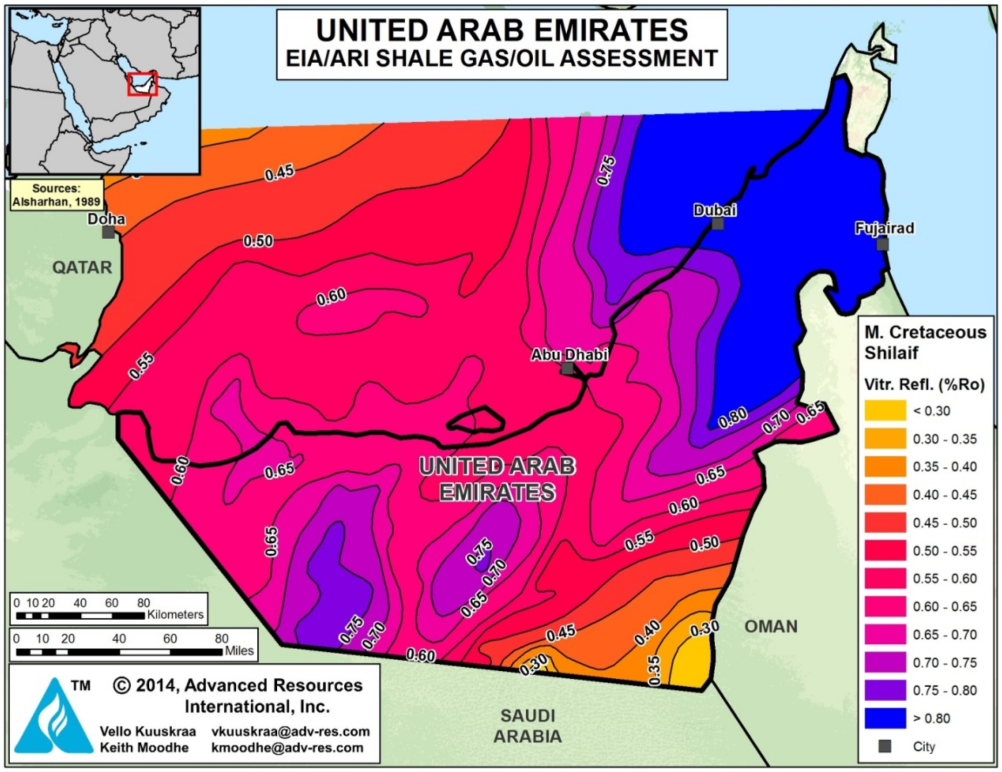
Source: Alsharhan and Scott, 2000

Figure 20. Shilaif-Khatiya Formation (Middle Cretaceous) Present Source-Rock Potential Based on Pyrolsis (P2 yields measured in kg/tonne) in the UAE.



After ADNOC Staff, 1984.
Source: Alsharhan, 1989.

Figure 21. Shilaif Formation Vitrinite Reflectance



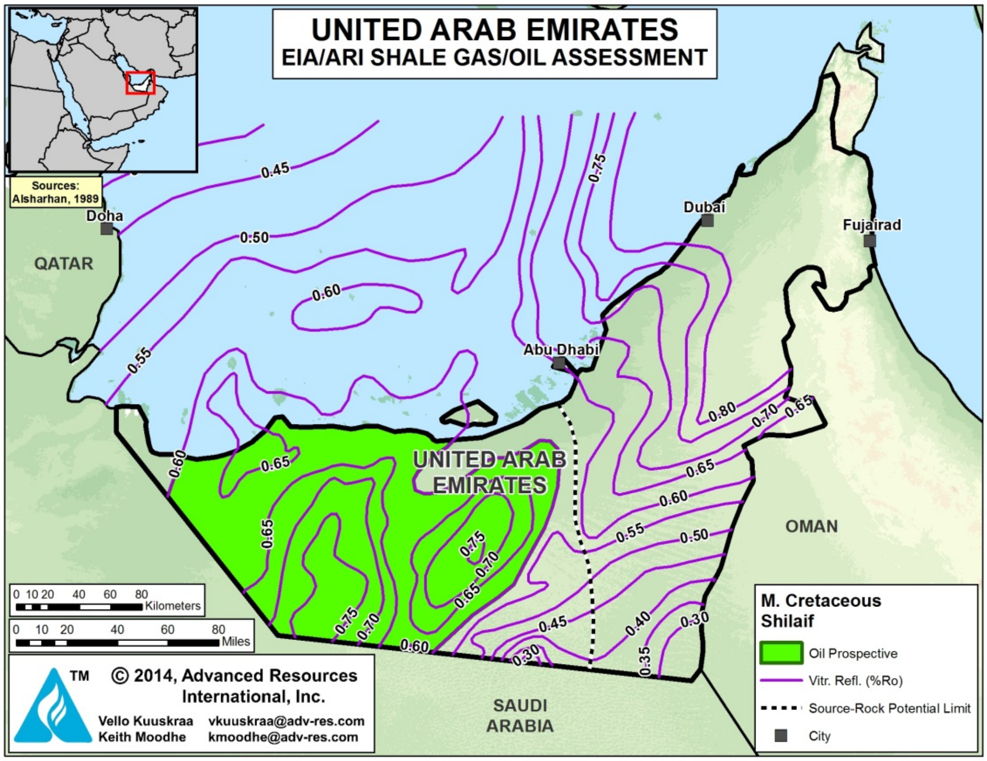
Source: ARI, 2014

3.3 Resource Assessment

The 9,670 mi^2 area prospective area of the onshore Middle Cretaceous Shilaif Formation is bounded by the 0.6% Ro to 0.8% Ro contour, the Saudi Arabia and Oman borders with the UAE, and the offshore/onshore boundary, Figure 23.

Within the 9,670 mi^2 area prospective for oil, the Shilaif Formation has a resource concentration of 58 million barrels per mi^2. The risked resource in-place for the onshore prospective area is estimated at 367 billion barrels. Based on moderately favorable reservoir properties, we estimate a risked, technically recoverable shale oil resource of 22 billion barrels. The Shilaif shale oil resource also holds significant volumes of associated gas, estimated at 157 Tcf of resource in-place, with 19 Tcf as the risked, technically recoverable shale gas resource.

Figure 22. Shilaif Formation Oil Prospective Area



Source: ARI, 2014

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