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Technically Recoverable Shale Oil and Shale Gas Resources:

Jordan

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Executive Summary

Introduction

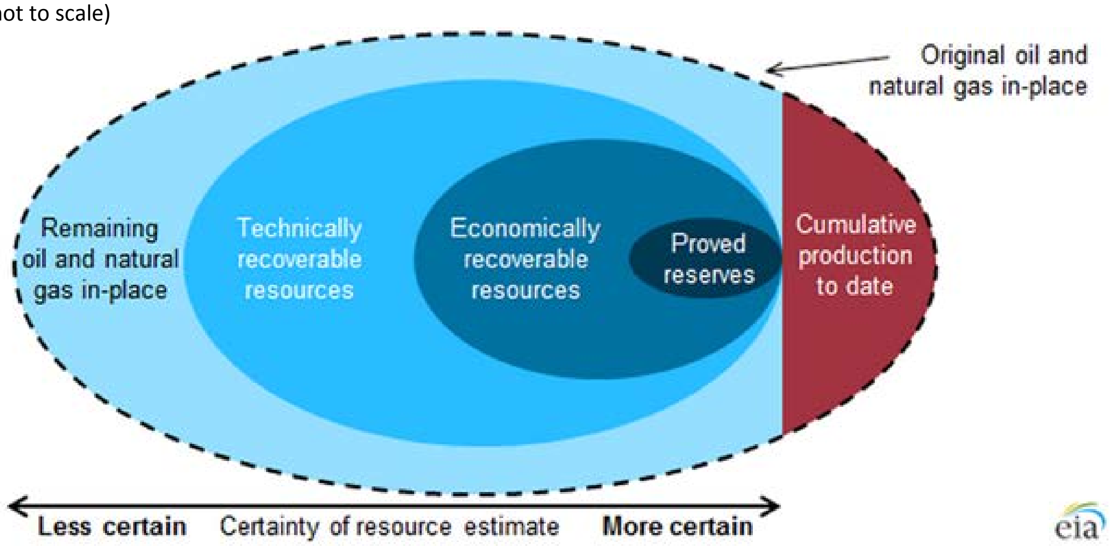
Although the shale resource estimates presented in this report will likely change over time as additional information becomes available, it is evident that shale resources that were until recently not included in technically recoverable resources constitute a substantial share of overall global technically recoverable oil and natural gas resources. This chapter is from 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.

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

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[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.

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:

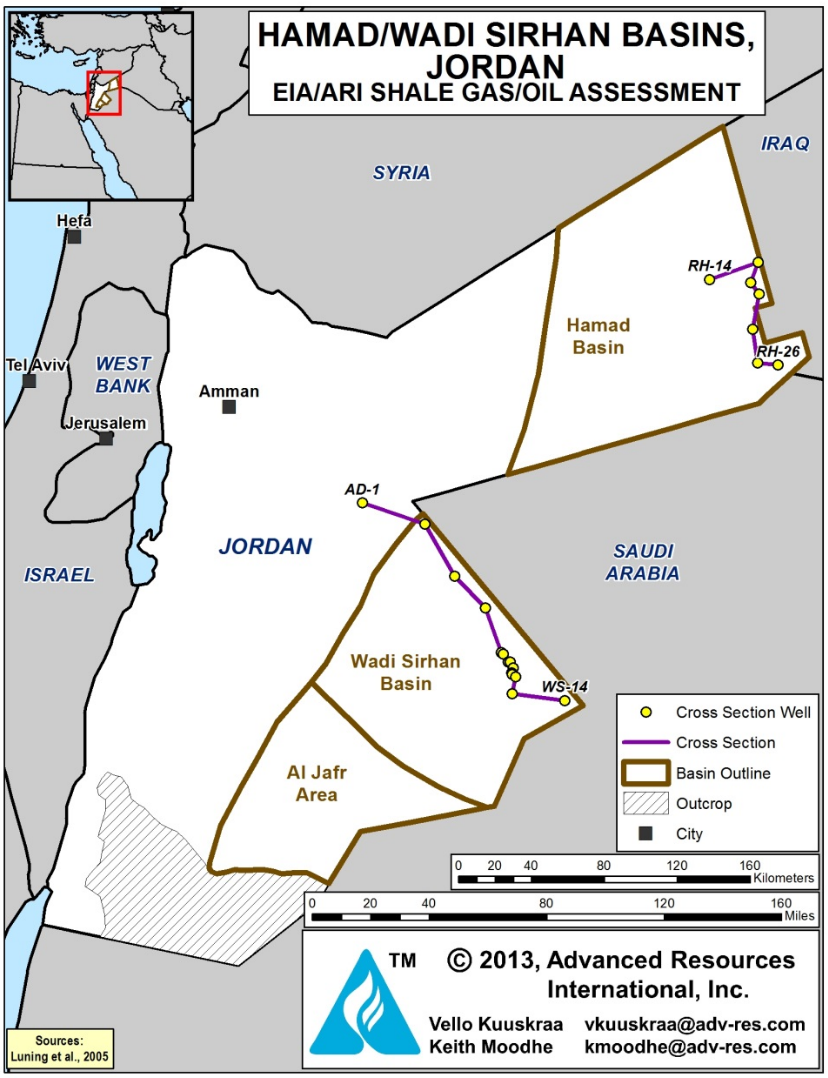
1. **Tight oil produced from low permeability sandstone and carbonate formations** that can often be found adjacent to shale oil formations. Assessing those formations was beyond the scope of this supplement as in the previous report.
2. **Coalbed methane and tight natural gas** and other natural gas 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.

XXV. JORDAN

SUMMARY

Jordan has two basins with potential for shale gas and oil, the Hamad (Risha area) and Wadi Sirhan, Figure XXV. The target horizon is the organic-rich Silurian-age Batra Shale within the larger Mudawwara Formation.

Figure XXV-1. Base Map and Cross-Section Location, Jordan.



Source: ARI, 2013.

Our assessment is that the Batra Shale in these two basins contains 35 Tcf of risked shale gas in-place with 7 Tcf of risked, technically recoverable shale gas resource, Table XXV-1. In addition, we estimate that the Batra Shale holds 4 billion barrels of risked shale oil in-place, with about 0.1 billion barrels of risked, technically recoverable shale oil resource, Table XXV-2.

Table XXV-1. Shale Gas Reservoir Properties and Resources of Jordan

			Hamad	Wadi Sirhan
Basic Data	Basin/Gross Area		(6,700 mi^2)	(4,700 mi^2)
	Shale Formation		Batra	Batra
	Geologic Age		Silurian	Silurian
	Depositional Environment		Marine	Marine
Physical Extent	Prospective Area (mi^2)		3,300	1,050
	Thickness (ft)	Organically Rich	160	120
		Net	80	60
	Depth (ft)	Interval	6,500 - 10,000	4,500 - 6,500
		Average	8,500	5,500
Reservoir Properties	Reservoir Pressure		Normal	Normal
	Average TOC (wt. %)		2.0%	4.0%
	Thermal Maturity (% Ro)		1.30%	0.80%
	Clay Content		Medium	Medium
Resource	Gas Phase		Dry Gas	Assoc. Gas
	GIP Concentration (Bcf/mi^2)		25.3	3.7
	Risked GIP (Tcf)		33.4	1.6
	Risked Recoverable (Tcf)		6.7	0.2

Source: ARI 2013.

Table XXV-2. Shale Oil Reservoir Properties and Resources of Jordan

Basic Data	Basin/Gross Area		Wadi Sirhan (4,700 mi^2)
	Shale Formation		Batra
	Geologic Age		Silurian
	Depositional Environment		Marine
Physical Extent	Prospective Area (mi^2)		1,050
	Thickness (ft)	Organically Rich	120
		Net	60
	Depth (ft)	Interval	4,500 - 6,500
		Average	5,500
Reservoir Properties	Reservoir Pressure		Normal
	Average TOC (wt. %)		4.0%
	Thermal Maturity (% Ro)		0.80%
	Clay Content		Medium
Resource	Oil Phase		Oil
	OIP Concentration (MMbbl/mi^2)		8.8
	Risked OIP (B bbl)		3.7
	Risked Recoverable (B bbl)		0.15

Source: ARI, 2013.

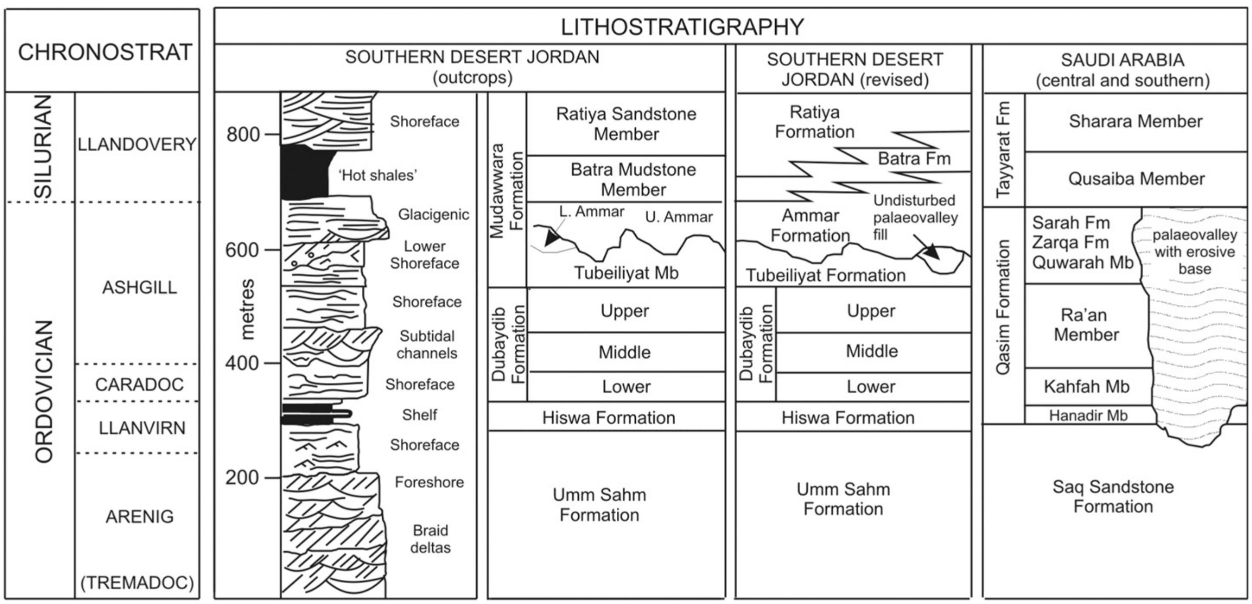
INTRODUCTION

Eastern Jordan contains Silurian-age organic-rich marine shales in the Batra Member of the Mudawwara Formation. Similar Silurian organic-rich shales are a major source of hydrocarbons in North Africa, Iraq and Saudi Arabia. The Batra Shale is time equivalent to the Tanezzuft Formation in Libya and the Qusaiba Shale of the Qalibah Formation in Saudi Arabia.[1] These Lower Silurian-age shales are often called “Hot Shales” because of their high uranium content, having gamma-ray values of >150 API units, Figure XXV-2.[2]

Additional organically enriched marine shales exist in the uppermost Ordovician-age Risha Formation. These shales are 60 to 120 feet thick and have thermal maturities for dry gas.[3,4] However, the TOC values of these Upper Ordovician shales generally range from 0.5% to 1.5%, below the TOC cut-off set forth for this study.

For the shale gas and oil resource assessment of Jordan, we have drawn heavily on the most valuable geological work and publications of Luning (2000,[1] 2005[3]), Armstrong (2005,[5] 2009[2]), Keegan (1990[6]), and Ahlbrandt (1997[7]). In addition, Jordan's Petroleum Directorate within the Natural Resources Authority provided important information in their 2006 publication entitled, "Petroleum Exploration Opportunities in Jordan".[8]

Figure XXV-2. Lithostratigraphy for the Ordovician and Silurian of Jordan and Saudi Arabia,



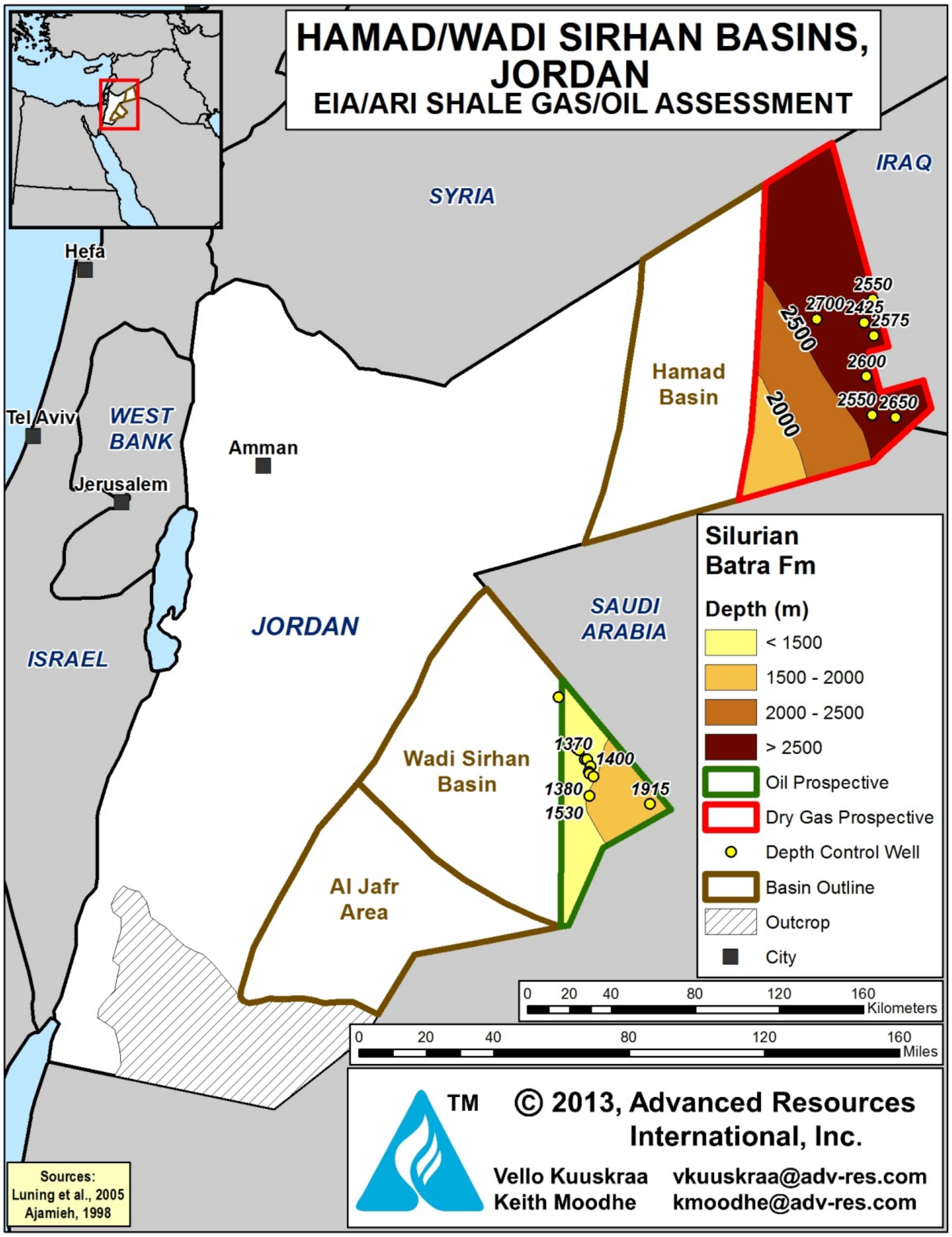
Source: Lithostratigraphy and chronostratigraphy for the Ordovician and Silurian of Jordan and Saudi Arabia, showing generalized depositional environments for outcrops in the Southern Desert region of Jordan (redrawn from Turner et al., 2005). Armstrong (2009)

1. GEOLOGIC SETTING

The Batra Shale is present in the sub-surface in the Hamad (Risha area) and Wadi Sirhan basins of eastern Jordan, as well as in the near-surface in the Al Jafr area and outcrops of the Southern Desert of Jordan. The Hercynian sub-crop establishes western limits of the Batra Shale in Jordan. The Syria, Iraq and Saudi Arabia borders with Jordan set the northern, southern and eastern limits of the Jordan portion of this shale deposit. The Batra Shale is a Type I/II marine shale, deposited along the margins of the receding Gondwana shelf. Figure XXV-3 provides the depth and areal extent for the prospective areas of Batra Shale in Jordan.[3]

The Batra Shale contains three distinct organic-rich intervals - - a highly organic-rich unit called the "Lower Hot Shale", a middle unit within lower organic content, and the "Upper Hot Shale".[3] We have included the "Lower Hot Shale" and the "Upper Hot Shale" units in our resource assessment.

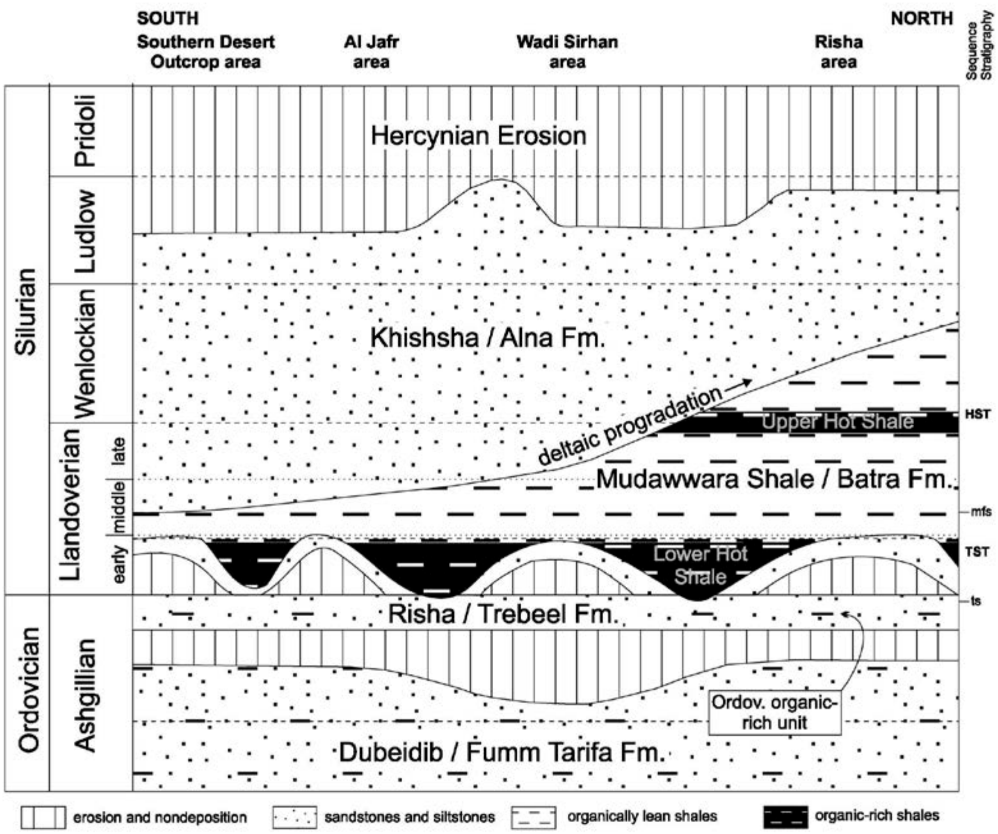
Figure XXV-3. Depth and Prospective Areas - - Batra Shale, Jordan



Source: ARI, 2013.

The "Lower Hot Shale" unit, deposited at the base of the Batra Shale and above the underlying Dubaydib Formation, is present in southeastern Jordan (Wadi Sirhan Basin). The "Lower Hot Shale" thins to the west, north and south in the Wadi Sirhan area. The "Upper Hot Shale" exists in the Hamad Basin's Risha gas field area along the Iraqi border. The "Upper Hot Shale" is at the top of the Batra Shale interval, XXV-Figure 4.[3]

Figure XXV-4. Chonostratigraphy of the Upper Ordovician-Silurian in Jordan.



Source: S. Luning, 2005.

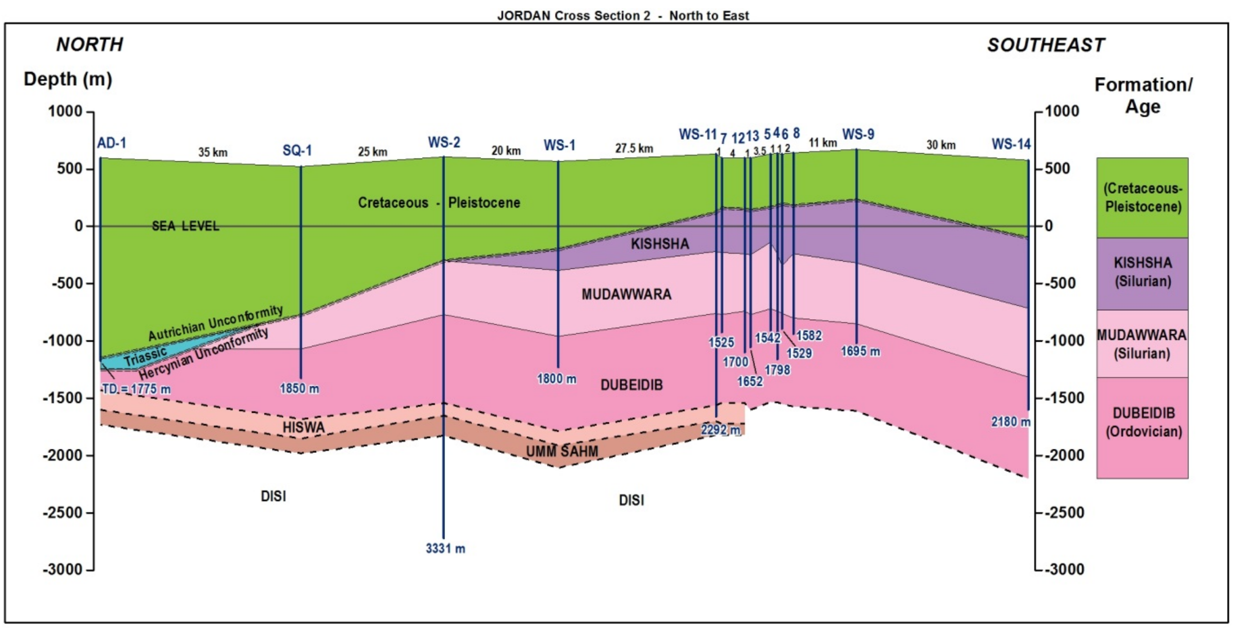
The thermal maturity of the Batra Shale increases from south to north and from west to east. The shale is immature to early-mature in the Al Jafr area, becomes middle-mature (oil window) in the Wadi Sirhan area, and is late to post-mature (gas window) in the Hamad Basin's Risha area.[3,7] The determination of the thermal maturity for the Batra Shale has been approximated using graptolite reflectance and maximum temperature. (Vitrinite did not yet exist during early Silurian time.)

As shown in Figure XXV-3, we have mapped a prospective area of 1,050 mi^2 for the "Lower Hot Shale" in the oil-prone Wadi Sirhan area and a prospective area of 3,300 mi^2 for the "Upper Hot Shale" in the gas-prone Risha area.

2. RESERVOIR PROPERTIES (PROSPECTIVE AREA)

Lower Hot Shale. In the Wadi Sirhan prospective area, the depth of the "Lower Hot Shale" ranges from 4,500 to 6,500 ft, averaging 5,500 ft. Based on analog data, we assume that the shale in this area is at normal pressure. The organic-rich gross interval of the "Lower Hot Shale" unit in the Wadi Sirhan prospective area ranges from 30 to 100 ft, with an average net pay of about 60 ft (using 150 API units of background gamma radiation). Figure XXV-5 provides a north to south cross-section for the Batra Shale in the Wadi Sirhan area.[8] (Figure XXV-1 provides the cross-section locations.[3,8])

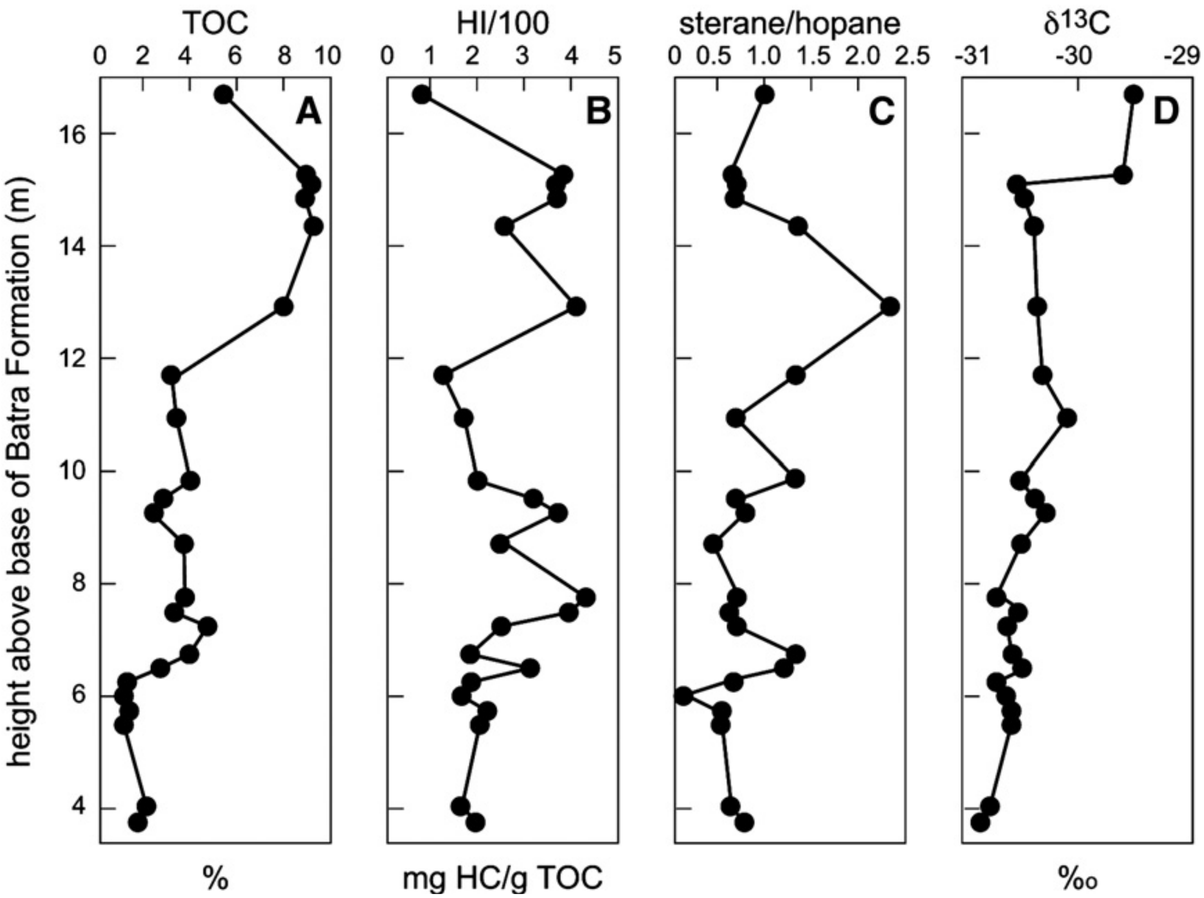
Figure XXV-5. North to South Regional Cross-Section, Wadi Sirhan Basin.



Source: NRA Petroleum Directorate Jordan, 2006.

The TOC of the "Lower Hot Shale" unit ranges from 1.5% to 9%, with an average value of about 4%, Figure XXV-6.[2] The thermal maturity of the shale unit is estimated at 0.7% to 1.0% R_o equivalent, averaging 0.8% R_o. We have used other Silurian-age "hot shale" deposits as analogs for supplemental reservoir data for the "Lower Hot Shale" in the Wadi Sirhan Basin.

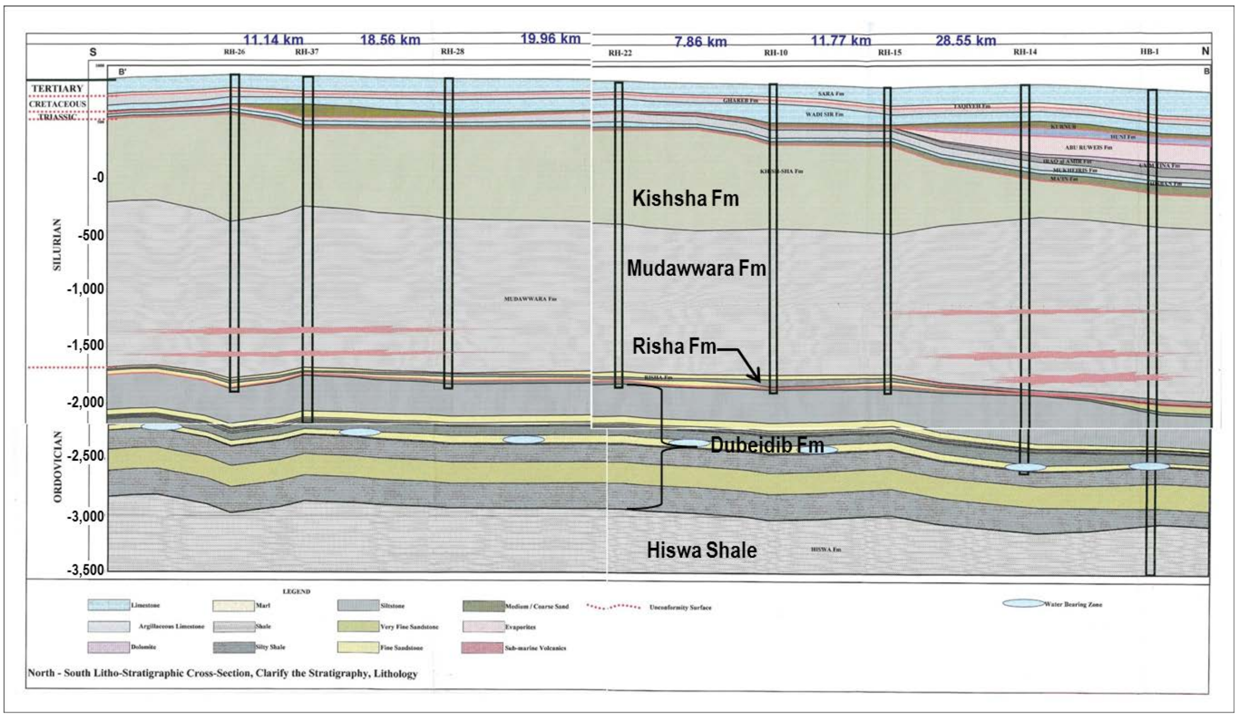
Figure XXV-6. Bulk Organic Carbon, Biomarker and Stable Carbon Isotope Data.



(A) Total organic carbon (TOC) content of the bulk sediment. (B) Hydrogen index (HI) of the bulk sediment (mg hydrocarbons (HC)/g TOC). (C) Steranes/17α-hopanes ratio shows its highest value at 12.94m above the base of the Batra formation. (D) δ13C values of organic carbon (OC) versus Vienna Peedee belemnite (VPDB) in parts per mil (‰).Source: Armstrong (2009)

Upper Hot Shale. In the Hamad Basin/Risha prospective area, the depth of the "Upper Hot Shale" ranges from 6,500 to 10,000 ft, averaging 8,500 ft. Based on limited well test data, we assume that the shale is at normal pressure. The organic-rich gross interval of the "Upper Hot Shale" unit in the Risha prospective area is about 160 ft thick, with an average net pay of about 80 ft, based on a minimum 2% TOC value cutoff. Figure XXV-7 provides a north to south cross-section for the Batra Shale in the Risha area (see Figure XXV-1 for cross-section location.).[8] The average TOC value is about 2%, after exclusion of the lower TOC value intervals using the net to gross pay ratio. The thermal maturity of the "Upper Hot Shale" is estimated at above 1.2% R_o equivalent[3]. We have used analog data from other Silurian-age "hot shale" deposits for supplemental reservoirs data for the "Upper Hot Shale" unit in the Hamad Basin (Risha Area).

Figure XXV-7. Regional Geologic Cross-Section, Eastern Hamad Basin (Risha Area).



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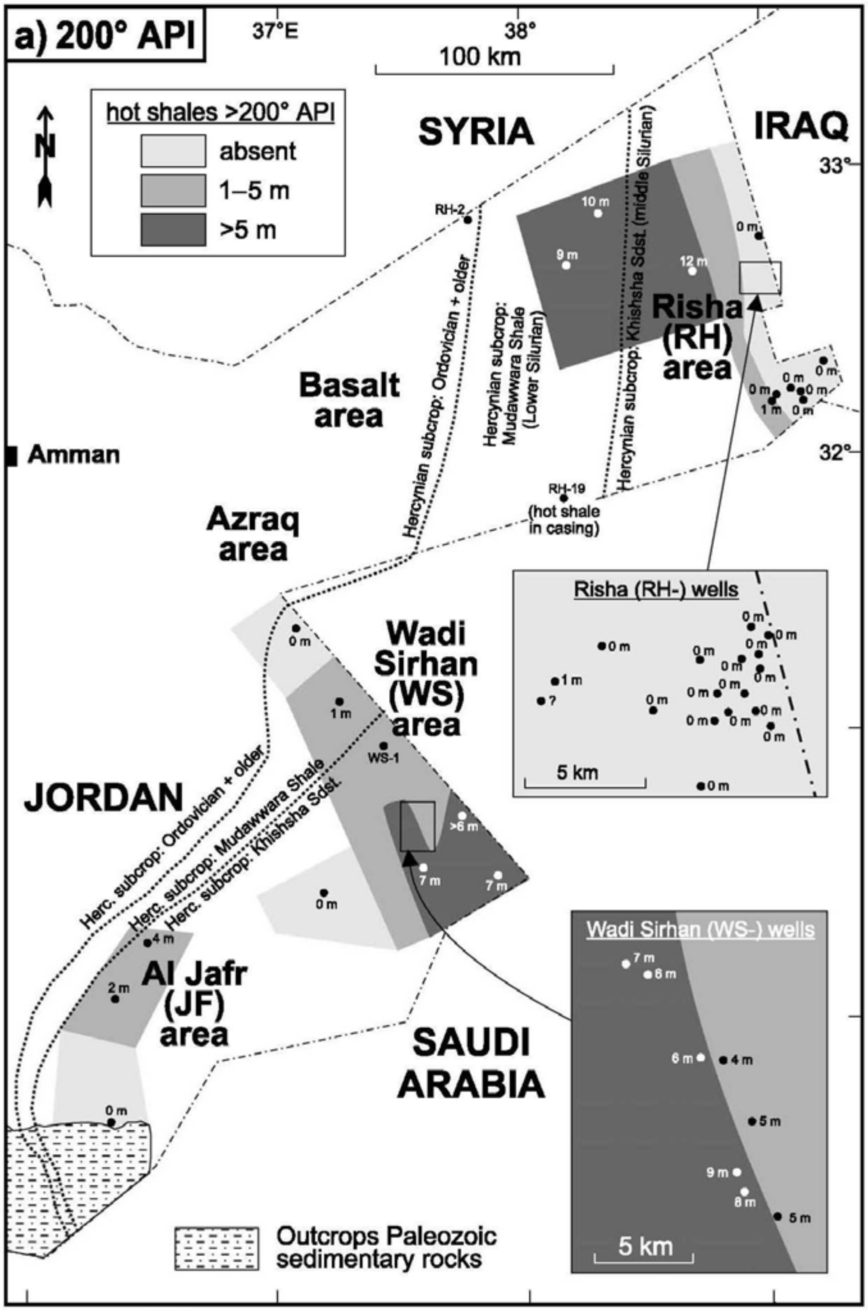
Source: NRA Petroleum Directorate Jordan, 2006

Figure XXV-8 is an isopach map for the Batra Shale using the 150 API gamma-ray background value for determining organically rich shale.[3]

Figure XXV-8. Isopach Map of Organic-Rich Silurian Shales with Total Gamma-Ray Values Exceeding 150 API Corresponding to Organic Richness.



Source: Luning, 2005

3. RESOURCE ASSESSMENT

Wadi Sirhan Basin. The prospective area for the Lower Batra Shale in the Wadi Sirhan Basin is limited on the west by the thinning and thermal maturity of the shale and on the east by the Jordanian border. Within the 1,050-mi^2 prospective area for oil, the Batra Shale has a resource concentration of 9 million barrels of oil per mi^2 plus moderate volumes of shale associated gas.

The risked resource in-place for the shale oil prospective area of the Wadi Sirhan Basin is estimated at 4 billion barrels of oil plus 2 Tcf of associated shale gas. Based on moderately favorable reservoir properties, we estimate a risked, technically recoverable shale oil resource of 0.1 billion barrels plus small volumes of associated shale gas for the Batra Shale in the Wadi Sirhan Basin.

Hamad/Risha Area. The prospective area for the Upper Batra Shale in the Hamad Basin/Risha area is limited on the west by the pinch-out of the shale and on the north, south and east by the Jordanian border. Within the 3,300-mi^2 prospective area for wet and dry gas, the Batra Shale has a resource concentration of 25 Bcf/mi^2.

The risked shale resource in-place for the gas prospective area is estimated at 33 Tcf. Based on moderately favorable reservoir properties, we estimate a risked, technically recoverable shale gas resource of about 7 Tcf for the Batra Shale in the Hamad Basin/Risha area.

4. RECENT ACTIVITY

A number of deep exploration wells have been drilled in the Wadi Sirhan area prospecting for oil. One well (Wadi Sirhan #4) is reported to have produced 25 barrels per day of 42^o API oil from sandstones associated with the Batra Shale, while other exploration wells have reported shows of light oil.[8] However, much of the data from these deep exploration wells remains confidential. Another series of wells (31) have been drilled in the Hamad Basin/Risha area into the Risha tight sandstone member of the Ordovician-age Dubaydib Formation. Five of the wells are reported to be producing at a combined rate of 30 MMcfd.[7] The Batra Shale, in the overlying Silurian-age Mudawwara Formation, is considered the source of this gas accumulation.

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