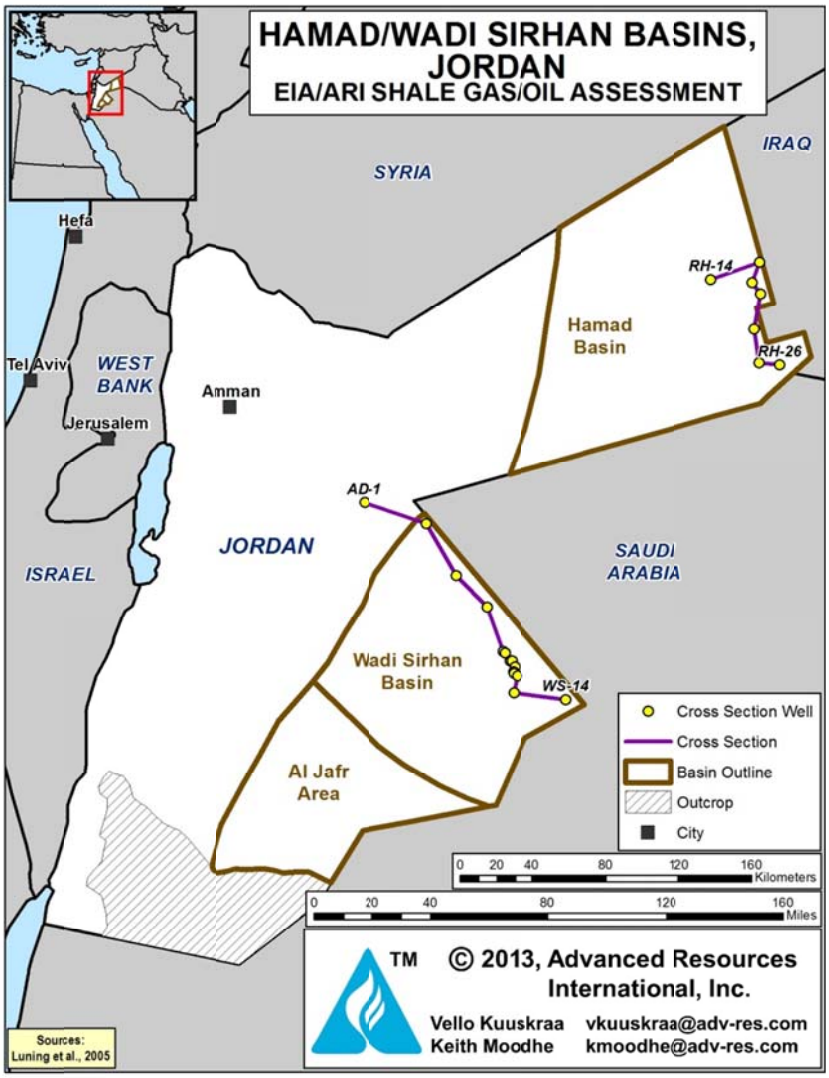
XXV. JORDAN

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

Basic Data	Basin/Gross Area		Hamad (6,700 mi^2)	Wadi Sirhan (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.

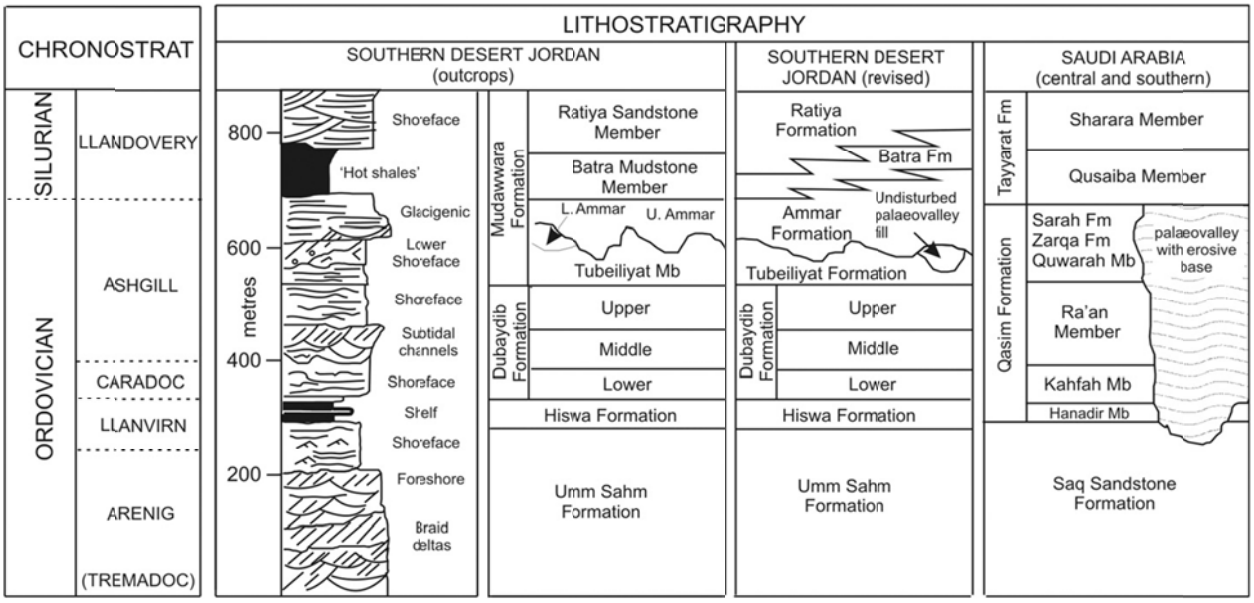
INTRODUCTION

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,



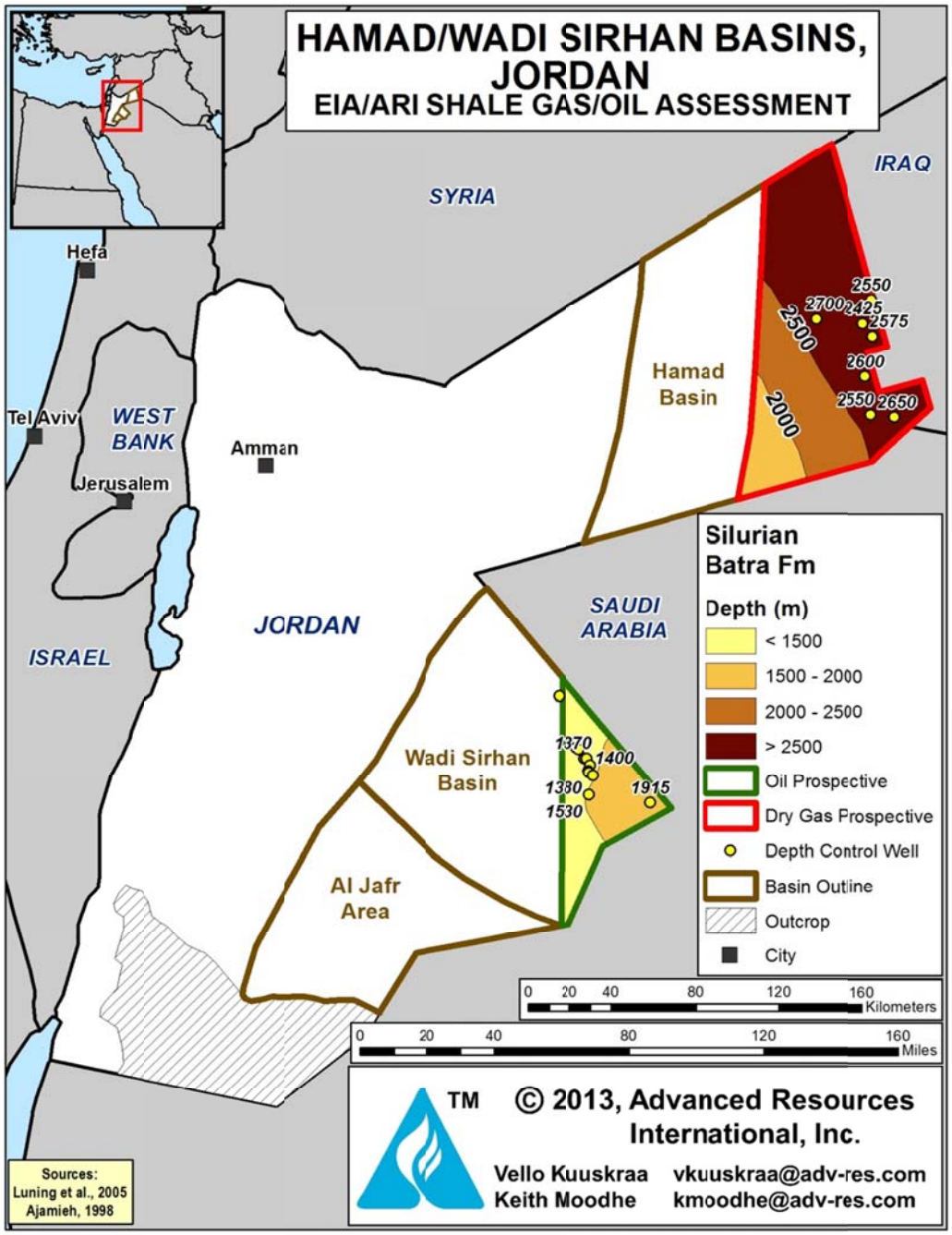
Source: Lithostratigraphy and chronostratigraphy for the Ordovician and Silurian of Jordan and Saudi Arabia, showing generalized depositional environments for outcrops in the Southern Desert region of Jordan (redrawn from Turner et al., 2005). Armstrong (2009)

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.

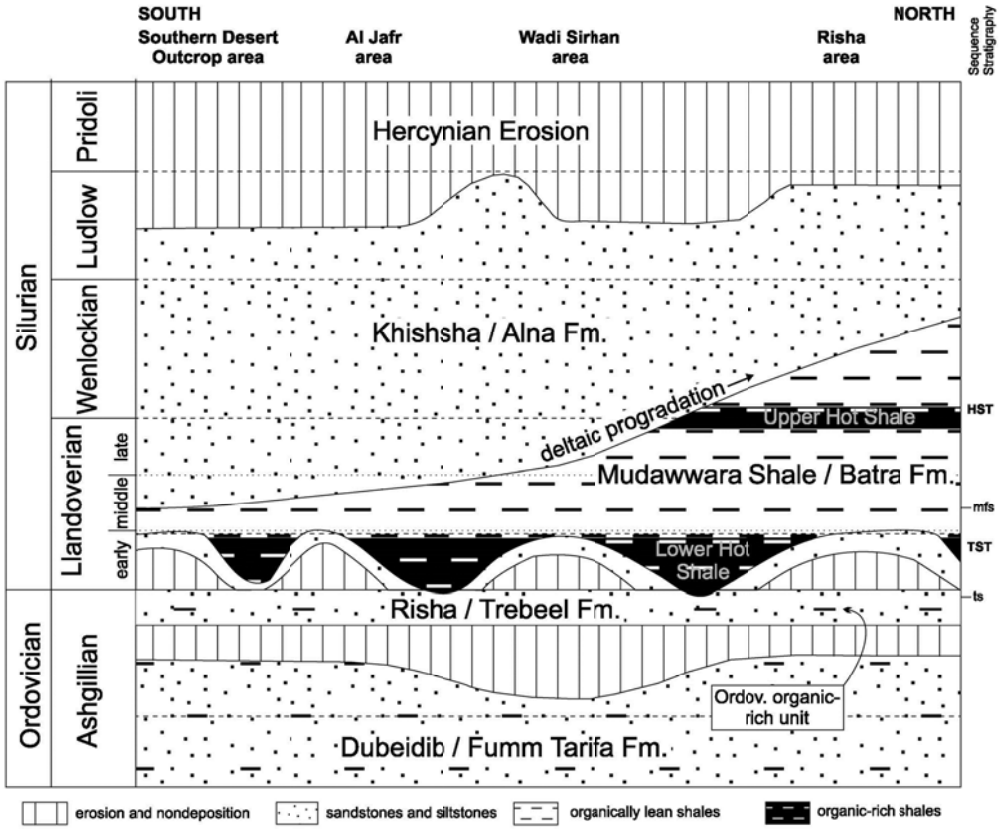
Figure XXV-3. Depth and Prospective Areas - - Batra Shale, Jordan



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.

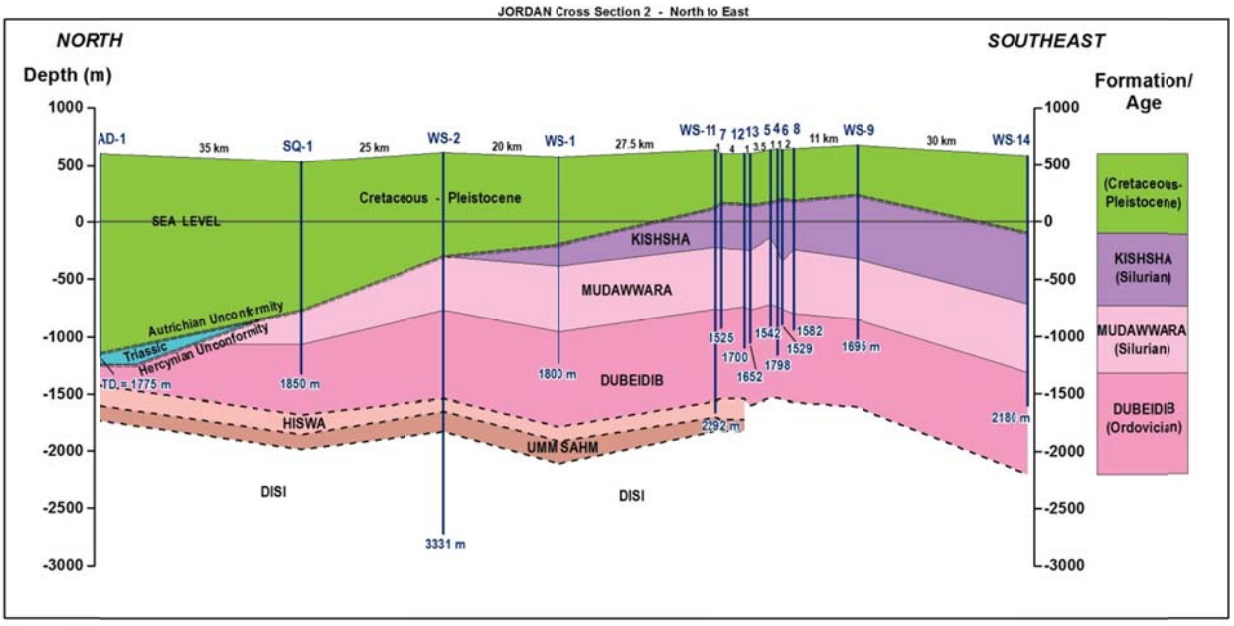
The thermal maturity of the Batra Shale increases from south to north and from west to east. The shale is immature to early-mature in the Al Jafr area, becomes middle-mature (oil window) in the Wadi Sirhan area, and is late to post-mature (gas window) in the Hamad Basin's Risha area.[3,7] The determination 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])

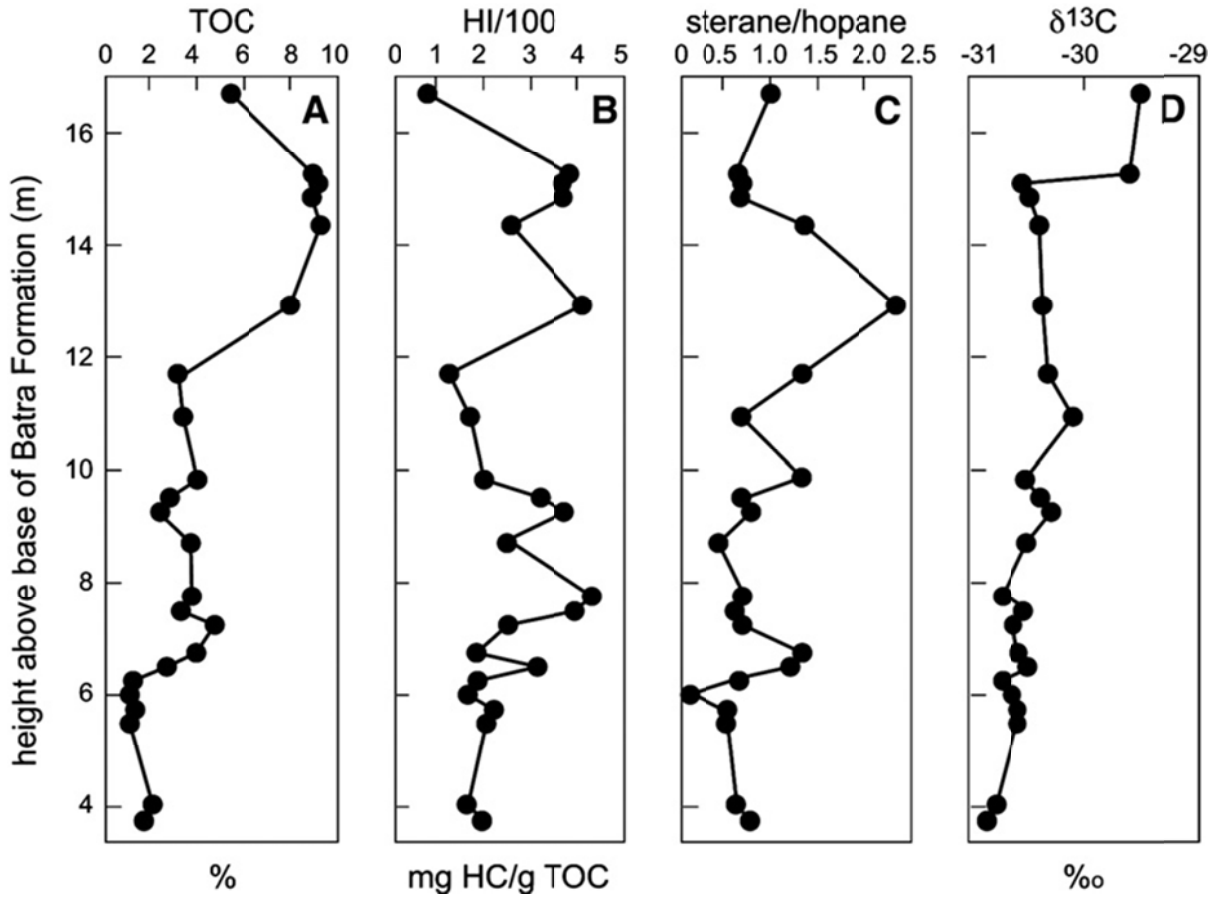
Figure XXV-5. North to South Regional Cross-Section, Wadi Sirhan Basin.



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.

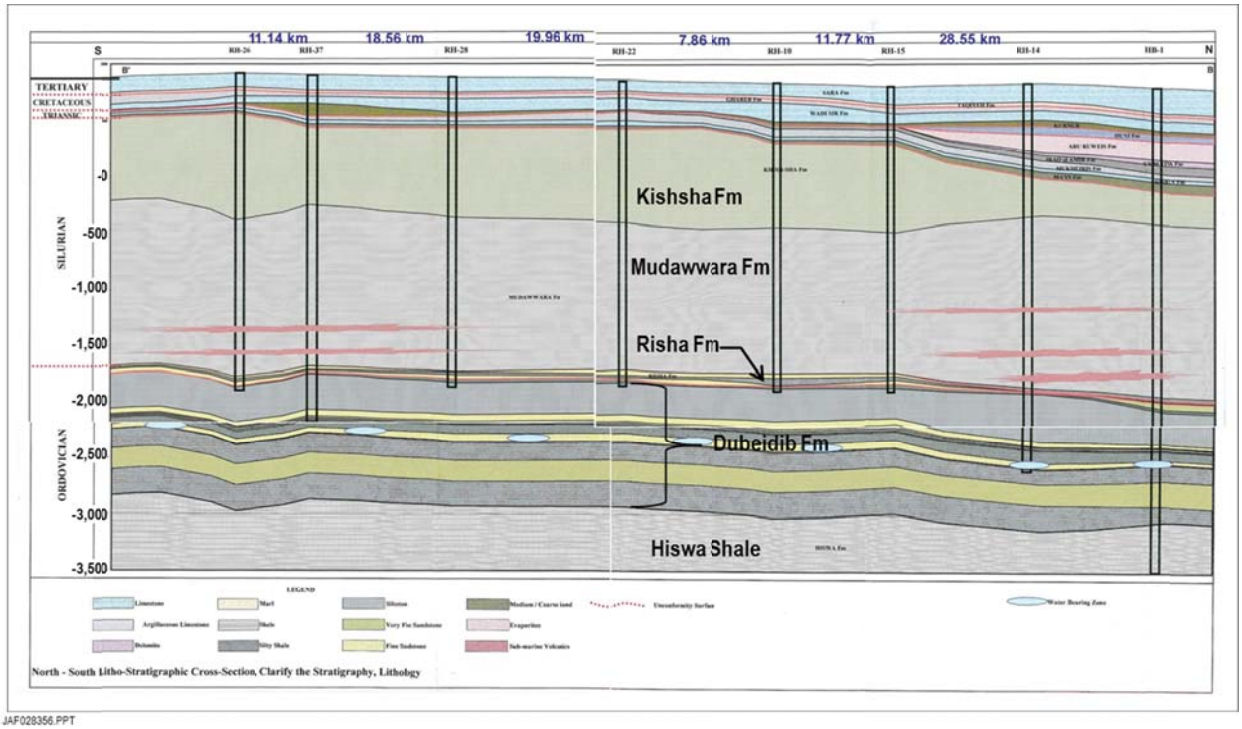


(A) Total organic carbon (TOC) content of the bulk sediment. (B) Hydrogen index (HI) of the bulk sediment (mg hydrocarbons (HC)/g TOC). (C) Steranes/17α-hopanes ratio shows its highest value at 12.94m above the base of the Batra formation. (D) δ13C values of organic carbon (OC) versus Vienna Peedee belemnite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

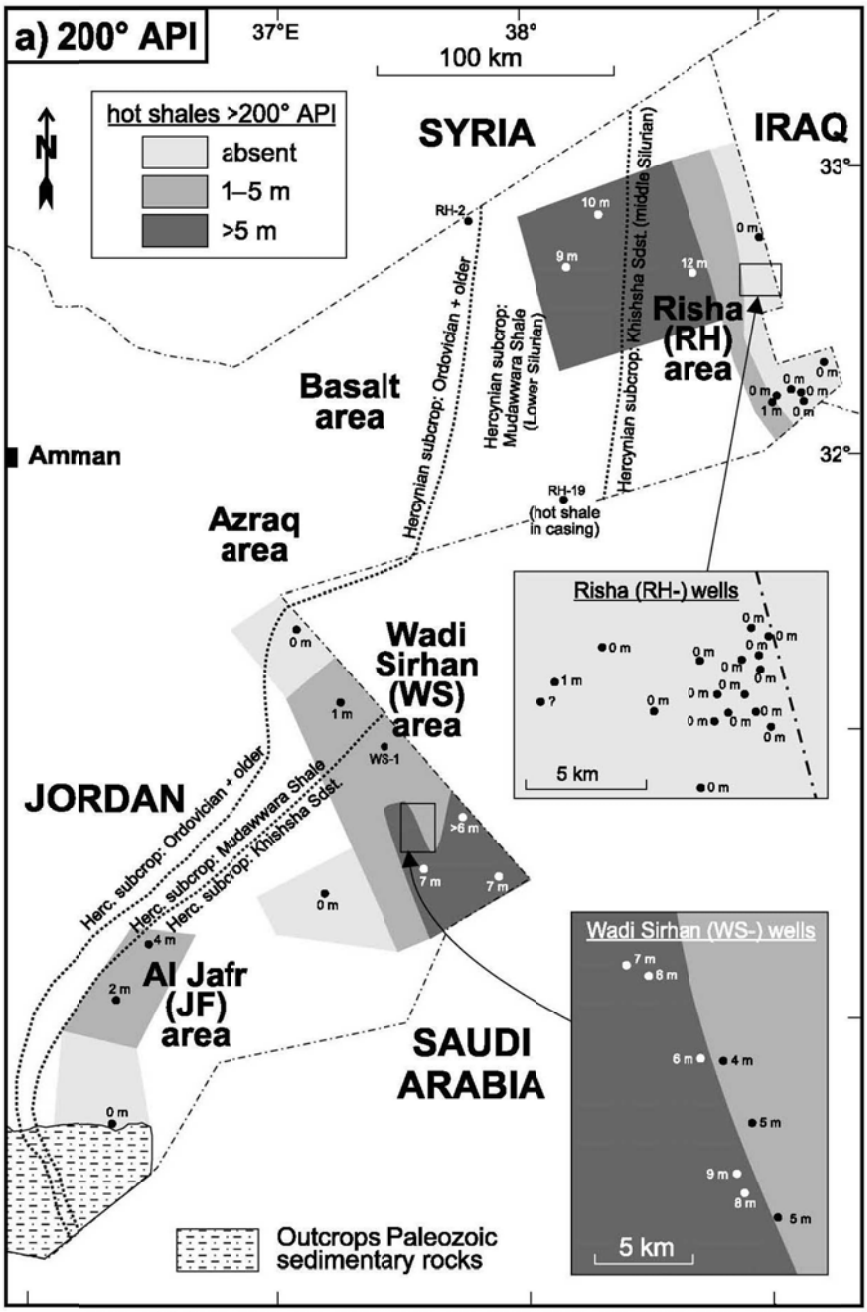
Figure XXV-7. Regional Geologic Cross-Section, Eastern Hamad Basin (Risha Area).



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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