National and Global Petroleum Assessment

Assessment of Continuous Oil and Gas Resources in Lower Silurian Shales of the Arabian Peninsula, 2019

Using a geology-based assessment methodology, the U.S. Geological Survey estimated undiscovered, technically recoverable mean resources of 4.6 billion barrels of oil and 561 trillion cubic feet of gas in the Lower Silurian Shale Total Petroleum System of the Arabian Peninsula.

Introduction

The U.S. Geological Survey (USGS) quantitatively assessed the potential for undiscovered, technically recoverable continuous oil and gas resources in the Lower Silurian Shale Total Petroleum System (TPS) of the Arabian Peninsula (fig. 1). During the early Paleozoic, the Arabian Peninsula was the eastern part of a broad, north-facing passive margin that stretched across North Africa from Morocco to the Arabian Peninsula. Lower Silurian organic-rich marine source rocks (basal shales; fig. 2) were deposited in north-trending paleochannels that formed during the retreat of the Ordovician ice cap (Le Heron and Craig, 2008; Hayton and others, 2017a). Closure of the paleo-Tethys Ocean and the amalgamation of Pangea in the middle Carboniferous led to regional uplift and erosion across North Africa and the Middle East (Konert and others, 2001; Ruban and others, 2007; Faqira and others, 2009), with significant local variation in erosion across the Arabian Peninsula (İnan and others, 2017). Uplift and erosion of as much as 2,800 meters occurred in the northern Arabian Peninsula, whereas uplift and erosion in the basinal areas of the southern Arabian Peninsula were on the scale of a few hundred meters, with more along the margins (Cantrell and others, 2014; İnan and others, 2017).

This assessment evaluates the differences in the geologic history and petroleum-system evolution between the northern and southern Arabian Peninsula and quantifies the potential oil and gas resources retained within lower Silurian shales and adjacent tight reservoirs (Al Duhailan and others, 2014), given the different burial and thermal histories (Hayton and others, 2017b).

Total Petroleum System and Assessment Units

The USGS defined the Lower Silurian Shale TPS and six continuous assessment units (AU) within the TPS. The Northern Arabian Peninsula Lower Silurian Shale Oil AU, Northern Arabian Peninsula Lower Silurian Shale Gas AU, and the Northern Arabian Peninsula Ordovician–Devonian Tight Gas AU were defined north of the Al Batin Arch based on thickness of organic-rich shale, total organic carbon, and thermal maturation for oil and gas. The Southern Arabian Peninsula Lower Silurian Shale Oil AU, Southern Arabian Peninsula Lower Silurian Shale Gas AU, and Southern Arabian Peninsula Ordovician–Permian Tight Gas AU were defined using similar geologic parameters.

Lower Silurian organic-rich shales form some of the most prolific petroleum source rocks in the world (Ulmishek and Klemme, 1990; Lüning and others, 2000). In the Arabian Peninsula, lower Silurian shales contain as much as 20 weight percent total organic carbon, have hydrogen indices as much as 600 milligrams of hydrocarbon per gram of organic carbon, are as

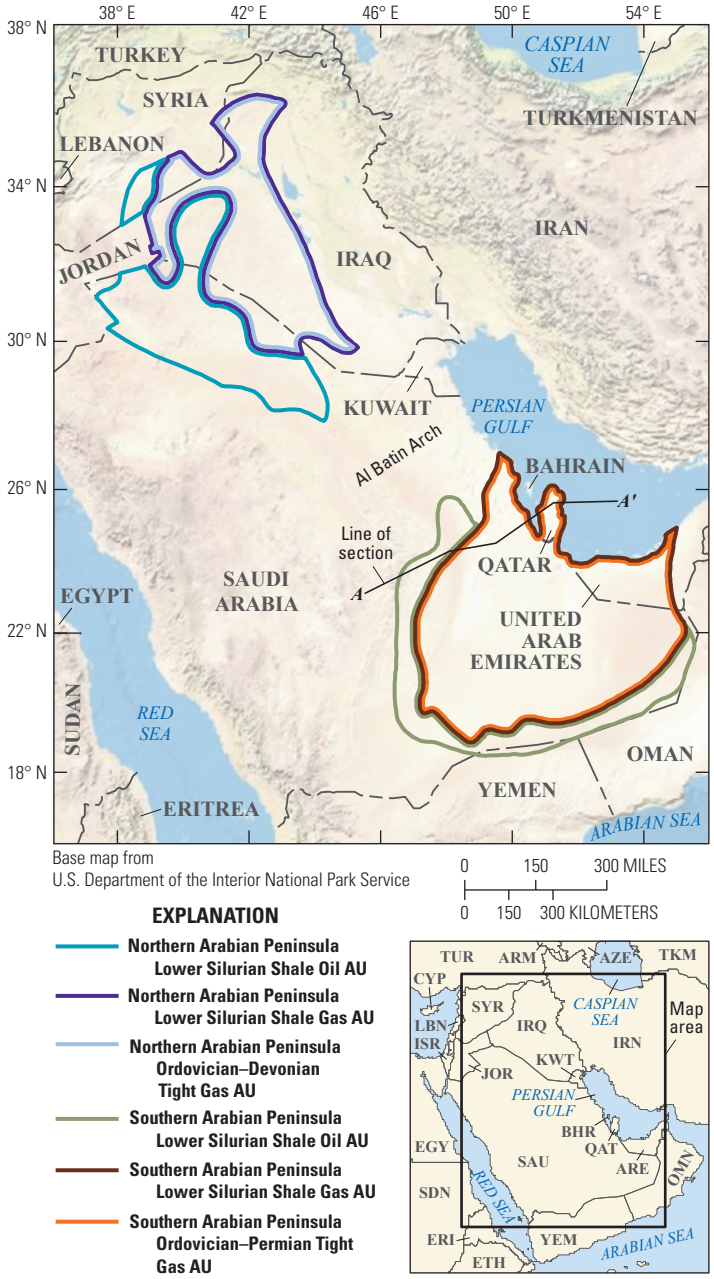

Figure 1. Map showing location of six continuous assessment units (AUs) in the Lower Silurian Shale Total Petroleum System of the Arabian Peninsula. Adjacent lines indicate a shared boundary at the outermost line.

much as 70 meters thick, and are thermally mature for oil and gas over wide areas (Mahmoud and others, 1992; Cole and others, 1994; Carrigan and others, 1998; Lüning and others, 2000; Al-Hadidy, 2007; Al-Juboury and Al-Hadidy, 2009; Alsharhan, 2014; Cantrell and others, 2014).

The assessment input data are summarized in table 1.

Table 1. Input data for six continuous assessment units in the Lower Silurian Shale Total Petroleum System of the Arabian Peninsula.

[The average EUR input is the minimum, median, maximum, and calculated mean. Shading indicates not applicable. AU, assessment unit; %, percent; EUR, estimated ultimate recovery (per well); MMBO, million barrels of oil; BCFG, billion cubic feet of gas]

Assessment input data—Continuous AUs	Northern Arabian Peninsula Lower Silurian Shale Oil AU				Northern Arabian Peninsula Lower Silurian Shale Gas AU			
	Minimum	Mode	Maximum	Calculated mean	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	600	15,250,800	38,127,000	17,792,800	600	19,405,000	48,513,000	22,639,533
Average drainage area of wells (acres)	80	120	160	120	80	120	160	120
Success ratio (%)	10	50	90	50	10	50	90	50
Untested area in AU (%)	100	100	100	100	100	100	100	100
Average EUR (MMBO, oil; BCFG, gas)	0.01	0.03	0.1	0.034	0.05	0.1	0.8	0.137
AU probability	1.0				1.0			
Assessment input data—Continuous AUs	**Northern Arabian Peninsula Ordovician–Devonian Tight Gas AU**				**Southern Arabian Peninsula Lower Silurian Shale Oil AU**			
	Minimum	Mode	Maximum	Calculated mean	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	600	24,256,500	48,513,000	24,256,700	1,000	15,359,500	30,719,000	15,359,833
Average drainage area of wells (acres)	60	100	140	100	80	120	160	120
Success ratio (%)	10	50	90	50	10	50	90	50
Untested area in AU (%)	100	100	100	100	100	100	100	100
Average EUR (BCFG, gas; MMBO, oil)	0.05	0.1	0.8	0.137	0.01	0.03	0.1	0.034
AU probability	1.0				1.0			
Assessment input data—Continuous AUs	**Southern Arabian Peninsula Lower Silurian Shale Gas AU**				**Southern Arabian Peninsula Ordovician–Permian Tight Gas AU**			
	Minimum	Mode	Maximum	Calculated mean	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	1,000	42,447,118	106,118,000	49,522,039	1,000	42,447,118	106,118,000	49,522,039
Average drainage area of wells (acres)	80	120	160	100	60	100	140	100
Success ratio (%)	10	50	90	50	10	50	90	50
Untested area in AU (%)	100	100	100	100	100	100	100	100
Average EUR (BCFG, gas)	0.1	2.0	3.0	2.020	0.1	0.4	1.2	0.441
AU probability	1.0				1.0			

Geologic Models for Assessment

Distinct differences in the thermal and burial histories between the northern and southern Arabian Peninsula led to the development of one geologic model for the three northern AUs and a different geologic model applicable to the three southern AUs. The geologic model for the northern AUs is for oil to have been generated from lower Silurian shales, possibly beginning in the Devonian. By the lower Carboniferous, oil retained in the shales in the deeper part of the basin cracked to gas. However, oil and gas generation from Silurian shales in northern Saudi Arabia was a complex process possibly related to hydrothermal fluids (Hayton and others, 2017b). As much as 2,800 meters of regional uplift and erosion in the middle Carboniferous led to gas expansion, reduction in reservoir pressure, fracturing, and possible loss of gas and oil from lower Silurian shales and adjacent sandstones. Uplift ended any further thermal maturation, and the oil and gas would have been retained within shales since the middle Carboniferous.

The geologic model for the three southern Arabian Peninsula AUs is for oil to have reached peak generation from lower Silurian shales in the Late Jurassic, with peak gas generation during the Late Cretaceous. Maturation postdates the middle Carboniferous uplift and is broadly the same age as the formation of the gentle Mesozoic folds that trapped much of the oil and gas in conventional fields. The nearly continuous burial of Silurian shales from the Permian into the Tertiary led to more effective retention of oil and gas within the lower Silurian shales and tight sandstone reservoirs in the southern Arabian Peninsula (Hayton and others, 2010; Faqira and others, 2011; Al Duhailan and others, 2014). As shown in the cross section (fig. 3), the lower Silurian shales are present across much of the southern Arabian Peninsula.

Undiscovered Resources Summary

The USGS quantitatively assessed undiscovered continuous oil and gas resources within the Lower Silurian Shale TPS of the Arabian Peninsula (table 2). The estimated mean totals for continuous resources are 4,614 million barrels of oil (MMBO), or 4.6 billion barrels of oil, with an F95–F5 range from 960 to 10,924 MMBO; 561,022 billion cubic feet of gas (BCFG), or 561 trillion cubic feet of gas, with an F95–F5 range from 126,964 to 1,240,387 BCFG; and 3,056 million barrels of natural gas liquids (MMBNGL) with an F95–F5 range from 613 to 7,209 MMBNGL. Of the mean total of 561,022 BCFG, about 94 percent in estimated to be in the AUs of the southern Arabian Peninsula.

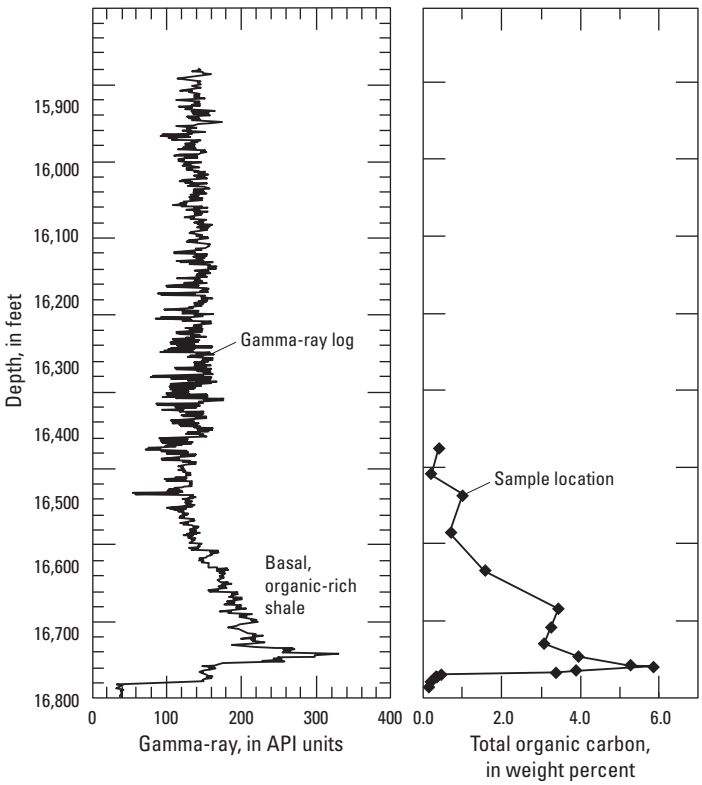

Figure 2. Example of a gamma-ray well log through the Qusaiba Formation in Saudi Arabia illustrating the organic-rich basal shale that is the primary Silurian source rock (modified from Jones and Stump, 1999).

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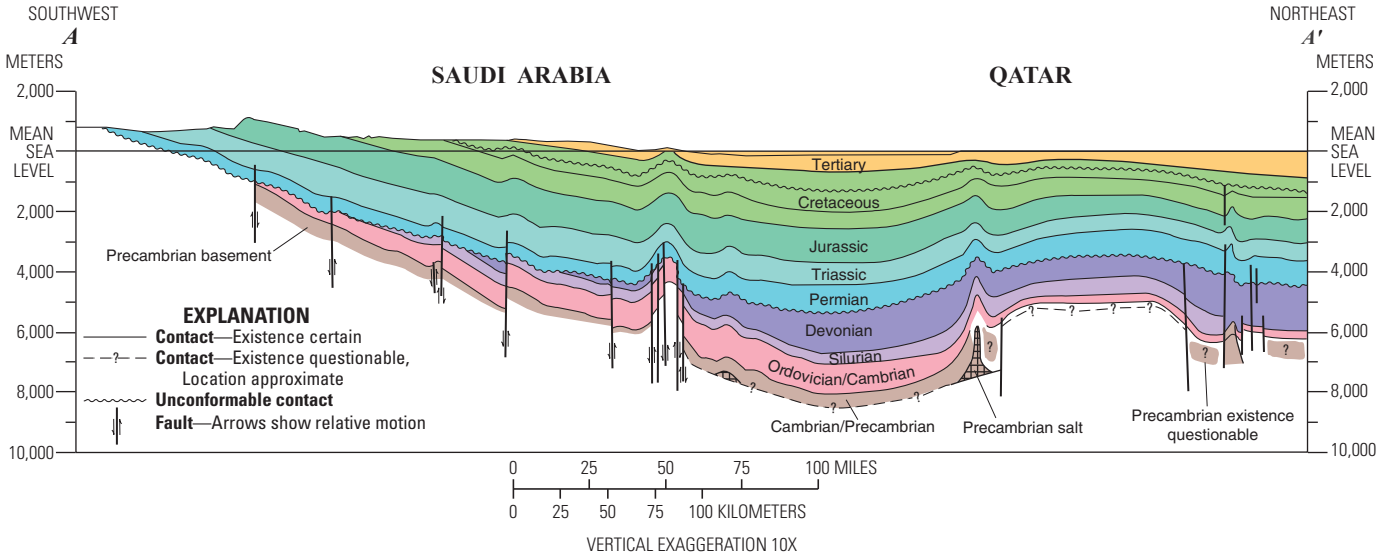

Figure 3. Schematic southwest–northeast cross section *A–A′* in the southern Arabian Peninsula illustrating the extent of the Silurian source rock and potential Ordovician sandstone reservoirs (modified from Konert and others, 2001). Location of the cross section shown on figure 1.

Table 2. Results for six continuous assessment units in the Lower Silurian Shale Total Petroleum System of the Arabian Peninsula.

[Results shown are fully risked estimates. F95 represents a 95-percent chance of at least the amount tabulated; other fractiles are defined similarly. Shading indicates not applicable. MMBO, million barrels of oil; BCFG, billion cubic feet of gas; NGL, natural gas liquids; MMBNGL, million barrels of natural gas liquids]

Total petroleum system and assessment units (AUs)	AU probability	Accumulation type	Total undiscovered resources											
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Lower Silurian Shale Total Petroleum System														
Northern Arabian Peninsula Lower Silurian Shale Oil AU	1.0	Oil	510	2,038	5,920	2,471	250	1,200	4,086	1,562	3	14	50	19
Northern Arabian Peninsula Lower Silurian Shale Gas AU	1.0	Gas					2,143	9,149	34,968	12,601	11	53	217	76
Northern Arabian Peninsula Ordovician–Devonian Tight Gas AU	1.0	Gas					2,893	11,959	44,822	16,314	8	38	157	55
Southern Arabian Peninsula Lower Silurian Shale Oil AU	1.0	Oil	450	1,794	5,004	2,143	219	1,064	3,513	1,361	3	12	43	16
Southern Arabian Peninsula Lower Silurian Shale Gas AU	1.0	Gas					99,500	375,875	895,057	420,198	526	2,150	5,824	2,527
Southern Arabian Peninsula Ordovician–Permian Tight Gas AU	1.0	Gas					21,959	90,683	257,941	108,986	62	286	918	363
Total undiscovered continuous resources			**960**	**3,832**	**10,924**	**4,614**	**126,964**	**489,930**	**1,240,387**	**561,022**	**613**	**2,553**	**7,209**	**3,056**

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For More Information

Assessment results are also available at the USGS Energy Resources Program website at https://energy.usgs.gov.

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