Assessment of Undiscovered Oil and Gas Resources in the Lower Indus Basin, Pakistan, 2017

Using a geology-based assessment methodology, the U.S. Geological Survey estimated mean undiscovered, technically recoverable resources of 164 million barrels of oil and 24.6 trillion cubic feet of gas in the Lower Indus Basin, Pakistan.

Introduction

The U.S. Geological Survey (USGS) completed an assessment of undiscovered, technically recoverable oil and gas resources within the Lower Indus Basin, Pakistan (fig. 1). The Lower Indus Basin is on the Indian-Pakistan plate, and as part of the supercontinent Gondwana during the Permian to Middle Jurassic, it underwent multiple phases of extension culminating in the separation of the Indian-Pakistan plate from Somalia in the Late Jurassic to Early Cretaceous (Robison and others, 1999; Zaigham and Mallick, 2000; Ahmad and others, 2012a). Subsequent separation of the Madagascar and Seychelles blocks from the Indian-Pakistan plate in the Late Cretaceous to Paleogene led to further extension and the initial formation of conventional structural traps that have been the focus of petroleum exploration (fig. 2) (Naeem and others, 2016). The western margin of the Indian-Pakistan plate was passive from the Early Cretaceous to Eocene, and petroleum source rocks of the Lower Goru and Sembar Formations were deposited along the west-facing passive margin during the Early Cretaceous.

Beginning in the Eocene, the Indian-Pakistan plate collided with Eurasia, which led to the formation of the Kirthar fold belt and the adjacent foreland basin. The Eocene collision also resulted in inversion, uplift, and erosion across the Indus Basin area, but deformation was focused within the fold belt.

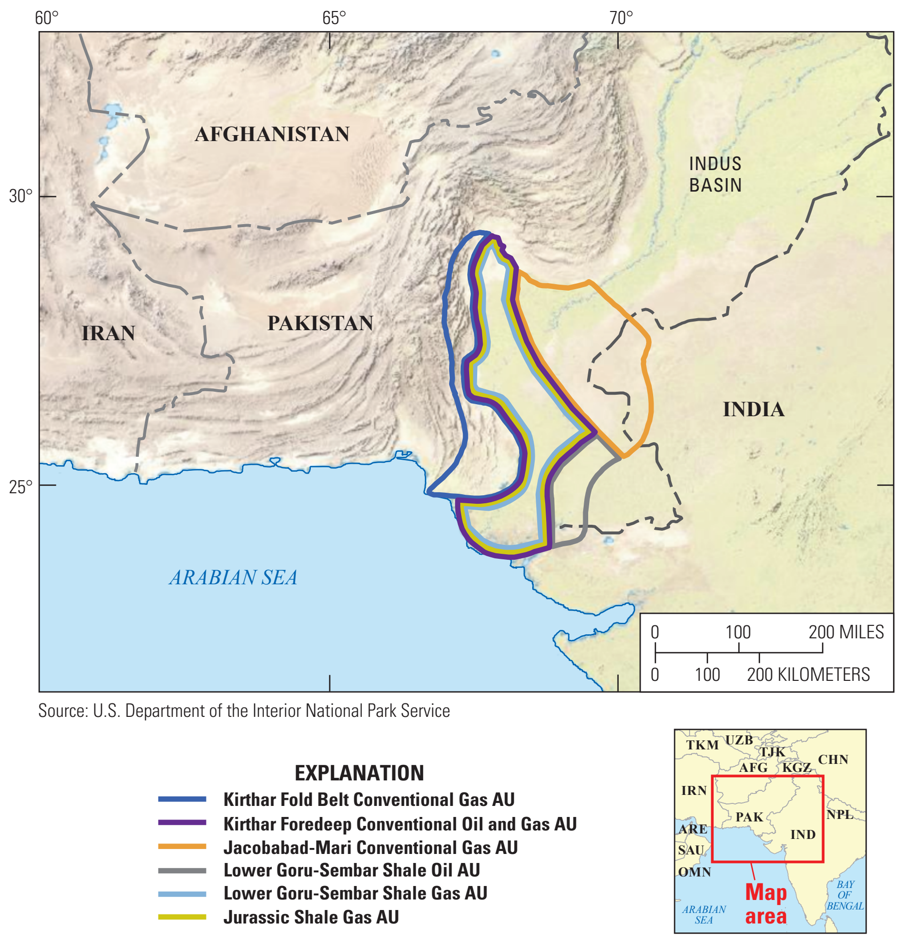

Figure 1. Location of the Lower Indus Basin, Pakistan, and the six assessment units (AUs) defined in this study.

Geologic Models for Assessment

In the Lower Indus Basin, the USGS defined the Lower Cretaceous Composite Total Petroleum System (TPS) with five assessment units (AUs) and the Jurassic TPS with one AU.

In the Lower Cretaceous Composite TPS, five AUs were geologically defined based on the presence and thermal maturation of marine and terrestrial organic matter in shales of the Lower Goru and Sembar

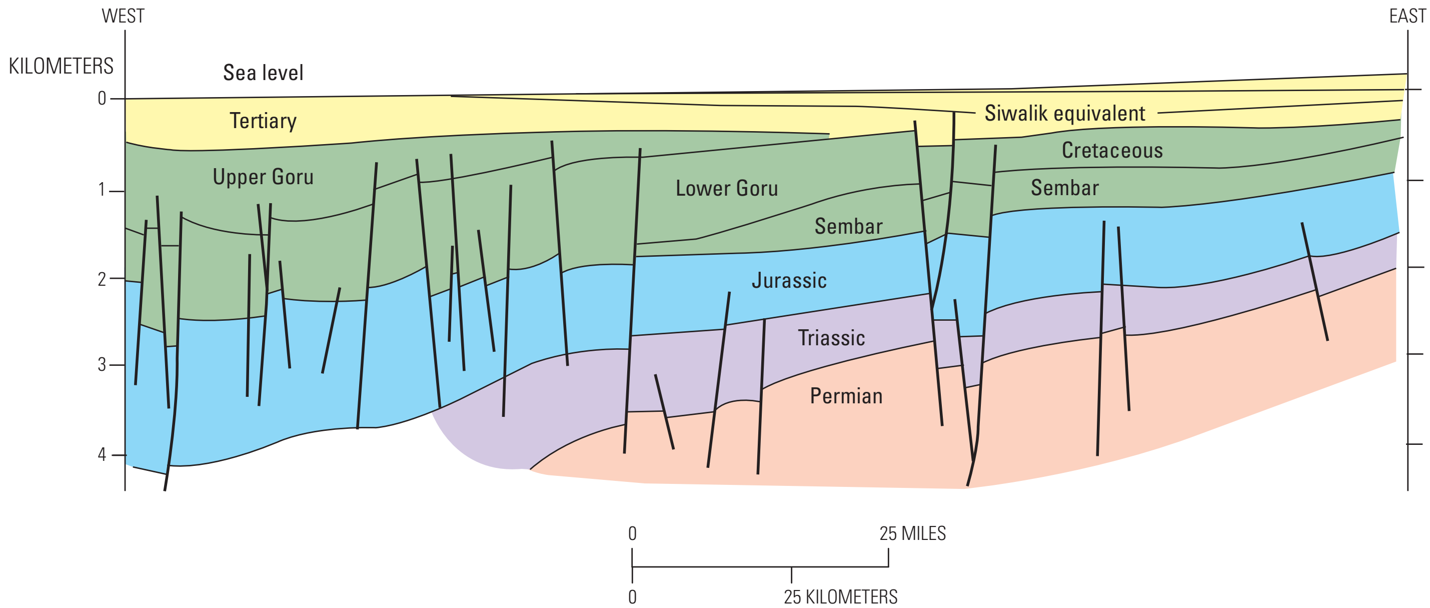

Figure 2. West–east cross section in the southern part of the Lower Indus Basin, Pakistan (modified from Robison and others, 1999).

Formations (Quadri and Shuaib, 1986; Ahmad and others, 2012b; Siddiqui and others, 2014; Qayyum and others, 2016). Thickness of these source rocks is as much as 300 meters, total organic carbon is as much as 9.5 weight percent, and shales contain Type II/III organic matter. The Kirthar Fold Belt Conventional Gas AU, the Kirthar Foredeep Conventional Oil and Gas AU, and the Jacobabad-Mari Conventional Gas AU were defined based on the regional tectonic setting and the presence of structural and stratigraphic traps (Ahmad and others, 2012a). Conventional traps within these AUs may contain low-permeability reservoirs (Nizamuddin and others, 2010; Majeed and Mahessar, 2016).

The geologic model for continuous accumulations in the Lower Goru-Sembar Shale Oil AU and Lower Goru-Sembar Shale Gas AU is for some portion of the oil and gas generated in these shales to have remained within the shales following migration, inversion, and uplift subsequent to the collision with Eurasia in the Eocene.

In the Jurassic TPS, the geologic model for the assessment of the Jurassic Shale Gas AU is for organic-rich marine shales of the Jurassic (Type II organics, total organic carbon up to 2.8 weight percent, and thickness up to 50 meters) to have been buried deeply enough to reach thermal maturity for dry gas generation (Robison and others, 1999) with some portion of the gas retained within the shales to form a continuous shale-gas accumulation.

Assessment input data for each AU are shown in table 1. For continuous AUs, well drainage areas, estimated ultimate recoveries, and success ratios are taken from U.S. shale-oil and shale-gas analogs.

Undiscovered Resources Summary

The USGS quantitatively assessed undiscovered conventional and continuous oil and gas resources within the Lower Indus Basin (table 2). For total undiscovered oil and gas resources, the estimated means are 164 million barrels of oil (MMBO) with an F95–F5 range from 5 to 436 MMBO; 24,625 billion cubic feet of gas (BCFG), or 24.6 trillion cubic feet of gas, with an F95–F5 range from 6,033 to 57,255 BCFG; and 601 million barrels of natural gas liquids (MMBNGL) with an F95–F5 range from 118 to 1,482 MMBNGL. Values of zero at F95 reflect the chance that continuous gas might not be present in the AU, and the geologic AU probability was estimated to be less than one.

For undiscovered conventional oil and gas resources, the estimated means are 12 MMBO with an F95–F5 range from 5 to 21 MMBO, 7,139 BCFG with an F95–F5 range from 2,838 to 13,414 BCFG, and 139 MMBNGL with an F95–F5 range from 52 to 276 MMBNGL. Estimated mean resources in the Kirthar Fold Belt Conventional Gas AU are 4,005 BCFG with an F95–F5 range from 1,520 to 7,662 BCFG and 79 MMBNGL with with an F95–F5 range from 28 to 159 MMBNGL. The estimated means for oil resources in the Kirthar Foredeep Conventional Oil and Gas AU are 12 MMBO with an F95–F5 range from 5 to 21 MMBO, 32 BCFG (associated gas) with an F95–F5 range from 13 to 60 BCFG, and 1 MMBNGL with an F95–F5 range from 0 to 2 MMBNGL. The estimated means for nonassociated gas resources in the Kirthar Foredeep Conventional Oil and Gas AU are 1,312 BCFG with an F95–F5 range from 578 to 2,365 BCFG and 51 MMBNGL with an F95–F5 range from 21 to 98 MMBNGL. In the Jacobabad-Mari Conventional Gas

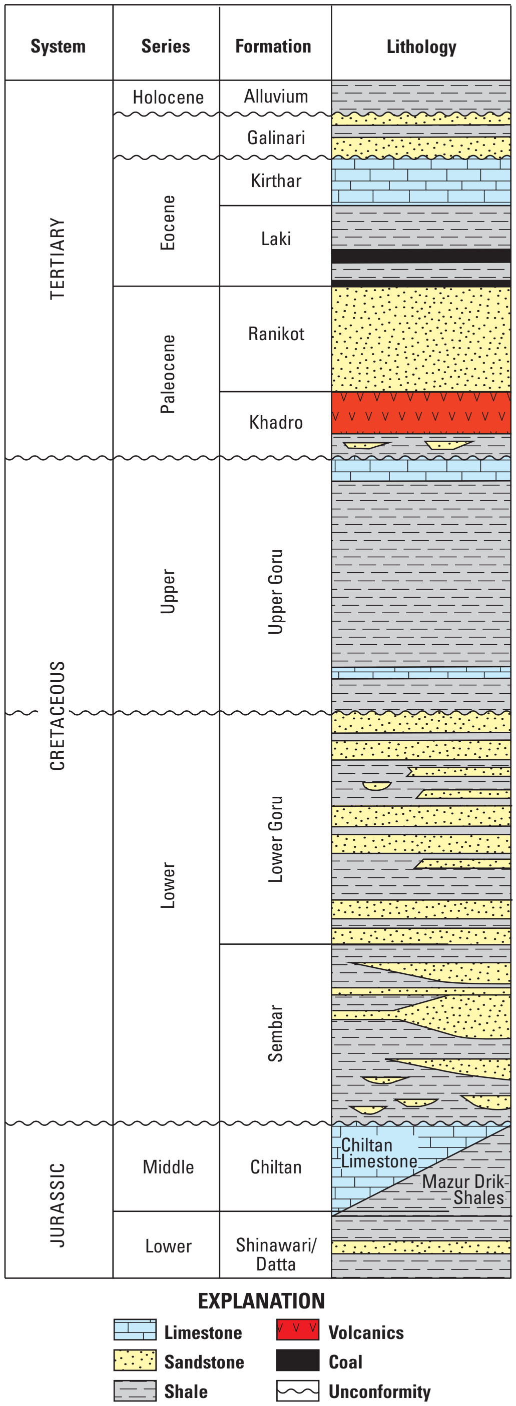

Figure 3. Stratigraphic column for the Lower Indus Basin, Pakistan (modified from Mahmoud, 2015).

Table 1. Key assessment input data for six assessment units in the Lower Indus Basin, Pakistan.

[AU, assessment unit; BCFG, billion cubic feet of gas; MMBO, million barrels of oil; %, percent; EUR, estimated ultimate recovery per well. EUR, well drainage area, and success ratios are partly from U.S. shale-oil and shale-gas analogs. The average EUR input is the minimum, median, maximum, and calculated mean. Shading indicates not applicable]

Assessment input data	Kirthar Fold Belt Conventional Gas AU			
	Minimum	Median	Maximum	Calculated mean
Number of gas fields	1	60	180	63.8
Sizes of gas fields (BCFG)	3	18	3,000	62.8
AU probability	1.0			
Assessment input data	**Kirthar Foredeep Conventional Oil and Gas AU**			
	Minimum	Median	Maximum	Calculated mean
Number of oil fields	1	10	30	10.6
Number of gas fields	1	50	150	53.2
Sizes of oil fields (MMBO)	0.5	0.8	12	10.6
Sizes of gas fields (BCFG)	3	12	600	24.7
AU probability	1.0			
Assessment input data	**Jacobabad-Mari Conventional Gas AU**			
	Minimum	Median	Maximum	Calculated mean
Number of gas fields	1	40	120	42.5
Sizes of gas fields (BCFG)	3	18	1,200	42.0
AU probability	1.0			
Assessment input data	**Lower Goru-Sembar Shale Oil AU**			
	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	1,200	1,807,000	3,614,000	1,807,400
Average drainage area of wells (acres)	80	160	240	160
Success ratios (%)	10	50	90	50
Average EUR (MMBO)	0.01	0.03	0.1	0.034
AU probability	0.8			
Assessment input data	**Lower Goru-Sembar Shale Gas AU**			
	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	1,200	8,158,000	16,316,000	8,158,400
Average drainage area of wells (acres)	80	120	160	120
Success ratios (%)	10	50	90	50
Average EUR (BCFG)	0.08	0.4	1	0.427
AU probability	1.0			
Assessment input data	**Jurassic Shale Gas AU**			
	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	1,200	3,263,000	16,316,000	6,526,733
Average drainage area of wells (acres)	80	120	160	120
Success ratios (%)	10	50	90	50
Average EUR (BCFG)	0.08	0.15	1	0.196
AU probability	0.5			

AU, the estimated means are 1,790 BCFG with an F95–F5 range from 727 to 3,327 BCFG and 8 MMBNGL with an F95–F5 range from 3 to 17 MMBNGL.

For continuous shale-oil and shale-gas resources, the estimated total means are 152 MMBO with an F95–F5 range from 0 to 415 MMBO, 17,486 BCFG with an F95–F5 range from 3,195 to 43,841 BCFG, and 462 MMBNGL with an F95–F5 range from 66 to 1,206 MMBNGL. In the Lower Goru-Sembar Shale Oil AU, estimated means are 152 MMBO with an F95–F5 range from 0 to 415 MMBO, 390 BCFG (associated) with an F95–F5 range from 0 to 1,108 BCFG, and 10 MMBNGL with an F95–F5 range from 0 to 30 MMBNGL. Estimated means for the Lower Goru-Sembar Shale Gas AU are 14,455 BCFG (nonassociated) with an F95–F5 range from 3,195 to 32,068 BCFG and 438 MMBNGL with an F95–F5 range from 66 to 1,116 MMBNGL. In the Jurassic Shale Gas AU, estimated means are 2,641 BCFG with an F95–F5 range from 0 to 10,665 BCFG and 14 MMBNGL with an F95–F5 range from 0 to 60 MMBNGL

Table 2. Assessment results for six assessment units in the Lower Indus Basin, Pakistan.

[MMBO, million barrels of oil; BCFG, billion cubic feet of gas; NGL, natural gas liquids; MMBNGL, million barrels of natural gas liquids. Results shown are fully risked estimates. For gas accumulations, all liquids are included in the NGL category. F95 represents a 95-percent chance of at least the amount tabulated; other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. Shading indicates not applicable]

Total petroleum systems 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 Cretaceous Composite Total Petroleum System														
Kirthar Fold Belt Conventional Gas AU	1.0	Gas					1,520	3,663	7,662	4,005	28	70	159	79
Kirthar Foredeep Conventional Oil and Gas AU	1.0	Oil	5	11	21	12	13	29	60	32	0	1	2	1
		Gas					578	1,220	2,365	1,312	21	47	98	51
Jacobabad-Mari Conventional Gas AU	1.0	Gas					727	1,651	3,327	1,790	3	7	17	8
Total undiscovered conventional resources			**5**	**11**	**21**	**12**	**2,838**	**6,563**	**13,414**	**7,139**	**52**	**125**	**276**	**139**
Lower Cretaceous Composite Total Petroleum System														
Lower Goru-Sembar Shale Oil AU	0.8	Oil	0	127	415	152	0	314	1,108	390	0	8	30	10
Lower Goru-Sembar Shale Gas AU	1.0	Gas					3,195	12,606	32,068	14,455	66	349	1,116	438
Jurassic Total Petroleum System														
Jurassic Shale Gas AU	0.5	Gas					0	321	10,665	2,641	0	1	60	14
Total undiscovered continuous resources			**0**	**127**	**415**	**152**	**3,195**	**13,241**	**43,841**	**17,486**	**66**	**358**	**1,206**	**462**
Total undiscovered resources			**5**	**138**	**436**	**164**	**6,033**	**19,804**	**57,255**	**24,625**	**118**	**483**	**1,482**	**601**

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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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