

National and Global Petroleum Assessment

Assessment of Paleozoic Shale-Oil and Shale-Gas Resources in the Tarim Basin of China, 2018

Using a geology-based assessment methodology, the U.S. Geological Survey estimated undiscovered, technically recoverable mean resources of 1.4 billion barrels of shale oil and 26.9 trillion cubic feet of shale gas in Paleozoic formations in the Tarim Basin of China.

Introduction

The U.S. Geological Survey (USGS) quantitatively assessed the potential for unconventional (continuous) oil and gas resources within two Paleozoic organic-rich shales in the Tarim Basin of China (figs. 1 and 2): Lower Cambrian Yuertusi Formation and shales in the Middle Ordovician Series. These strata are the principal source rocks for conventional oil and gas fields in the interior of the Tarim Basin (Li and others 2018; Zhu, Chen, and others, 2018).

The Tarim Basin, the largest petroleum basin in China, encompasses 563,000 square kilometers (km), and its Phanerozoic strata are as much as 16 km thick (Qiu and others, 2012). Although numerous oil and gas fields have been developed along its northern margin and in several uplifts in the basin's interior, large parts of this remote basin remain unexplored. The USGS previously assessed the Tarim Basin's conventional oil and gas resources (Charpentier and others, 2012). Paleozoic marine formations are currently preserved at depth and locally exposed around the basin's periphery. They were deposited on the passive margin of the Tarim craton, a continental fragment proximal to the Gondwana margin. Since the late Paleozoic assembly of Central Asia, the Tarim Basin has been a vast nonmarine basin bounded on the south by the Tibetan Plateau and on the north by the Tien Shan. From the Carboniferous to the present, the basin's margins have been strongly influenced by contractional deformation, including the ongoing Himalayan orogeny. This tectonic history has resulted in a relatively cool geothermal setting throughout the basin's history; the current geothermal gradient is in the range of 20–23 degrees Celsius per km (Zhang, Huang, and others, 2015).

Geologic Background

The basal Cambrian Yuertusi Formation and the Middle Ordovician deep-marine section (Heituo and Shaergan Formations, for example) include organic-rich black shales with Type II kerogen (Qiu and others, 2012) that represent maximum flooding surfaces in transgressive systems tracts both on the continental slope and in platform sags (Gao and others, 2007). The present total organic carbon (TOC) content of the Cambrian Yuertusi is 7–14 weight percent in outcrops north of the basin, whereas the Middle Ordovician source rocks have TOC contents of 0.5–2.9 weight percent. The Yuertusi is preserved at depth in the central and eastern part of the basin and is as much as 100 meters (m) thick (Zhu, Chen, and others, 2018). The Middle Ordovician source rocks are similarly distributed with thicknesses of as much as 100 m (Gao and others, 2007). Thermal maturities (R_o equivalent) of the Yuertusi exceed 4 percent through much of the central part of the basin; R_o equivalent values are considerably lower (1–1.5 percent) at the top of the Middle Ordovician in the central part of the basin (Zhang, Liang, and others, 2007; Zhang, Huang, and others, 2015; Zhu, Huang, and others, 2015). Burial-history models indicate that the Yuertusi was buried to depths sufficient to generate oil by the Ordovician or Silurian Periods (depending on location in the basin) and then oil was cracked to gas in the Mesozoic or Paleogene (Zhang, Huang, and others, 2015; Zhu, Huang, and others, 2015). Late Paleozoic and Mesozoic uplift raised the Ordovician section (in parts of the basin) into the oil-generation window where it has remained through the present day. Oil is preserved in the Ordovician section to depths of at least 7–8 km in the present Tarim Basin (Zhang, Huang, and others, 2015; Ma and others, 2017).



Deformed northern margin of the Tarim Basin and southern foothills of the Tien Shan, China.

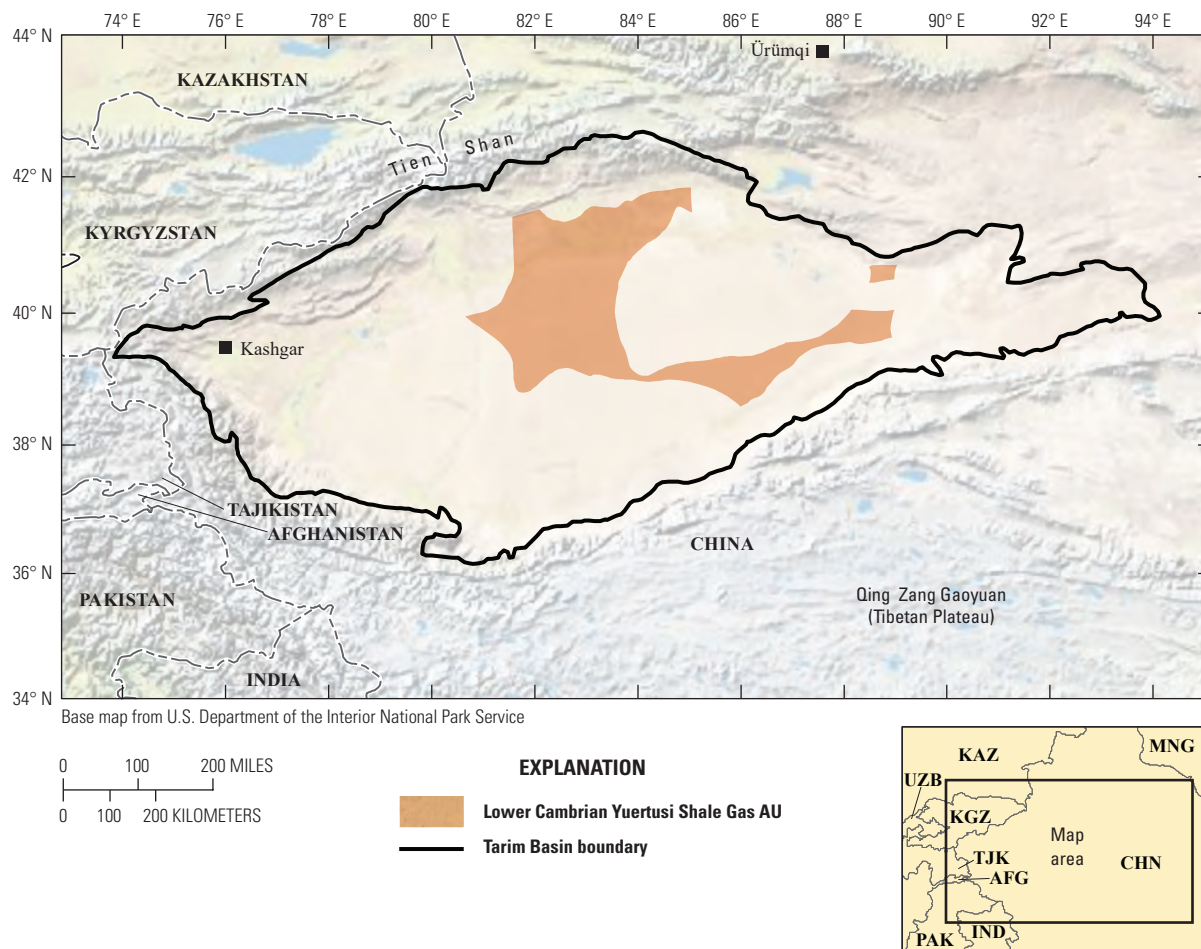


Figure 1. Map showing location of the Tarim Basin, China, and the location of the Lower Cambrian Yuertusi Shale Gas Assessment Unit (AU).

Assessment Units

We defined three assessment units (AUs) (figs. 1 and 2): Lower Cambrian Yuertusi Shale Gas AU, Ordovician Shale Oil AU, and Ordovician Shale Gas AU. The AUs include only those areas where the organic-rich shale has sufficient thickness (greater than 15 m, the minimum net thickness permitted in USGS screening of international shale-gas and shale-oil resources) (Charpentier and Cook, 2011). In addition, areas where the potential shale reservoirs are deeper than 10 km are excluded, acknowledging the challenges of hydraulically stimulating wells at those depths. The margins of the basin are excluded from these AUs because they are strongly affected by fold/thrust belts and other faults, greatly increasing the leakage risk and disrupting the continuity of the reservoirs. The Ordovician Shale Oil AU includes those areas where the Middle Ordovician section is less than about 8 km deep, and the Ordovician Shale Gas AU includes those areas where the Middle Ordovician section is about 8–10 km deep.

The geologic model for the Lower Cambrian Yuertusi Shale Gas AU incorporates oil generation from the organic-rich shale during early to middle Paleozoic voluminous continental-margin sedimentation, followed by preservation of the oil in the source rock through several periods of uplift in the late Paleozoic and Mesozoic Eras, and subsequent cracking of oil to gas during the Mesozoic to early Cenozoic. The presence of Yuertusi-sourced hydrocarbons in shallower conventional accumulations indicates that large volumes of hydrocarbons must have migrated out of the source rock during the basin's evolution, whereas retention of a shale-gas resource in this AU would require that parts of the shale reservoir were relatively undisturbed by fractures and faults (migration pathways) during the Paleogene to present Himalayan orogeny. Recently, commercial quantities of gas attributed to a Yuertusi source were discovered in a conventional field at 6.9-km depth, higher within the Lower Cambrian Series (Zhu, Huang, and others, 2015; Zhu, Chen, and others, 2018).

The geologic model for the Ordovician Shale Oil AU includes oil generation from organic-rich shale possibly beginning in the Permian but principally occurring in Paleogene time because burial of this unit was interrupted by several periods of uplift in the Paleozoic and Mesozoic Eras. Oil is preserved in the shale source rock at depths as much as 8 km, below which it has likely cracked to gas. The Ordovician Shale Gas AU encompasses the volume of rock in which the oil has cracked to gas, between 8 and 10 km deep. Success of these Ordovician AUs also depends on the presence of relatively unfractured volumes of self-sourced shale reservoir.

No Paleozoic shale-gas or shale-oil resources have been produced from the Tarim Basin, and we have assigned an AU-level probability of 0.9 to all these AUs (table 1), meaning there is a 10-percent chance that there are no accumulations of the minimum size.

Continuous oil and gas accumulations in the United States were used as analogs in these assessments. Table 1 lists the principal input data used for the assessments.

Undiscovered Resources Summary

The USGS quantitatively assessed shale-oil and shale-gas resources in Paleozoic strata of the Tarim Basin in China. The estimated mean total for continuous oil resources is 1,373 million barrels of oil (MMBO), or 1.4 billion barrels of oil, with an F95–F5 range from 0 to 3,918 MMBO. The mean total for continuous gas resources is 26,925 billion cubic feet (BCFG), or 26.9 trillion cubic feet, with an F95–F5 range from 0 to 71,946 BCFG. The mean total for natural gas liquids is 128 million barrels of natural gas liquids (MMBNGL) with an F95–F5 range from 0 to 361 MMBNGL. These estimates are for undiscovered, technically recoverable resources of oil, gas, and natural gas liquids and do not reflect economically recoverable resources.

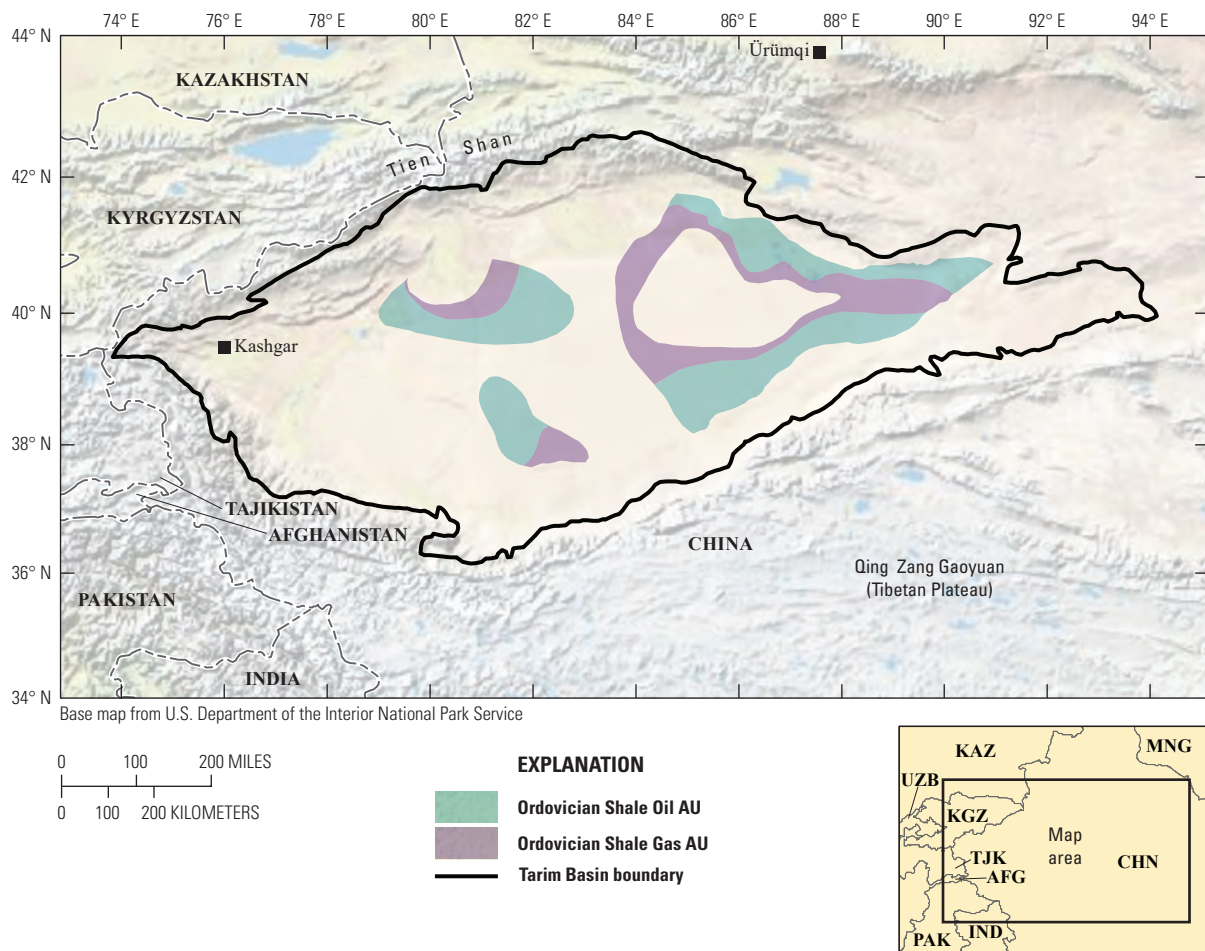


Figure 2. Map showing location of the Tarim Basin, China, and the location of the Ordovician Shale Oil and Ordovician Shale Gas Assessment Units (AUs).

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Table 1. Key input data for three continuous assessment units (AUs) in the Tarim Basin, China.

[%, percent; EUR, estimated ultimate recovery per well; MMBO, million barrels of oil; BCFG, billion cubic feet of gas. Well drainage area, success ratio, and EUR are defined partly using 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— Continuous AUs	Ordovician Shale Oil AU				Ordovician Shale Gas AU			
	Minimum	Mode	Maximum	Calculated mean	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	1,000	1,000,000	18,700,000	6,567,000	1,000	2,000,000	11,597,600	4,532,867
Average drainage area of wells (acres)	60	100	120	93.3	40	80	120	80
Success ratio (%)	10	50	90	50	10	50	90	50
Average EUR (MMBO, oil; BCFG, gas)	0.02	0.04	0.1	0.043	0.2	0.35	0.8	0.373
AU probability	0.9				0.9			

Assessment input data— Continuous AU	Lower Cambrian Yuertusi Shale Gas AU			
	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	1,000	3,000,000	19,653,000	7,551,333
Average drainage area of wells (acres)	40	80	120	80
Success ratio (%)	10	50	90	50
Average EUR (BCFG)	0.2	0.35	0.8	0.373
AU probability	0.9			

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For More Information

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

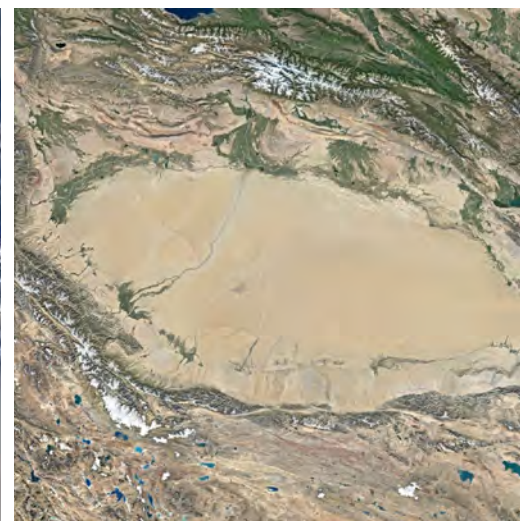
Table 2. Results for three continuous assessment units (AUs) in the Tarim Basin, China.

[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. 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
Ordovician Total Petroleum System														
Ordovician Shale Oil AU	0.9	Oil	0	1,032	3,918	1,373	0	650	2,978	959	0	15	77	24
Ordovician Shale Gas AU	0.9	Gas					0	7,916	25,653	9,743	0	31	106	39
Cambrian Total Petroleum System														
Lower Cambrian Yuertusi Shale Gas AU	0.9	Gas					0	13,015	43,315	16,223	0	51	178	65
Total undiscovered continuous resources			0	1,032	3,918	1,373	0	21,581	71,946	26,925	0	97	361	128



Photograph by Karen Nyberg, an Expedition 36 crew member on board the International Space Station, of the Tien Shan mountain range, central Asia.



Google Earth image of the Tarim Basin, China, showing about 1,000 kilometers (east-west); base map data from Google, Landsat/Copernicus, 2019.