Geology and Assessment of Unconventional Oil and Gas Resources of the Phitsanulok Basin, Thailand

By U.S. Geological Survey Phitsanulok Basin Assessment Team

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Introduction

The U.S. Geological Survey (USGS) quantitatively assessed the potential for unconventional oil and gas resources within the Phitsanulok Basin of Thailand (fig. 1). Unconventional resources for the USGS include shale gas, shale oil, tight gas, tight oil, and coalbed gas. In the Phitsanulok Basin, only potential shale-oil and shale-gas resources were quantitatively assessed (U.S. Geological Survey Phitsanulok Basin Assessment Team, 2014).

Figure 1. Location of the Phitsanulok Basin and other Cenozoic basins in northern Thailand. Modified from Morley and others (2001), Morley (2009), and Palin and others (2013).

Phitsanulok Basin

The Phitsanulok Basin is one of the largest Cenozoic basins of onshore Thailand, occupying an area of about 10,000 square kilometers (km^2). The structural evolution of the Phitsanulok Basin began in the Oligocene with extension, which was most pronounced in the middle Miocene (Morley and others, 2001) and continued to the upper Miocene. Minor structural inversion occurred at this time. Up to 8 km of nonmarine sediments were deposited in the basin (Flint and others, 1988; Ainsworth and others, 1999). These sediments were deposited in alluvial fan, fluvial, deltaic, and deep lacustrine environments (fig. 2) (Pinyo, 2011). Sandstones of the lower Miocene Lan Krabu Formation form the conventional oil reservoirs discovered along the margins of the basin, and synrift organic-rich mudstones of the lower Miocene Chum Saeng Formation are interpreted as the petroleum source rocks in the basin (fig. 3). Petroleum was generated from Type I and Type III kerogen within the shales (Lawwongngam and Philp, 1993). The Chum Saeng Synrift Lacustrine Total Petroleum System is defined by the extent of petroleum generated by thermally mature organic-rich shales (fig. 4). Oil from Chum Saeng Formation shales migrated updip into conventional traps within fluvial-deltaic reservoirs (fig. 4). In addition, recoverable oil and gas remain in the source rock to form unconventional shale-oil and shale-gas accumulations. Gas shows from the organic-rich shales suggest the presence of moveable gas and the potential for a shale-gas accumulation (fig. 5).

Methodology

The USGS approach to assessing unconventional shale-oil and shale-gas resources in non-U.S. reservoirs includes (1) developing a complete geologic framework description for each province based mainly on published literature, and (2) defining petroleum systems and unconventional assessment units within these systems. A series of geologic maps are developed to define potential areas within candidate reservoirs. To be considered for assessment, the potential shale-gas or shale-oil reservoir rock must (1) have greater than 2 weight percent total organic carbon (TOC), (2) be within the proper thermal maturity window for oil or gas generation oil, (oil, vitrinite reflectance range from about 0.55 to 1.3 percent; gas, vitrinite reflectance range greater than 1.3 percent), (3) have greater than 15 meters (m) of organic-rich shale, (4) be greater than 1,000 m depth, (5) contain Type I or II organic matter, and (6) have evidence of moveable gas or oil in matrix storage (Charpentier and Cook, 2011). When applied to any given shale-oil or shale-gas reservoir, these specific criteria may reduce the potential resource area compared to maps made with greater than 1 percent TOC, for example.

Chum Saeng Synrift Lacustrine Total Petroleum System

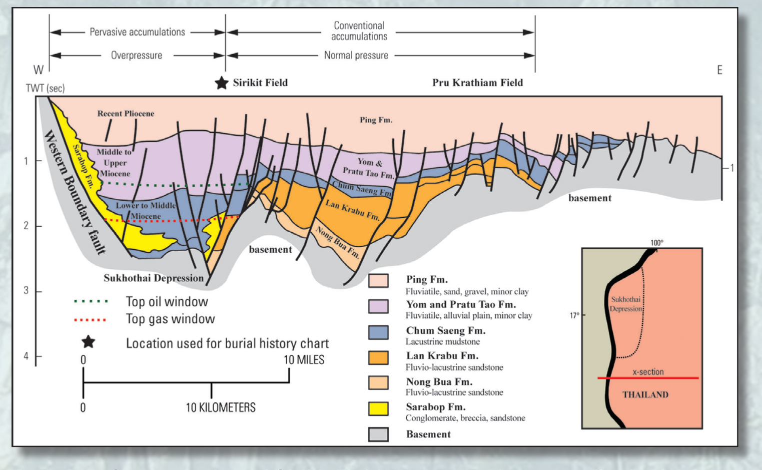

Figure 2. Cross section of Sirikit Field on the southeastern flank of the Phitsanulok Basin. The oil in Sirikit Field is interpreted to have been sourced by Chum Saeng Formation shales in the deep Sukhothai Depression (Pinyo, 2011). [Fm, Formation; TWT, Two-way transit time; sec, seconds]

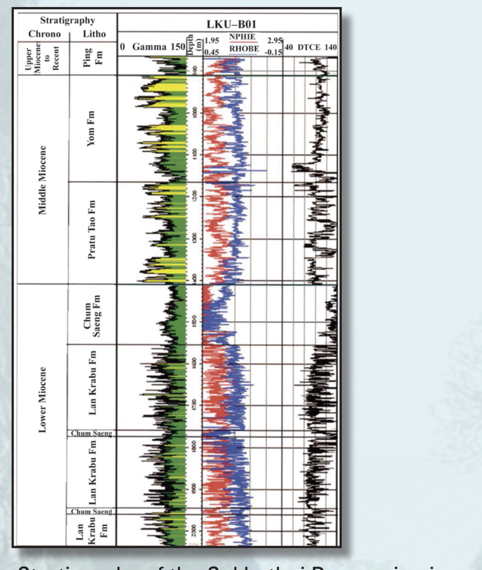

Figure 3. Stratigraphy of the Sukhothai Depression in the Phitsanulok Basin. The Chum Saeng Formation organic-rich shales are the principal petroleum source rocks. For conventional oil accumulations, clastics of the Lan Krabu Formation are the main reservoir rocks (Pinyo, 2011). [LKU–B01 is official name of well.]

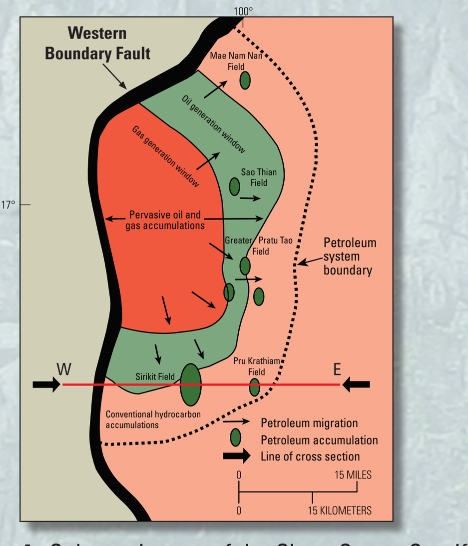

Figure 4. Schematic map of the Chum Saeng Synrift Lacustrine Total Petroleum System in the Phitsanulok Basin. The deep basin shales are purported to have sourced the updip conventional oil accumulations, the largest being Sirikit Field (Pinyo, 2011).

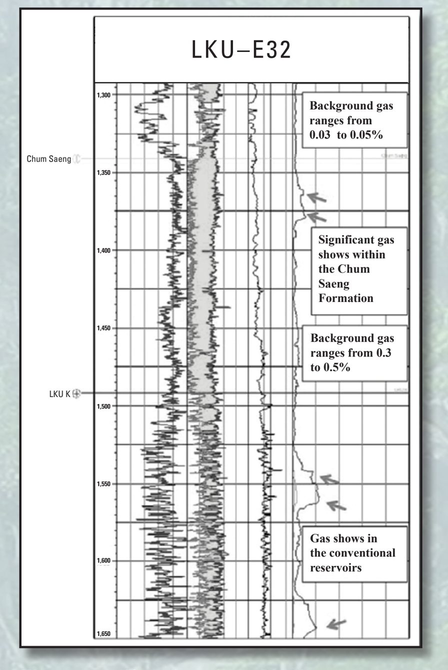

Figure 5. Plot showing significant gas shows within the Chum Saeng Formation shales. Significant gas shows range from 1 to 5 percent (Pinyo, 2011). [LKU–E32 is offical name of well.]

Definition of Assessment Units

The USGS approach to defining an assessment unit (AU) in the Chum Saeng Formation of the Phitsanulok Basin is based on specific geological, geophysical, and geochemical criteria. The isopach map of the Chum Saeng Formation shows the entire section of source rock is thicker than 15 m (fig. 6). The data for total organic carbon (TOC) show that only a small portion of the southwest part of the basin has less than 2 weight percent TOC (fig. 7). The thermal maturity map of the Chum Saeng Formation shows that much of the deeper portion of the basin is thermally mature for oil and gas (fig. 8), supported by burial history modeling (fig. 9). The data for pressure show that much of the deeper part of the basin is overpressured (fig. 10). Using these maps, the intersection of the datasets resulted in the areas for the modal shale-oil area (green) and shale-gas area (red) that defined two assessment units (fig. 11).

Assessment Input

Input to the assessment of unconventional oil and gas resources includes several key parameters that represent probability distributions that illustrate the uncertainty in these parameters (table 1). The area of resource potential incorporates TOC, maturity, depth, and thickness data, and represents one of the key parameters for geologic uncertainty. The distributions for estimated ultimate recovery (EUR), well drainage areas, and success ratios are from U.S. analog oil and gas unconventional accumulations (Charpentier and Cook, 2011).

Definition of Assessment Units

Isopach Map

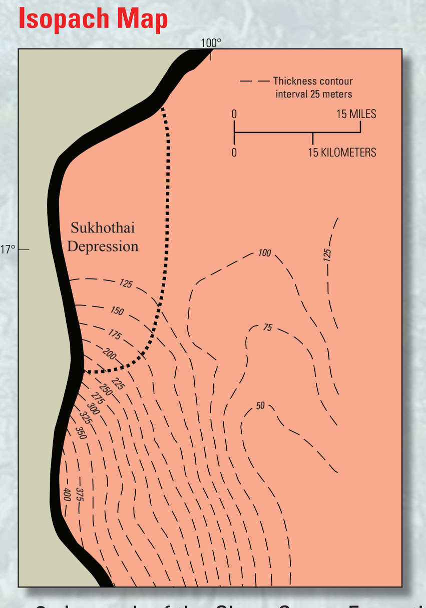

Figure 6. Isopach of the Chum Saeng Formation shales in the Phitsanulok Basin. All of the Phitsanulok has greater than the 15-meter (m) thickness threshold used in the assessment (Pinyo, 2011).

Total Organic Carbon

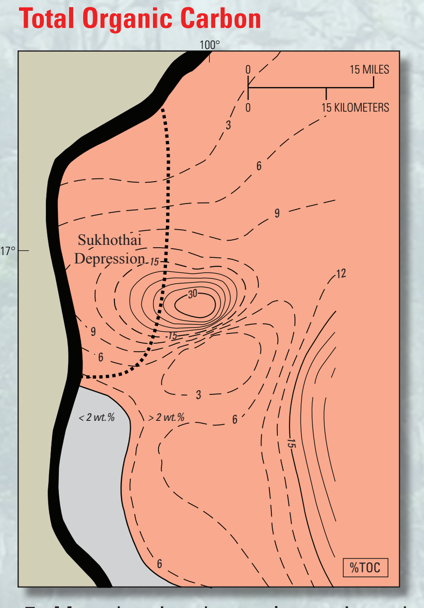

Figure 7. Map showing the total organic carbon (TOC) data in weight percent for Type I lacustrine Chum Saeng Formation shale in the Phitsanulok Basin. Values of TOC greater than 2 weight percent define areas in this study that pass the threshold for quantitative assessment. Note that much of the Chum Saeng Formation shale in this basin contains more than 2 weight percent TOC (Pinyo, 2011).

Thermal Maturity

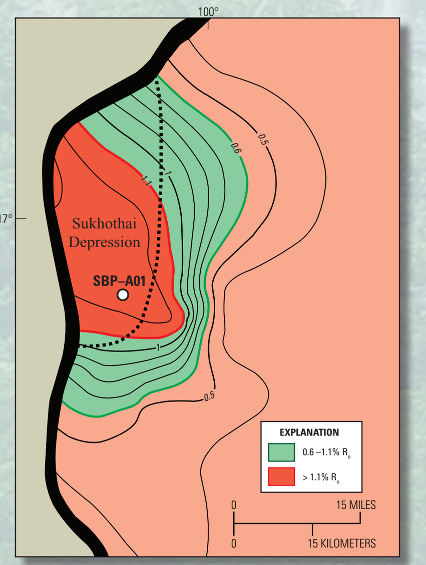

Figure 8. Map showing the extent of thermally mature Chum Saeng Formation shale in the Phitsanulok Basin. The boundaries on this map are uncertain (Pinyo, 2011). Location of well SBP–A01 is shown. [R_o, vitrinite reflectance]

Burial History Model of Well SBP–A01

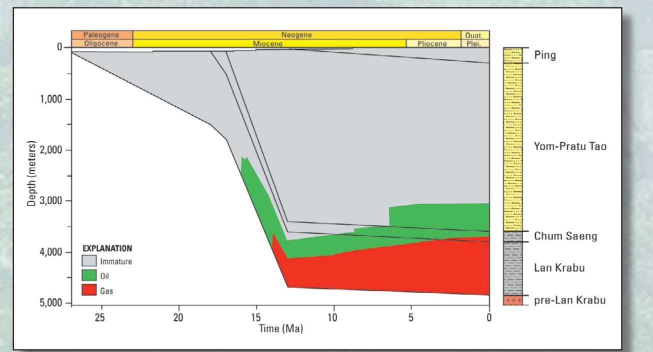

Figure 9. Burial history model of well SBP–A01 in the Sukhothai Depression illustrates that Chum Saeng Formation shales are just within the gas generation window by using reasonable values for stratigraphic thicknesses, ages, Type I kinetics, and heat flow. [Ma, million years]

Overpressure

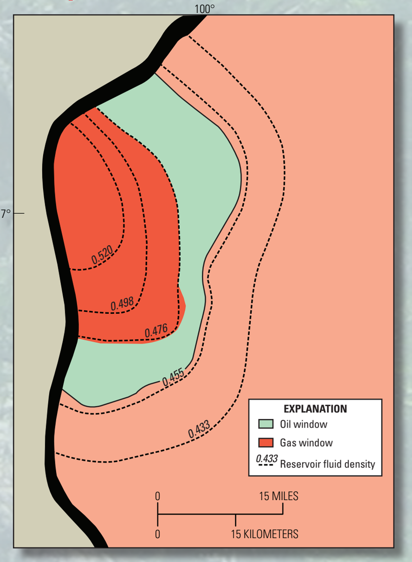

Figure 10. Map showing the area of the Chum Saeng Formation with greater than 0.45 pounds per square inch/foot, defining the area of overpressure within Chum Saeng Formation lacustrine shales in the Sukhothai Depression. From Pinyo (2011).

Assessment Units

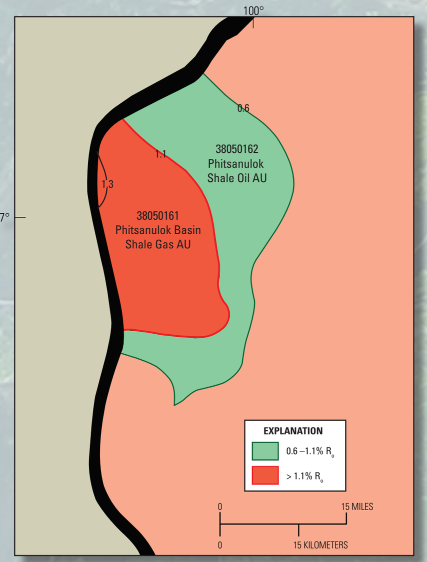

Figure 11. The resultant area with greater than 2 weight percent TOC, adequate thermal maturity for oil and gas generation, and overpressure. The green area defines the modal area of the Phitsanulok Basin Shale Oil Assessment Unit (AU), and the red area defines the modal area of the Phitsanulok Basin Shale Gas Assessment Unit. Both AUs were quantitatively assessed in this study. R_o is vitrinite reflectance in percent.

Assessment Input Data

Table 1. Key assessment input data for shale-oil and shale-gas assessment units for the Phitsanulok Basin, onshore Thailand.

[Estimated ultimate recovery (EUR) per well, well drainage areas, and well success ratios are taken from U.S. shale-gas and shale-oil analogs. The EUR input includes the minimum, median, maximum, and calculated means of the average EUR. Abbreviations: BCF, billion cubic feet; MMB, million barrels; AU, assessment unit; %, percent]

Assessment Input Data	Phitsanulok Basin Shale Oil AU				Phitsanulok Basin Shale Gas AU			
	Minimum	Mode	Maximum	Calculated mean	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	100,000	205,000	250,000	185,000	10,000	173,000	200,000	127,667
Average drainage area of wells (acres)	80	120	160	120	100	140	180	140
Average EUR (BCF, gas; MMB, oil)	0.05	0.08	0.12	0.08	0.3	0.7	1.0	0.71
Success ratios (%)	10	50	80	47	10	50	80	47

Assessment Results

Quantitative assessment results for two unconventional AUs of the Phitsanulok Basin are summarized in table 2. For unconventional oil resources, the mean total is 53 million barrels of oil (MMBO), with a range from 0 to 98 MMBO; for unconventional gas, the mean total is 320 billions of cubic feet of gas (BCFG), with a range from 0 to 622 BCFG; and a mean total of 5 million barrels of natural gas liquids (MMBNGL), with a range from 0 to 10 MMBNGL.

Table 2. Shale-oil and shale-gas assessment results from Phitsanulok Basin, Thailand.

[Results shown are fully risked estimates. For gas accumulations, all liquids are included as natural gas liquids. Total undiscovered gas resources are the sum of nonassociated gas (that is, gas-in-gas accumulations) and associated gas (gas-in-oil accumulations). The notation "F95" represents a 95-percent chance of at least the tabulated amount being present; other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. Gray shading indicates "not applicable." Abbreviations: MMBO, million barrels of oil; BCFG, billions of cubic feet of gas; MMBNGL, million barrels of natural gas liquids; TPS, total petroleum system; AU, assessment unit; NGL, natural gas liquids]

Total Petroleum Systems (TPS) and Assessment Units (AU)	AU Probability	Field Type	Total Undiscovered Resources											
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Chum Saeng Synrift Lacustrine TPS														
Phitsanulok Basin Shale Oil	0.90	Oil	0	54	98	53	0	31	63	32	0	1	1	1
Phitsanulok Basin Shale Gas	0.95	Gas					0	278	559	288	0	4	9	4
Total unconventional resources			0	54	98	53	0	309	622	320	0	5	10	5

Phitsanulok Basin Assessment Team

Christopher J. Schenk, Ronald R. Charpentier, Timothy R. Klett, Tracey J. Mercier, Marilyn E. Tennyson, Janet K. Pitman, and Michael E. Brownfield.

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