USGS
science for a changing world

Open-File Report 2015–1112

Geology and Assessment of Unconventional Oil and Gas Resources of Northeastern Mexico

By U.S. Geological Survey Mexico Assessment Team
2015

Introduction

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of State, quantitatively assessed the potential for unconventional oil and gas resources within the onshore portions of the Tampico-Misantla Basin, Burgos Basin, and Sabinas Basin provinces of northeastern Mexico (fig. 1). Unconventional resources of the Veracruz Basin were not quantitatively assessed because of a current lack of required geological information. Unconventional resources include shale gas, shale oil, tight gas, tight oil, and coalbed gas. Undiscovered conventional oil and gas resources were assessed in Mexico in 2012 (U.S. Geological Survey World Energy Assessment Team, 2012).

Methodology

The USGS approach to assessing continuous shale-oil and shale-gas resources in non-U.S. reservoirs is based upon developing a complete geologic framework description for each province from published literature and defining petroleum systems and unconventional assessment units (AUs) within these systems. We developed specific geologic criteria and a series of maps that define areas of resource potential within candidate reservoirs. To be considered for assessment, the potential shale-oil or shale-gas reservoir must possess the following criteria: (1) contain greater than 2 weight-percent total organic carbon (TOC); (2) be within the proper thermal maturity window for oil or gas generation; (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 might reduce the potential area compared to maps made with greater than 1 weight-percent TOC, for example.

An important part of the geologic phase of this study was a formal USGS-PEMEX (Petroleos Mexicanos) Workshop on Unconventional Resources convened in Mexico City, Mexico, in June, 2012. The geology and current exploration results from within the various shale-oil and shale-gas assessment units (AU) of northeast Mexico were discussed in detail. PEMEX later supplied several maps with geologic data that were critical to the USGS assessment (PEMEX, 2012). The maps shown herein were combined to outline areas within the Sabinas, Burgos, and Tampico-Misantla Basins that were then considered for quantitative assessment using the six USGS criteria.

Publishing support provided by:
Denver Publishing Service Center

This and other USGS information products available at http://store.usgs.gov/
U.S. Geological Survey
Box 25286, Denver Federal Center
Denver, CO 80225

To learn about the USGS and its information products visit http://www.usgs.gov/
1-888-ASK-USGS

This report is available at http://dx.doi.org/10.3133/ofr20151112

For more information concerning this publication, contact:
Central Energy Resources Science Center
Box 25046, Mail Stop 939
Denver, CO 80225
(303) 236-1647

Or visit the Central Energy Resources Science Center Web site at:
http://energy.usgs.gov/

U.S. Department of the Interior
U.S. Geological Survey

Northeastern Mexico Geologic Provinces

Figure 1. Location of geologic provinces considered in this study.

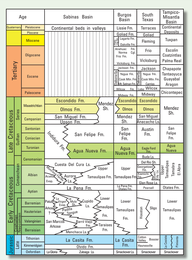

Figure 2. Stratigraphic column of northeast Mexico and southeast Texas. The Pimienta Formation of the Tampico-Misantla Basin is equivalent to the La Casita Formation of the Burgos Basin. The Eagle Ford Formation of south Texas is partly equivalent to the Agua Nueva Formation of northeast Mexico (Peterson, 1985). (Gp., Group; Fm., Formation; Cgl., conglomerate; Ls., limestone; Sh., shale; Evap., evaporite)

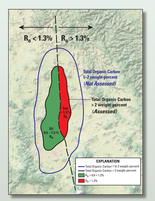

Figure 3. Schematic diagram showing geologic parameters for potential assessed areas. R_o, vitrinite reflectance, in percent.

Tampico-Misantla Basin

Tithonian Pimienta / La Casita Formation

The USGS approach to defining assessment units in the Tithonian Pimienta /La Casita Formation of the Tampico-Misantla Basin began with the map showing the distribution of total organic carbon (TOC) (fig. 4). The intersection of the map of TOC greater than 2 weight-percent (fig. 5) with the thermal maturity map (fig. 6) produced the AU map (fig. 7) for the modal shale-oil area (green) and shale-gas area (red) used in the assessment.

Figure 4. Map showing the area of the Tampico-Misantla Basin with greater than 1 weight-percent total organic carbon (TOC) within Tithonian marine shales. About 21 percent of the area with TOC greater than 1 weight-percent is characterized by values greater than 2 weight-percent TOC (data from PEMEX, 2012).

Figure 5. Map showing the total organic carbon (TOC) data greater than 2 weight-percent for Type II marine Tithonian shale in the onshore part of the Tampico-Misantla 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 Tithonian shale in this basin contains less than 2 weight-percent TOC. Of the area greater than 1 weight-percent, 21 percent is greater than 2 weight-percent TOC. This value of 21 percent was used to characterize Tithonian shales in the Burgos and Sabinas Basins as the map available for those basins only illustrated rock with greater than 1 weight-percent TOC (data from PEMEX, 2012).

Figure 6. Map showing the extent of thermally mature Tithonian shale in the onshore part of the Tampico-Misantla Basin. Maturity data were categorized by T_{max} values from Rock-Eval analyses. T_{max} values greater than 465 °C defined the area of source rock thermally mature for gas (red area); T_{max} values between 435 and 465 °C defined the oil maturity window (green area), and values less than 435 °C were defined as thermally immature for Type II kerogen. The boundaries on this map as derived from T_{max} values are uncertain (data from PEMEX, 2012).

Figure 7. Map showing the intersection of figures 5 and 6, and represents the resultant area with both greater than 2 weight-percent total organic carbon and adequate thermal maturity for oil and gas generation. The green area defines the modal area of the Tithonian Shale Oil Assessment Unit (AU), and the red area defines the modal area of the Tithonian Shale Gas AU. Both AUs were quantitatively assessed in this study.

Turonian Agua Nueva Formation

The USGS approach to defining AUs in the Turonian Agua Nueva Formation of the Tampico-Misantla Basin began with the map showing the distribution of TOC (fig. 8). The intersection of the map of TOC greater than 2 weight-percent (fig. 9) with the thermal maturity map (fig. 10) produced the AU map (fig. 11) for the modal shale-oil area (green) and shale-gas area (red) used in the assessment.

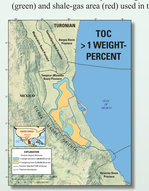

Figure 8. Map showing only the area of the Tampico-Misantla Basin with greater than 1 weight-percent total organic carbon (TOC) within Turonian marine shales. About 64 percent of the area with TOC greater than 1 weight-percent is characterized by values greater than 2 weight-percent TOC (data from PEMEX, 2012).

Figure 9. Map showing the total organic carbon (TOC) data greater than 2 weight-percent for Type II marine Turonian shale in the onshore part of the Tampico-Misantla Basin. Values of TOC greater than 2 weight-percent define areas in this study that exceed the threshold for quantitative assessment. Of the area greater than 1 weight-percent TOC, 64 percent is greater than 2 weight-percent TOC. This value of 64 percent was used to characterize the Turonian shales in the Burgos and Sabinas Basins as the map available for those basins only illustrated rock with greater than 1 weight-percent TOC (data from PEMEX, 2012).

Figure 10. Map showing the extent of thermally mature Turonian shale in the onshore part of the Tampico-Misantla Basin. Maturity data were categorized by T_{max} values from Rock-Eval analyses. T_{max} values greater than 465 °C defined the area of source rock thermally mature for gas (red areas); T_{max} values between 435 and 465 °C defined the oil maturity window (green area), and values less than 435 °C were thermally immature for Type II kerogen. The boundaries on this map as derived from T_{max} data are uncertain (data from PEMEX, 2012).

Figure 11. Map showing the intersection of figures 9 and 10, and presents the resultant area with greater than 2 weight-percent total organic carbon and adequate thermal maturity for oil and gas generation. The green area defines the modal area of the Turonian Agua Nueva Shale Oil Assessment Unit (AU), and the red areas define the modal area of the Turonian Agua Nueva Shale Gas AU. Both AUs were quantitatively assessed in this study.

Burgos Basin

The USGS approach to defining AUs in the Turonian Agua Nueva Formation and in the Tithonian La Casita Formation of the Burgos Basin began with the map showing the distribution of TOC greater than one weight-percent (figs. 12–14). Using analog percentages for areas with greater than 2 weight-percent from the Tampico-Misantla Basin, the AUs were defined as areas with greater than 2 weight-percent TOC, and with the additional condition that because of adverse effects of tectonism only about one third of the remaining area was estimated to have potential for shale oil or shale gas.

Agua Nueva Shale Oil AU

Figure 12. Map showing the outline of potential shale-oil area (1,100,000 acres) in the Agua Nueva Formation with greater than 1 weight-percent total organic carbon (TOC) by PEMEX (2012) in the Burgos Basin. For the U.S. Geological Survey assessment, the potential area at the mode is 704,000 acres (table 1), which is the total area (1,100,000 acres) multiplied by the Tampico-Misantla Basin analog area in the Aqua Nueva Formation with greater than 2 weight-percent TOC (64 percent).

Agua Nueva Shale Gas AU

Figure 13. Map showing the outline of potential shale-gas area (3,530,000 acres) in the Agua Nueva Formation with greater than 2 weight-percent total organic carbon (TOC) by PEMEX (2012) in the Burgos Basin. For the U.S. Geological Survey assessment, the potential area at the mode is 2,259,000 acres (table 1), which is the total area (3,530,000 acres) multiplied by the Tampico-Misantla Basin analog area in the Aqua Nueva Formation with greater than 2 weight-percent TOC (64 percent).

La Casita Shale Gas AU

Figure 14. Map showing the outline of potential shale-gas area (3,941,000 acres) in the La Casita Formation with greater than 1 weight-percent total organic carbon (TOC) by PEMEX (2012) in the Burgos Basin. For the U.S. Geological Survey assessment, the potential area at the mode is 828,000 acres (table 1), which is the total area (3,941,000 acres) multiplied by the Tampico-Misantla Basin analog area in the Pimienta Formation with greater than 2 weight-percent TOC (21 percent).

Wilcox-Lobo Tight Gas AU

Figure 15. Map showing the extent of the Wilcox-Lobo Tight Gas Assessment Unit (AU) in the Burgos Basin. This mapped area is an extension of a much larger Wilcox-Lobo AU in the United States. Sandstones of the Wilcox-Lobo stratigraphic interval are part of a large disrupted zone with slide blocks and related deformational features within which are the Wilcox-Lobo low-permeability (tight) gas sandstone reservoirs.

Rio Escondido Olmos Coalbed Gas AU

Figure 16. Map showing the extent of Olmos Formation coals in the Burgos Basin, as mapped by Warwick (2007). The coals define the extent of the Rio Escondido Olmos Coalbed Gas Assessment Unit (AU).

Exposure of the Eagle Ford Formation (partly equivalent to the Agua Nueva Fm.) on the south bank of Lantry Creek in Pump Canyon, Val Verde County, Texas. Photograph taken by Michael Lewan, U.S. Geological Survey, August 19, 2010.

Sabinas Basin

The USGS approach to defining AUs in the Turonian Agua Nueva Formation and in the Tithonian La Casita Formation of the Sabinas Basin began with the map showing the distribution of TOC greater than 1 weight-percent (figs. 17 and 18). Using analog percentages for areas with greater than 2 weight-percent from the Tampico-Misantla Basin, the AUs were defined as areas with greater than 2 weight-percent TOC, and with the additional condition that because of adverse effects of tectonism only about one third of the remaining area was estimated to have potential for shale oil or shale gas.

Agua Nueva Shale Gas AU

Figure 17. Map showing the outline of potential shale-gas area (3,667,000 acres) in the Agua Nueva Formation with greater than 1 weight-percent total organic carbon (TOC) by PEMEX (2012) in the Sabinas Basin. For the U.S. Geological Survey assessment, the potential area at the mode is 704,000 acres (table 1), which is the total area (3,667,000 acres) multiplied by the Tampico-Misantla Basin analog area in the Aqua Nueva Formation with greater than 2 weight-percent TOC (64 percent), and then multiplied by 30 percent for the effects of structural complexity on the retention of gas.

La Casita Shale Gas AU

Figure 18. Map showing the outline of potential shale-gas area (6,961,000 acres) in the La Casita Formation with greater than 1 weight-percent total organic carbon (TOC) by PEMEX (2012) in the Sabinas Basin. For the U.S. Geological Survey assessment, the potential area at the mode is 565,000 acres (table 1), which is the total area (6,961,000 acres) multiplied by the Tampico-Misantla Basin analog area in the Pimienta Formation withgreater than 2 weight-percent TOC (21 percent), and then multiplied by 30 percent for the effects of structural complexity on the retention of gas.

Discussion

The quantitative methodology used by the USGS for this assessment of unconventional oil and gas resources differs from that used in other unconventional assessments. The differences in methodology must be considered when attempting to compare assessment results. The potential area assessed by the USGS must have source rocks with greater than 2 weight-percent TOC, have greater than 15 meter thickness of organic-rich shale, be within the proper thermal maturation windows for oil or gas generation. The maps supplied by PEMEX for the Agua Nueva and La Casita Formations in the Burgos Basin and Sabinas Basin were based on greater than 1 weight-percent TOC, so the areas used in the USGS assessments (>2 weight-percent TOC) are less than that shown on the PEMEX maps.

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 distribution of potential area incorporates TOC, maturity, depth, and thickness data, and represents one of the key sources of geologic uncertainty. The distributions for estimated ultimate recovery (EUR), well drainage areas, and success ratio are from U.S. analog unconventional accumulations.

Assessment Results

Quantitative assessment results for 11 unconventional AUs of northeast Mexico are summarized in table 2. For unconventional oil resources, the mean total is 776 million barrels of oil (MMBO), with a range from 353 to 1,365 MMBO; for unconventional gas the mean total is 23,474 billion cubic feet (BCFG), with a range from 7,431 to 44,630 BCFG; and a mean total of 883 million barrels of natural gas liquids (MMBNGL), with a range from 278 to 1,690 MMBNGL.

Of the mean unconventional oil total of 776 MMBO, about 82 percent is in the Tampico-Misantla Basin (55 percent; 426 MMBO) is estimated to be in the Agua Nueva Shale Oil AU; (27 percent; 212 MMBO) is in the Pimienta Shale Oil AU. The Agua Nueva Shale Oil AU in the Burgos Basin contains the remaining (18 percent; 138 MMBO).

For the mean unconventional gas total of 23,474 BCFG, about 66 percent (15,591 BCFG) is estimated to be in the Burgos Basin; 25 percent (5,822 BCFG) in the Sabinas Basin; and 9 percent (2,061 BCFG) in the Tampico-Misantla Basin.

Assessment Team

Christopher J. Schenk, Ronald R. Charpentier, Timothy R. Klett, Marilyn E. Tennyson, Stephanie Gaswirth, Michael E. Brownfield, Mark J. Pawlewicz, and Jean N. Weaver.

References

Charpentier, R.R., and Cook, T.A., 2011, USGS methodology for assessing continuous petroleum resources: U.S. Geological Survey Open-File Report 2011–1167, 75 p.

PEMEX, 2012, Mexico's shale oil/gas resources: PowerPoint presentation, July 10, 2012, 42 slides.

Peterson, J.A., 1985, Petroleum Geology and Resources of Northeastern Mexico: U.S. Geological Survey Circular 943, 30 p.

U.S. Geological Survey World Energy Assessment Team, 2012, Assessment of undiscovered conventional oil and gas resources of Mexico, Guatemala, and Belize, 2012: U.S. Geological Survey Fact Sheet 2012–3069, 4 p.

Warwick, P.D., 2007, Assessment of undiscovered oil and gas resources in Cretaceous-Tertiary coal beds of the Gulf Coast Region, 2007: U.S. Geological Survey Fact Sheet 2007–3039, 2 p.

Assessment Input Data

Table 1. Key assessment input data for unconventional assessment units in northeast Mexico.

[EUR (estimated ultimate recovery per well), well drainage area, and success ratios are from U.S. shale-gas, shale-oil, tight-gas, and coalbed gas analogs. MMB, million barrels of oil; BCFG, billion cubic feet of gas; AU, assessment unit. The average EUR input is the minimum, median, maximum, and calculated mean]

Assessment input data	Burgos Basin Rio Escondido Olmos Coalbed Gas AU 53000281				Burgos Basin La Casita Shale Gas AU 53000361			
	Minimum	Mode	Maximum	Calculated mean	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	10,000	250,000	750,000	338,667	100,000	828,000	2,500,000	1,142,667
Average drainage area of wells (acres)	40	80	160	93	80	120	160	120
Percent of AU untested	100	100	100	100	100	100	100	100
Success ratios (%)	50	70	90	70	40	60	80	60
Average EUR (MMBO, oil; BCFG, gas)	0.03	0.2	1	0.24	0.3	0.6	0.9	0.61
	Burgos Basin Agua Nueva Shale Oil AU 53000401				Burgos Basin Agua Nueva Shale Gas AU 53000462			
	Minimum	Mode	Maximum	Calculated mean	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	100,000	704,000	1,100,000	634,667	100,000	2,259,000	3,530,000	1,963,000
Average drainage area of wells (acres)	160	280	400	280	80	120	160	120
Percent of AU untested	100	100	100	100	100	100	100	100
Success ratios (%)	50	70	90	70	50	70	90	70
Average EUR (MMBO, oil; BCFG, gas)	0.04	0.09	0.2	0.086	0.4	0.8	1.2	0.813
	Burgos Basin Wilcox-Lobo Tight Gas AU 53000561				Sabinas Basin La Casita Shale Gas AU 53230161			
	Minimum	Mode	Maximum	Calculated mean	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	10,000	550,000	700,000	420,000	94,000	565,000	1,882,000	847,000
Average drainage area of wells (acres)	40	110	180	110	80	120	160	120
Percent of AU untested	100	100	100	100	100	100	100	100
Success ratios (%)	50	70	90	70	10	50	90	50
Average EUR (MMBO, oil; BCFG, gas)	0.25	0.6	1.5	0.645	0.3	0.6	0.9	0.610
	Sabinas Basin Agua Nueva Shale Gas AU 53230261				Tampico-Misantla Basin Pimienta Shale Oil AU 53010261			
	Minimum	Mode	Maximum	Calculated mean	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	704,000	704,000	2,400,000	1,060,000	100,000	695,000	2,100,000	965,000
Average drainage area of wells (acres)	80	120	160	120	140	240	300	227
Percent of AU untested	100	100	100	100	100	100	100	100
Success ratios (%)	10	50	90	50	40	60	80	60
Average EUR (MMBO, oil; BCFG, gas)	0.4	0.8	1.2	0.813	0.03	0.095	0.14	0.082
	Tampico-Misantla Basin Pimienta Shale Gas AU 53010262				Tampico-Misantla Basin Agua Nueva Shale Oil AU 53010361			
	Minimum	Mode	Maximum	Calculated mean	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU (acres)	10,000	33,000	100,000	47,667	1,052,000	2,104,000	2,735,000	1,963,667
Average drainage area of wells (acres)	80	120	160	120	160	280	400	280
Percent of AU untested	100	100	100	100	100	100	100	100
Success ratios (%)	40	60	80	60	50	70	90	70
Average EUR (MMBO, oil; BCFG, gas)	0.3	0.6	0.9	0.610	0.04	0.08	0.2	0.086
	Tampico-Misantla Basin Agua Nueva Shale Gas AU 53010362							
	Minimum	Mode	Maximum	Calculated mean				
Potential production area of AU (acres)	10,000	128,000	368,000	168,667				
Average drainage area of wells (acres)	80	120	160	120				
Percent of AU untested	100	100	100	100				
Success ratios (%)	50	70	90	70				
Average EUR (MMBO, oil; BCFG, gas)	0.4	0.8	1.2	0.813				

Assessment Results

Table 2. Northeast Mexico unconventional oil and gas resource assessment results.

[MMBO, million barrels of oil; BCFG, billion cubic feet of gas; MMBNGL, million barrels of natural gas liquids; TPS, total petroleum system; AU, assessment unit. Results shown are fully risked estimates. For gas fields, all liquids are included under the NGL (natural gas liquids) category. F95 represents a 95 percent chance of at least the amount tabulated. Other fractiles are defined similarly. Shading indicates not applicable]

Total Petroleum System (TPS) and Assessment Unit (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
BURGOS BASIN														
Olmos Coalbed Gas TPS														
Rio Escondido Coalbed Gas AU 53000281	1.0	*Gas*					125	479	1,544	612	0	0	0	0
Upper Jurassic La Casita TPS														
La Casita Shale Gas AU 53000361	1.0	*Gas*					1,148	3,253	6,730	3,516	69	195	407	211
Turonian Agua Nueva TPS														
Agua Nueva Shale Oil AU 53000461	1.0	*Oil*	52	129	251	138	96	252	533	275	2	5	11	6
Agua Nueva Shale Gas AU 53000462	1.0	*Gas*					3,211	9,320	15,982	9,403	127	368	654	376
Paleogene TPS														
Wilcox-Lobo Tight Gas AU 53000561	1.0	*Gas*					535	1,675	3,431	1,785	5	16	36	18
SABINAS BASIN														
Upper Jurassic La Casita TPS														
La Casita Shale Gas AU 53230161	1.0	*Gas*					577	1,899	4,687	2,172	17	56	144	65
Turonian Agua Nueva TPS														
Agua Nueva Shale Gas AU 53230261	1.0	*Gas*					941	3,189	7,922	3,650	37	127	321	146
TAMPICO-MISANTLA BASIN														
Upper Jurassic Pimienta TPS														
Pimienta Shale Oil AU 53010261	1.0	*Oil*	69	194	412	212	82	232	498	254	2	7	15	8
Pimienta Shale Gas AU 53010262	1.0	*Gas*					58	136	272	147	2	4	8	4
Turonian Agua Nueva TPS														
Agua Nueva Shale Oil AU 53010361	1.0	*Oil*	232	402	702	426	406	789	1,502	852	7	16	32	17
Agua Nueva Shale Gas AU 53010362	1.0	*Gas*					252	754	1,529	808	10	30	62	32
VERACRUZ BASIN														
Turonian Maltrata TPS														
Maltrata Shale Oil AU 53020261		*Oil*	Not quantitatively assessed											
Maltrata Shale Gas AU 53020262		*Gas*	Not quantitatively assessed											
Total unconventional resources			**353**	**725**	**1,365**	**776**	**7,431**	**21,978**	**44,630**	**23,474**	**278**	**824**	**1,690**	**883**