

# Coalbed Methane Resources of the Sabinas Basin, Coahuila, México

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## ABSTRACT

The coal deposits of México are located in the states of Sonora, Chihuahua, Coahuila, Hidalgo, Puebla, Oaxaca, and Tamaulipas. Particularly, the Sabinas Basin in Coahuila contains more than 5000 m of Upper Jurassic and Cretaceous rocks. The coal seams are at the top of the Upper Cretaceous section and occur from the present surface to a depth of about 900 m. They are identified on well logs by high resistivity, low density, and by lithology inferred from gamma-ray logs. Interpretation of logs from 12 wells in the Sabinas coal basin and 4 wells in the Río Escondido coal basin, all with thick Upper Cretaceous sections, allow regional identification of the Austin and Upson Formations, four units in the San Miguel Formation, the Olmos Formation, and a thick sandstone in the Escondido Formation. A preliminary interpretation of this study is that several coal seams assigned to the Olmos Formation likely are contained in the lower one-third of the Escondido Formation, although it is possible that coal seams may occur at other stratigraphic levels in other areas.

Coal in the Sabinas Basin was deposited in regressive, high-frequency, deltaic sequences characterized by overall lenticular geometries. A concentration of higher plants led to the accumulation of type III kerogen favorable for the in situ generation of methane. Coal in the Sabinas Basin is bituminous, with high-to-medium volatility. It has 45% fixed carbon, 14% volatile material, 40% ash content, and 1% sulfur and other impurities. Its caloric content is 1300 to 1400 Btu with a vitrinite reflectance of about 0.5, which places it between the zones of diagenesis and catagenesis with a maximum burial depth that may have been between 800 and 1200 m.

By drilling 60 shallow wells (average depth of 700 m) at a cost of \$US 21.6 million, approximately 18 million ft<sup>3</sup> of gas per day could be produced with a payout of the investment in 18 months calculated at a price of \$2.15 per thousand ft<sup>3</sup>. This area could potentially produce coalbed methane commercially for nearly 20 years, considering production increase through time as the coal seams desorb.

## INTRODUCTION

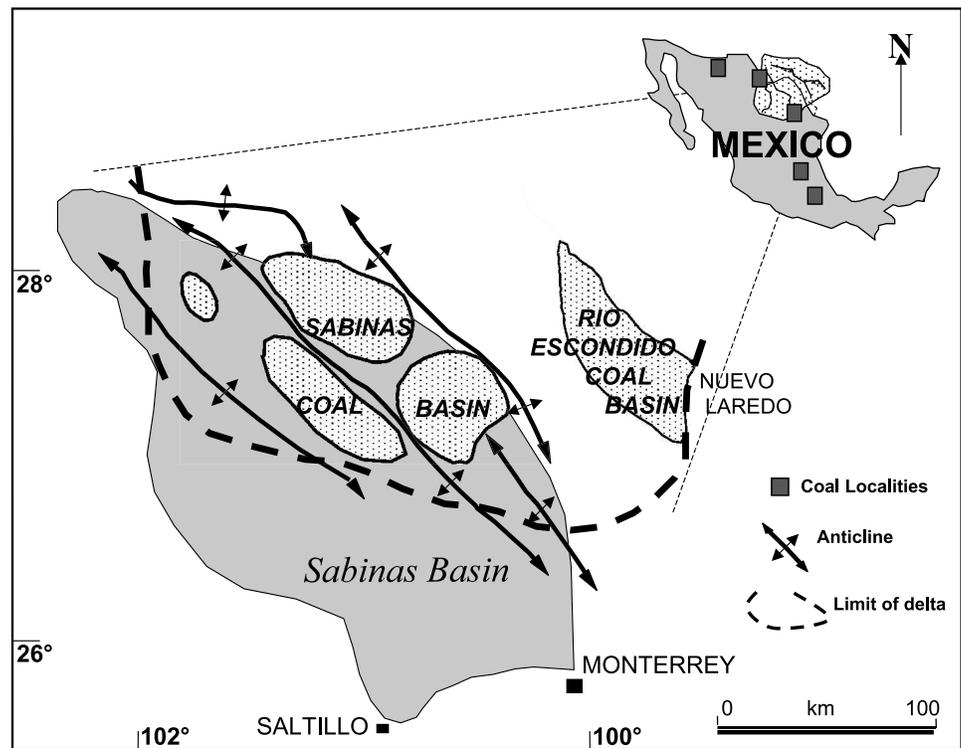
The study area covers more than 20,000 km<sup>2</sup> in the states of Coahuila and Nuevo León in northeastern

México, and is located along the border with the United States from lat. 26°15' to 28°15'N and long. 99°30' to 102°00'W. The coal seams occur in synclinal and homoclinal structures between anticlines where

**Figure 1.** Location of the study area and emplacement of coal in the Sabinas and Río Escondido Basins.

erosion has removed the upper coal-bearing levels (Figure 1). Following terminology in the geological literature (Robeck et al., 1956; Flores, 1991), the synclines and homoclines are referred to as basins and subbasins that have been given various names. The best known of these basins are the Sabinas Coal Basin and the Río Escondido Coal Basin, subdivided according to their principal mining districts (Verdugo and Arciniaga, 1991; Flores, 1991).

Numerous references cite the worldwide importance of coalbed methane extraction (Murray, 1996), but only few pertain to México (AHMSA, 1997; Eguiluz, 1998). Coal with different degrees of alteration has been reported in México in the states of Sonora, Chihuahua, Coahuila, Nuevo León, Tamaulipas, Puebla, Hidalgo, and Oaxaca (Flores, 1991). The Mexican mining industry and the Comisión Federal de Electricidad have undertaken numerous studies of these coal deposits, with a view toward their extraction and industrial use. In 1997, the federal government authorized a steel producer, Altos Hornos de México (AHMSA), to undertake the extraction and exploitation of methane gas derived as a by-product of coal for use in the operations of its subsidiaries. Mining companies (Carbonífera de Río Escondido and Minerales Monclova) have taken the first steps to extract methane from coal seams, mentioned in a press release in the *El Financiero* daily newspaper of México City, dated February 28, 2001, wherein the writer (M. Sánchez) points out that these companies have a project to extract, exploit, and sell coalbed methane gas. Gas pipelines in the Sabinas area have transported conventional gas from Upper Jurassic and Lower Cretaceous carbonate and terrigenous reservoirs; more than 355 billion ft<sup>3</sup> have been produced in the last 30 years to supply the needs of AHMSA, whose current consumption is more than 100 million ft<sup>3</sup> of gas per day.



The work discussed here derives from the first study by the authors of this paper, with the objective of understanding the characteristics of the coal deposits of Coahuila so as to understand coalbed methane as an investment opportunity. The need for natural gas in México is growing, and in the short term it will be necessary to use all of the available resources to satisfy the country's demand.

## STRATIGRAPHY

Mesozoic and Cenozoic rocks in this study area are more than 5000 m thick (Figure 2). The oldest marine sedimentary rocks are Upper Jurassic, and they are overlain by a transgressive succession consisting of carbonates, evaporites, and shallow-water clastics extending up to the Lower Cretaceous. The Upper Cretaceous is composed of regressive and transgressive cycles in shallow-water environments including carbonate platform, prodelta, delta, fluviodeltaic, and swamps, whereas the younger deposits represent the shallower-water environments. The paleogeographic evolution and distribution of these rocks has been outlined in previous studies by Eguiluz (2001) and Cuevas (1984).

The coal seams are traditionally assigned to the Olmos Formation, since they were described by

CENOZOIC	TERTIARY	PALEOGENE	EOCEN-PALEOCEN	Midway-Wilcox Groups	EROSION ?		
			UPPER	MAASTRICHTIAN		Taylor-Navarro Groups	
				CAMPANIAN		Upson Formation	
				SANTONIAN		Austin Formation	
				CONIACIAN		Eagle Ford Formation	
				TURONIAN		Buda Formation	
				CENOMANIAN		Del Rio Formation	
						Washita Group	
						ALBIAN	Tamaulipas Superior Formation
							APTIAN
				NEOCOMIAN		Cupido Formation	
			La Virgen Formation				
			La Mula Formation				
			Padilla Formation				
			Barril Viejo Formation				
Menchaca Formation							
UPPER	TITHONIAN	La Casita Formation					
	KIMMERIDGIAN	Zuloaga Group					
JURASSIC	UPPER	OXFORDIAN	Basement Complex				
		PRE - OXFORDIAN	Basement Complex				

**Figure 2.** Stratigraphic section of the Sabinas Basin. The Austin chalk is of Turonian-Coniacian age; Upson and four units of the San Miguel Formation are of Santonian-Campanian age; the Olmos Formation is an early(?) Maastrichtian deposit; and the Escondido Formation is a late(?) Maastrichtian deposit. The black line represents coal methane beds in the Escondido Formation. The Paleogene deposits are inferred and are removed by erosion in the area of the carboniferous Sabinas Basin.

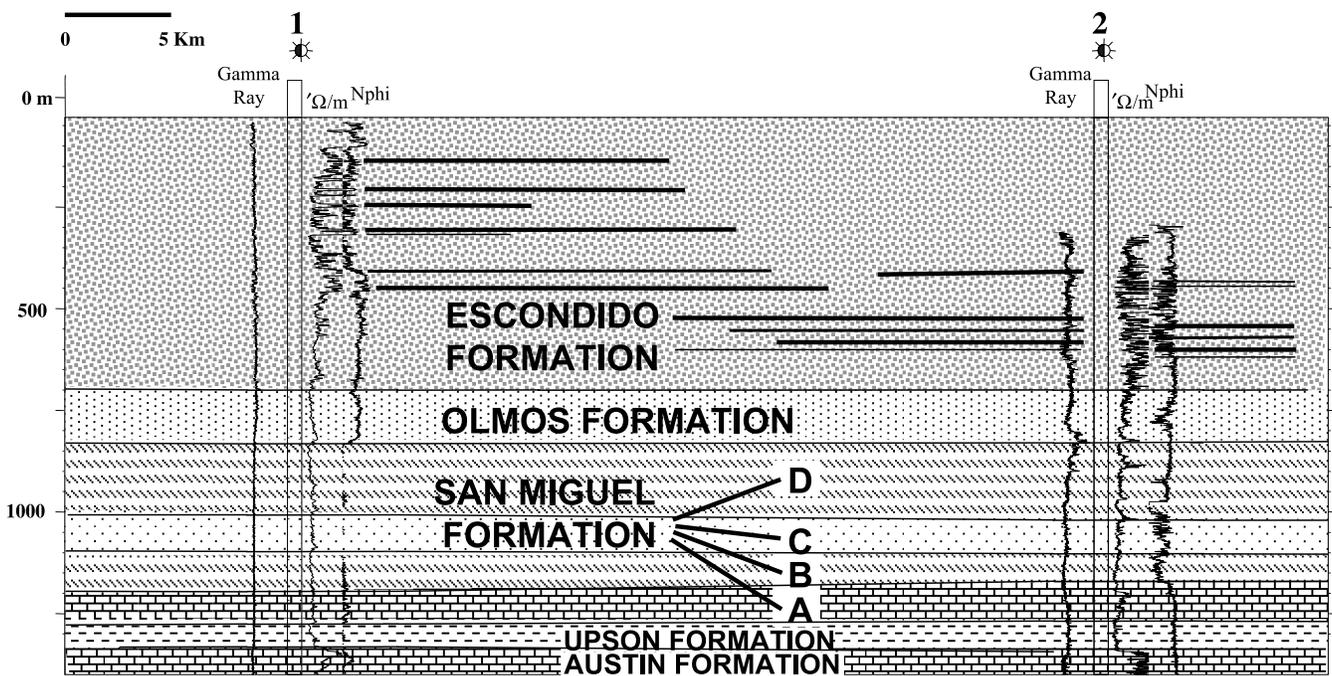
This unit is interpreted as a carbonate platform deposit in a regressive cycle. Unit B consists of marls, fine-grained sandstones, and shales with an average thickness of 150 m. Unit C is an areally continuous, 180-m body of thin-bedded, fine-grained sandstone interbedded with shale. The pattern of resistivity logs indicates the presence of upward-fining cycles, suggesting that Unit C represents high-frequency transgressive and regressive cycles.

Dumble and Stephenson (*in* Adkins, 1932). In this study, based on well cuttings and geophysical well logs supported by seismic data, the authors have identified several stratigraphic units that correlate with formations of the Taylor and Navarro groups.

According to correlations with induction, gamma-ray, and neutron logs on longitudinal and transverse cross sections (Figures 3 and 4), carbonates at the top of the Austin Formation are a regional horizon marker. A regional 120–150 m shale equivalent to the Upson Formation overlies this marker. This unit may represent a widespread flooding surface. Five regionally persistent lithologic units above the Upson Formation are included in the San Miguel Formation. Unit A, at the base, consists of impure carbonates, siltstones, and sandstones 120–170 m thick.

Unit D is 300–380 m-thick and forms the upper limit of the stratigraphic package assigned to the San Miguel Formation. Its upper boundary is difficult to define because its upper portion is lithologically similar to the base of the underlying Olmos Formation. Unit D has increasingly thicker beds of upward-fining sandstone. The lowermost beds contain marine foraminifera including *Globorotalia elevata*, *G. roseta*, and *G. stuartiformis* of Campanian age.

The base of the Olmos Formation is identified on well logs by a high-resistivity sandstone. In well cuttings, it is a coarse-grained gray sandstone with interbedded shales. It has an average thickness of 110 m and is devoid of fossils. Its top is characterized by coarser-grained, greenish-gray and reddish sandstones in gradational contact with conglomeratic sandstones



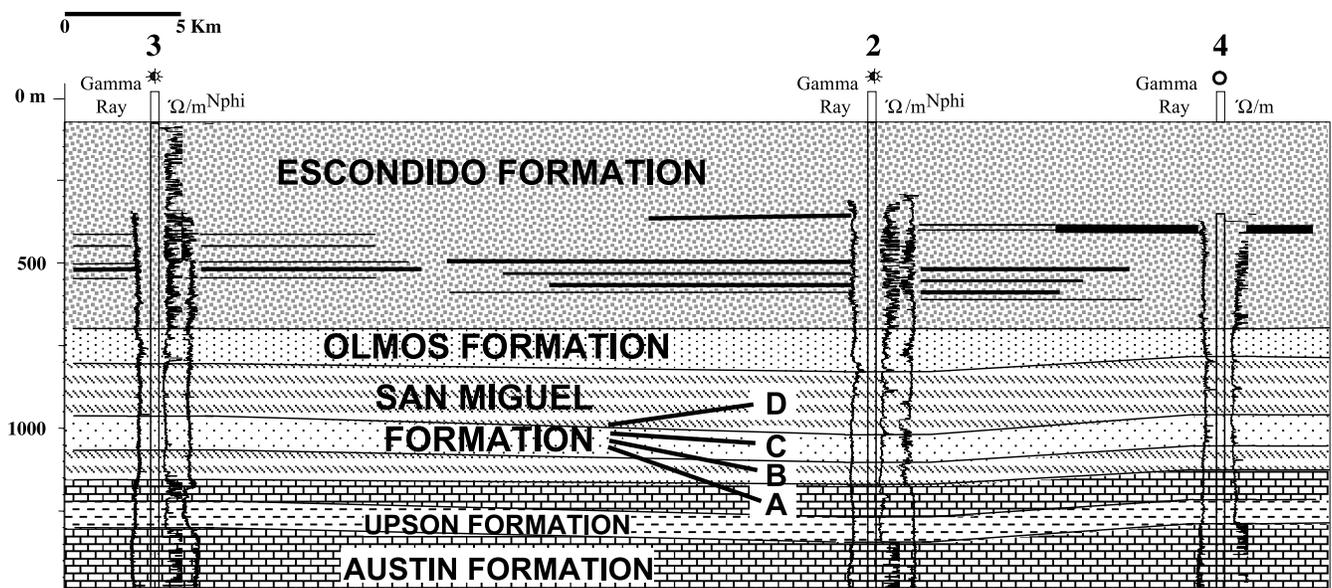
**Figure 3.** Data logs showing the top of the Austin Formation as a confident regional stratigraphic correlation northeast to southwest. The coal seams are represented by black lines that belong to a regressive system of deltaic facies of Maastrichtian age in the Escondido Formation.

of the underlying Escondido Formation. The contact may possibly be an erosional limit.

In the authors' opinions, the Olmos Formation of the Sabinas Basin does not contain coal deposits, as has been described in other published works (Dumble and Stephenson, *in* Adkins, 1932; Robeck

et al., 1956). Olmos Formation strata are mixed shallow-water or delta-front facies, and the coals occur in higher stratigraphic levels than the Olmos Formation in Texas (Dumble, *in* Adkins, 1932).

The Escondido Formation is assumed to be of Maastrichtian age. It is more than 1000 m thick and



**Figure 4.** Data logs showing the top of the Austin Formation as a confident regional stratigraphic correlation northwest to southeast. The coal seams are represented by black lines that belong to a regressive system of deltaic facies of Maastrichtian age in the Escondido Formation.

consists of very-coarse to conglomeratic, greenish-gray to reddish-gray sandstones. These are identified on well logs as thick intervals of high resistivity and few shale intercalations. The bases of coalbeds are associated with white and ochre sandstones. Updip wells in delta-plain facies contain coal in the lower part of the section, relative to wells located in the distal-delta facies. There are numerous coal seams ranging individually from a few centimeters to 5 m, with a minimum net total thickness of 10 m. The identification and positioning of the coal seams are based on well cuttings calibrated with resistivity, neutron, and density logs, where available. The thick coal seams cannot be confidently correlated between wells, and the many coal seams indicate high-frequency cyclicity in zones of tens of meters thick in a gross section of as much as 100 m. According to the generalized model proposed by Galloway (1975), the preservation of coal seams is favored by constructive and fluvially dominated deltas. The lithologic stacking pattern in this paper may suggest a highstand progradational complex with a well-developed delta plain including peat swamps. The widespread occurrence of coal denotes lateral migration of the deltaic subfacies.

Robeck et al. (1956) based their stratigraphy on fieldwork and on the observations of Dumble and Stephenson (*in* Adkins, 1932) concluding that the coal seams occur in the Olmos Formation. The thicknesses reported by those authors for the San Miguel (277 m) and Olmos (241 m) Formations are very thin compared to the sections penetrated by the wells in this study. The present study incorporates a stratigraphic framework assembled from more than 10 wells, supported by seismic lines that show sections with no structural complications. These results modify the preexisting stratigraphic concepts concerning the coal seams in the study area.

### THE COALBED GAS PLAY

The stratigraphy described above suggest a deltaic origin for the coal seams in Sabinas Basin, with abundant organic matter derived from higher plants forming the principal element of this play, further suggesting that the organic material was transformed into coal at deeper burial depths than at present. In the Río Escondido Basin, the stratigraphic section is thicker than that of the Sabinas Basin. Well sections in the Río Escondido Basin indicate that Eocene and Paleocene strata with more than 1500 m thick overlie the coal-bearing Escondido Formation.

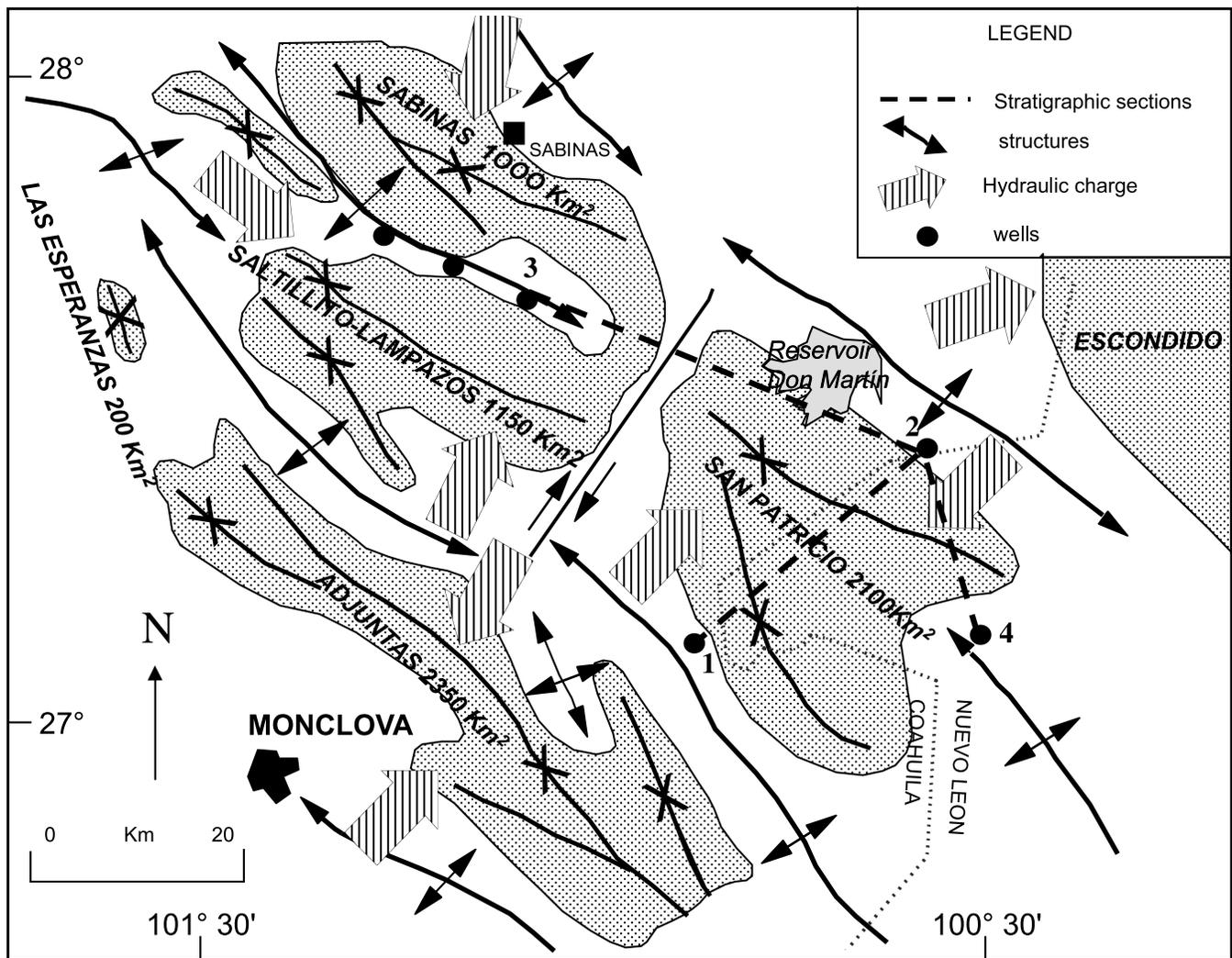
Coal seams from the eastern portion of the Río Escondido area are low- to medium-volatility with higher? caloric value than those of the Sabinas Basin (Verdugo and Arciniega, 1991). This leads to the assumption that burial depth may vary from west to east, with lesser burial depth in the western area and greater burial in the east, where distal delta facies are located. In order to produce vitrinite reflectance levels of 0.5 to 1.0, the organic material must have been buried between 800 and 1200 m (Tissot and Welte, 1978), and an equal thickness of rock must have been eroded in the localities where the coal currently crops out. A considerable section of rock also must have been eroded from the synclines where coal is still buried.

The quality of the coal is also favorable for play economics. The coal of the Sabinas Basin is bituminous with medium to high volatility, according to chemical analysis (Robeck et al., 1956). It has a fixed carbon of 45%, with 14% volatile material, 40% ash, and 1% sulfur content, and a caloric content of 1300 to 1400 Btu.

Another important element of this play involves the deformation that these rocks have undergone to form structural traps. The region has been affected by the Laramide orogeny and contains anticlinal folds between broad synclines where the coal seams are placed (Figure 5). Deformation in the western part of the Sabinas Basin is represented by broad synclines and narrow anticlines, while in the Escondido Basin only one structure is an eastward-dipping homocline. The structural framework provides a hydrodynamic element with zones of meteoric water that recharge the buried coal seams (Figure 5). The water table in the Sabinas mines is about 250 m below the surface. This, in addition to present burial depths, may lead to favorable pressures in the gas deposits but also could delay dehydration of the coal seams necessary to initiate desorption of the gas.

The permeability of the gas seams is considered to be favorable, assuming that the rocks are naturally fractured, as they are in the conventional Jurassic and Lower Cretaceous gas reservoirs in this area where fracturing of low-porosity rocks leads to high permeabilities (Eguiluz, 2001). In addition to natural fractures, coal typically develops orthogonal partitions (cleats) that enhance the migration of gas as it diffuses out of the coal matrix.

An unknown element of this play is the gas content of the coal. It may be that AHMSA (1997) already has data to confirm this important component to support the development of a play. In coalbed methane



**Figure 5.** Structural map of coal in the Sabinas Basin showing hydraulic recharge zones and syncline extension.

basins in the United States of America (Logan, 1988), the minimum economic threshold per well is about 100,000 cfd, and in the San Juan Basin, the average maximum daily production is about 524,000 cf per well. Productivity depends on the quality of the coal, the thickness of the seams, and others factors such as changes of facies across the area, changes in ash and sulfur content, and fracture permeability. These comprise the greatest risk elements for the Sabinas Basin gas play.

#### QUANTIFICATION OF THE GAS RESOURCE

From the late 1980s to the present, economic production of coalbed methane in the United States of America has provided 10% of domestic gas supply

(Murray, 1996). Other countries hope to achieve similar results and are conducting tests and evaluations. In México, only AHMSA (1997) has investigated the feasibility of an investment in coalbed methane extraction. Since 1997, Mexican laws covering exploration, exploitation, transport, and commercialization of gas have been in the process of change; in the near future, this gas resource may be available for private investment. Pemex has not yet conducted studies to evaluate the resource. This paper is the first work that establishes the coal stratigraphy of the Taylor and Navarro Groups in the Sabinas Basin, and makes a preliminary evaluation of this nonconventional gas resource.

Coalbed methane is generated in the coal, in contrast to conventional gas deposits where gas is usually generated at different stratigraphic levels, from

which it migrates into the reservoir. This is an important distinction because this gas, being a by-product of the coal, would belong to the owner of the mineral rights. At this time, coalbed gas is vented to the atmosphere in order to eliminate risks while mining. This practice is inconsistent with the current need for gas.

From data assembled in this study, it is calculated that the Sabinas Basin covers an area of about 6900 km<sup>2</sup> (Figure 5), including the Sabinas (1000 km<sup>2</sup>), Saltillito-Lampazos (1150 km<sup>2</sup>), Adjuntas (2350 km<sup>2</sup>), Las Esperanzas (200 km<sup>2</sup>) synclines, and the San Patricio syncline (which is the second largest, at 2100 km<sup>2</sup> and also where the coal seams are at an average depth of 700 m). About 50% of this area contains coal seams ranging in thickness from 0.5 to 3 m over a gross interval of 100 m with a net exploitable thickness of 10 m. With a coal density of 1.4 gr/cm<sup>3</sup>, total coal tonnage may be 147 billion metric tons. At a minimum gas recovery of 100 ft<sup>3</sup> per ton, this resource could be as great as 14.7 trillion cubic feet (TCF) of methane. If only 10% of this is extracted, the volume would be 1.47 TCF, or the equivalent of 311 million barrels of oil.

Assuming that a 700 m well costs about \$US 361,000 to drill and complete, the cost of 60 wells to develop the deposit would require an investment of \$US 21.6 million. If each well produces an average of 0.3 million ft<sup>3</sup> per day, the field could yield 18 million ft<sup>3</sup> per day. At a market price of \$US 2,150 per million ft<sup>3</sup>, 18 million ft<sup>3</sup> would yield \$US 38,700 per day, and the investment would be recovered in 560 days, whereas production in the field could last for several years. The area contains some pipelines that could be used to reduce transportation costs. The water to be disposed of could be used for agriculture or industrial use in this semidesertic area.

Modern coalbed methane-play evaluation techniques are described by Logan (1988). Using 3-D seismic data, artificial fracturing, open-hole completions, nitrogen injection and other technologies, the profitability of the field could be enhanced, especially since Pemex has acquired 2-D seismic data in the area and pipelines to nearby markets already exist at the Nava thermoelectric plant and the AHMSA steel-production facility.

## CONCLUSIONS

The coalbeds of the Sabinas and Río Escondido Basins occur within a regressive fluvio-deltaic and

paludal sequence of Late Cretaceous age. The strata have undergone moderate compressional deformation, and the coal occurs in synclines and homoclines. Well logs, calibrated with well cuttings, allow regional mapping of the Austin and Upson Formations, and for the first time in petroleum-related studies in this area, four units in the San Miguel Formation, and in the Olmos and Escondido Formations have been identified. The coal seams occur in the bottom one-third of the Escondido Formation and are contained in a framework of coarse-grained sandstones and conglomerates. The coal-bearing interval averages 100 m thick, but individual coalbeds have an average thickness of 2 to 3 m with cyclic repetition in the interval. The coals probably were buried to depths of 800 to 1200 m. This study concludes that favorable elements exist for a commercial coalbed methane play. However, the amount of gas contained in the coal and the discontinuous facies changes of the coal seams are major risk elements.

Resource calculation of one structure seems to support the existence of a viable commercial venture that would partially satisfy gas-market requirements in this part of Coahuila State.

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