Play-Element Characterization of the Miocene and Pliocene Veracruz Basin, Southeastern Mexico

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Abstract

A basin characterization and play analysis were conducted over the Miocene and Pliocene section of the Veracruz Basin to assess remaining gas potential. The comprehensive data set included information from 144 wells, more than 5600 miles (9,000 km) of 2-D seismic, and more than 200 mi^2 (500 km^2) of 3-D seismic. In addition, production-engineering, well-test, and geochemical data were analyzed and synthesized into the basin evaluation.

Reservoir, trap, source, migration pathways, and timing play elements were individually characterized, mapped, and integrated into a framework of play types and play fairways. Reservoirs are dominated by channelized to fan-dominated siliciclastic turbidites. Long-lived compressional and strike-slip forces created abundant four-way and three-way closures. Valid stratigraphic traps are present and currently produce gas. Gas chimneys, geopressure, and locally intense structuring contribute to top-seal uncertainties. Source rocks are considered adequate for gas across the study area. Biogenic gas prevails in many upper Miocene and lower Pliocene reservoirs, eliminating the need for deep-seated, fault-induced migration pathways. Surface seeps and gas shows are common.

Thirty-two plays were evaluated on the basis of a combination of stratigraphic age, depositional facies, and trap type. Play areas were defined according to reservoir limits of either channel-dominated or fan-dominated facies. Trap density and postulated trap areas for each play were determined by a detailed mapping of existing reservoirs, anomalies, and closures within two calibration areas. Future trap numbers and sizes for each play were based on the ratio of the calibration area to the play area as a whole. Using of this method, we attempt to extrapolate play-characteristic geology from an area of high data quality and quantity to areas of lower confidence.

Introduction

We conducted a detailed analysis of the Miocene and Pliocene part of the Veracruz Basin, southeastern Mexico, to provide a framework that helped rank, chance, and forecast the future potential of PEMEX's portfolio of gas-prone prospects. As of January 2001, three fields had cumulatively produced 200 billion cubic feet of gas from Tertiary deepwater channels and lobes. These gas fields were discovered in the 1960's and are largely depleted. Much of the Tertiary section remained underevaluated for gas reserves until the recent acquisition of new 3-D surveys, which are promoting a surge in the basin's gas potential (e.g., Guzman and Yanez-Mondragon, 1998; Rodriguez et al., 2000; Guzman, 2002). The surveys, combined with well calibration and production data, reveal a broad range of deepwater reservoir types, reservoir qualities, and trap types. Many of the shallow gas reservoirs display bright amplitudes in the full-stack, 3-D seismic volumes, and new opportunities, unseen on the regional 2-D grid, are currently being drilled.

The new seismic surveys are consequently identifying new opportunities in a basin thought to have only modest potential (Guzman and Yanez-Mondragon, 1998; Guzman, 2002)

The data set made available for this joint PEMEX-BEG study is one of the largest ever assembled for the onshore southern Gulf of Mexico. The comprehensive data set included information from 144 wells, more than 5600 miles (9,000 km) of 2-D seismic, and more than 200 mi^2 (500 km^2) of 3-D seismic (Fig. 1). This study offers an opportunity to advance several areas of research in basin analysis, play assessment, and reservoir characterization. Consider the following:

- The data set permits an examination of the interplay between active tectonics and deepwater sedimentation because of spatially and temporally varying combinations of extension, shortening, and volcanic activity.
- The quality of the 3-D surveys is excellent and, with well calibration and production-engineering data, they provide insight into reservoir architecture and depositional patterns, as well as amplitude expression of gas- and water-bearing sandstones and conglomerates.
- A basin of this type is different from the classic Tertiary basins from the northern Gulf of Mexico. Deepwater depositional systems of the Veracruz Basin are more similar to those that developed along high-relief, active continental margins (e.g., lower Tertiary basins off West Africa and southern Brazil) than those from the Gulf Coast Basin. Consequently, a different strategy for play analysis is required.
- The paucity of field-size data provides a challenge to develop a quantitative resource assessment because statistically meaningful distributions of volumetric parameters based on conventional historical field data do not exist. We therefore were required to carefully build this missing data from the geologic characteristics of the basin.

Study of the Miocene and Pliocene gas plays provides an integrated geologic framework to help assess the basin's future potential for gas. Results of the assessment, including future exploration strategies, were considered confidential by PEMEX at the time of publication. Accordingly, only geologic aspects of play elements and the methods used to define them are presented in this paper.

Geologic Setting

The Veracruz Basin is located along the tectonically active southwest margin of the Gulf of Mexico Basin at the convergence of the North American, Pacific, and Caribbean tectonic plates. Regional structures define the geographic boundaries of the Veracruz Basin: the buried Laramide-age tectonic front lies to the west, with the offshore Anegada High and coastal Los Tuxtlas volcanic massif to the east; the Trans-Mexican Volcanic belt lies to the north; and the Salinas del Istmo basin abuts the Veracruz Basin to the south.

Jennette et al. (2002; in review) informally subdivided the basin into several major structural domains, or trends, that share structural style, kinematics, and timing of deformation (Fig. 2). From west to east, the trends are the western Homocline, the Loma Bonita Anticline, the Tlacotalpan Syncline, the Antón Lizardo Trend, and the highly deformed south end of the basin, here termed the Coatzacoalcos Reentrant. The volcanic massifs are part of the Anegada Trend. Most of the basin's gas reserves have come from the basinward edge of the western Homoclinal and the Loma Bonita Trends.

Conglomerates, sandstones, and shales dominate the Miocene strata of the Veracruz Basin. The bulk of the paleobathymetric data indicate that bathyal conditions prevailed during most of the Tertiary (Cruz Helú et al., 1977). The west and southwest basin margin became steep, high relief because of the stacked thrust sheets that existed along the leading edge of the tectonic front (Cruz-Helú et al., 1977).

Play-Element Analysis

The goal of play analysis is to develop an integrated classification scheme that constrains the range of geologic and engineering parameters used to calculate undiscovered hydrocarbon volumes (Baker et al., 1984). The play is considered the fundamental part of the hydrocarbon system (Otis and Schneidermann, 1997), and play elements are fundamental parts of the play. The play elements and subelements addressed during this study were reservoir facies, reservoir quality, reservoir distribution, closure type, seal type, seal integrity, migration pathways, and timing of trap formation relative to gas charge (White, 1988).

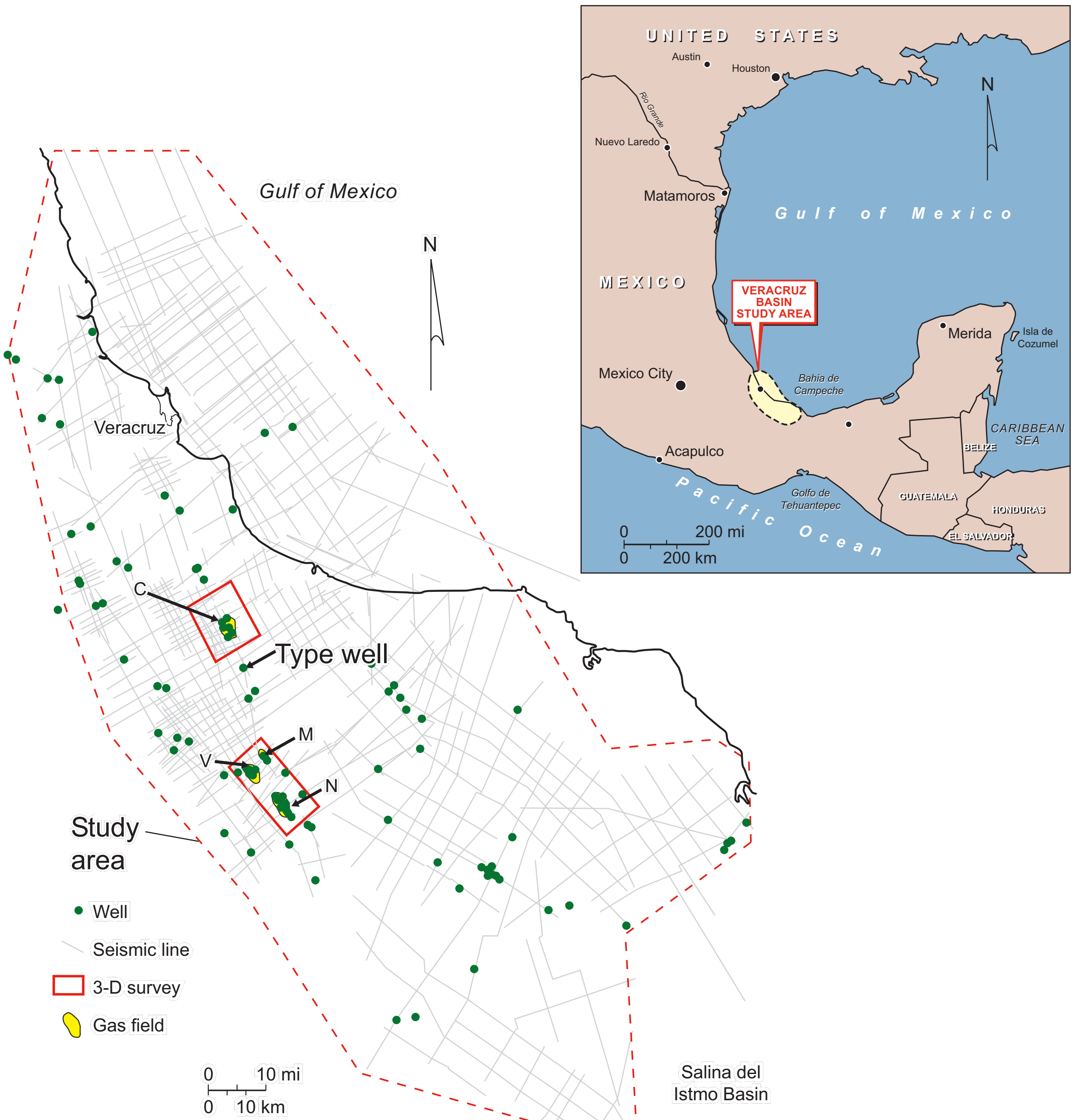

Figure 1. Location map highlighting study area and distribution of wells and seismic data (2D and 3D surveys). Gas fields with Miocene/Pliocene production are Cocuite (C), Novillero (N), Veinte (V), and Mirador (M). The type well for the Tertiary section is southeast of Cocuite field.

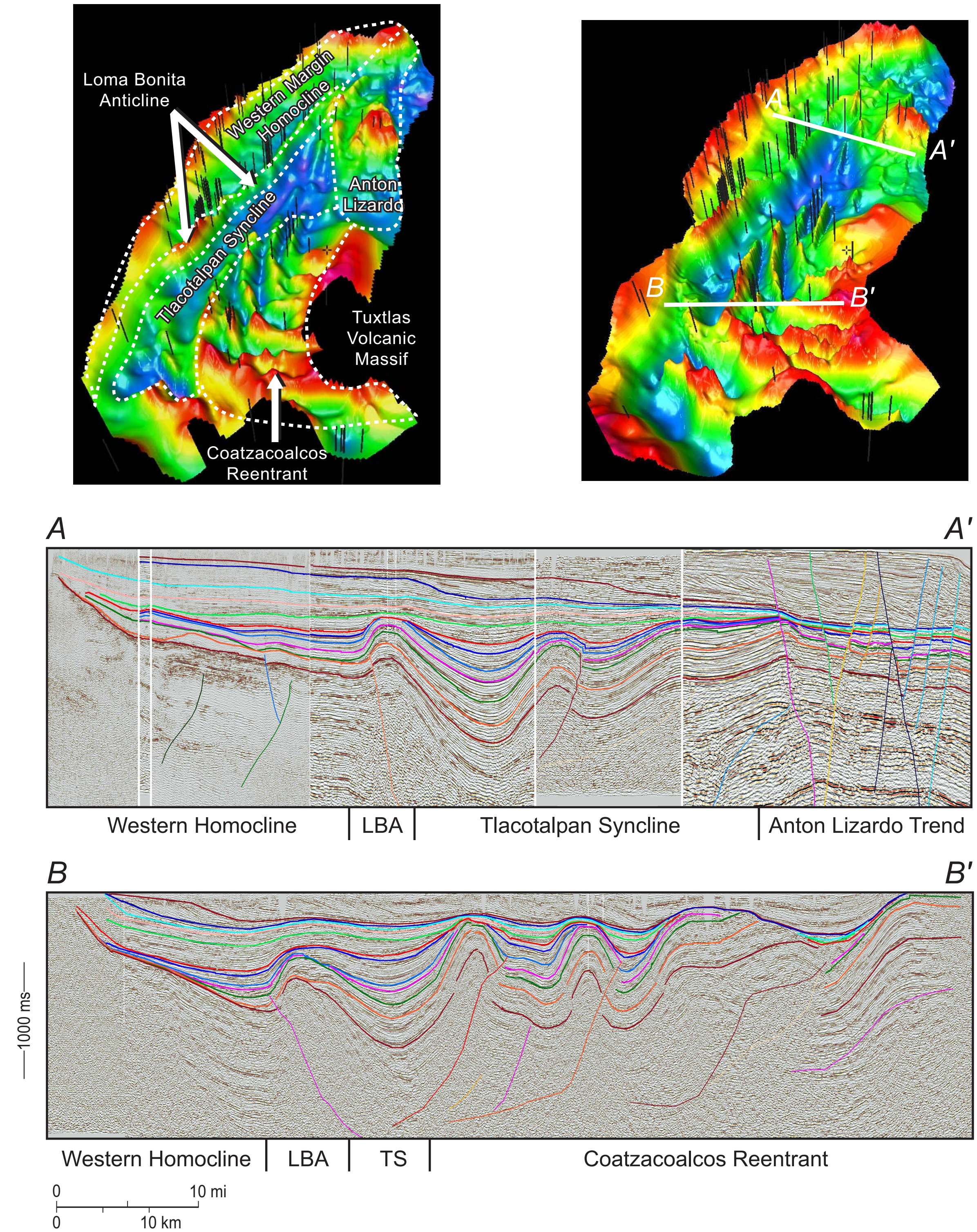

Figure 2. Structural relief map, based on a middle Miocene horizon (green horizon), illustrating structural trends. The composite seismic lines A-A' and B-B' illustrate cross-sectional characteristics of the main structural trends (WH: Western Homocline, LBA: Loma Bonita Anticline, and TS: Tlacotalpan Syncline).

Reservoir

Depositional facies and environments were established through the integration of conventional core, well log patterns, seismic characteristics, and map patterns. A basinwide chronostratigraphic framework based on sequence boundaries permitted the stratigraphic division into genetically related packages suitable for reservoir mapping (Fig. 3). Well-log-to-seismic calibration and regional stratigraphic analysis were helped by a good correlation between amplitude and lithology. High amplitudes are associated with sandstone and conglomerate, and shaley units are typically associated with lower amplitude seismic facies. (Fig. 3). Reconnaissance of the 3-D surveys reveals a wide range of deepwater reservoir types and lithologies (Figs. 4, 5).

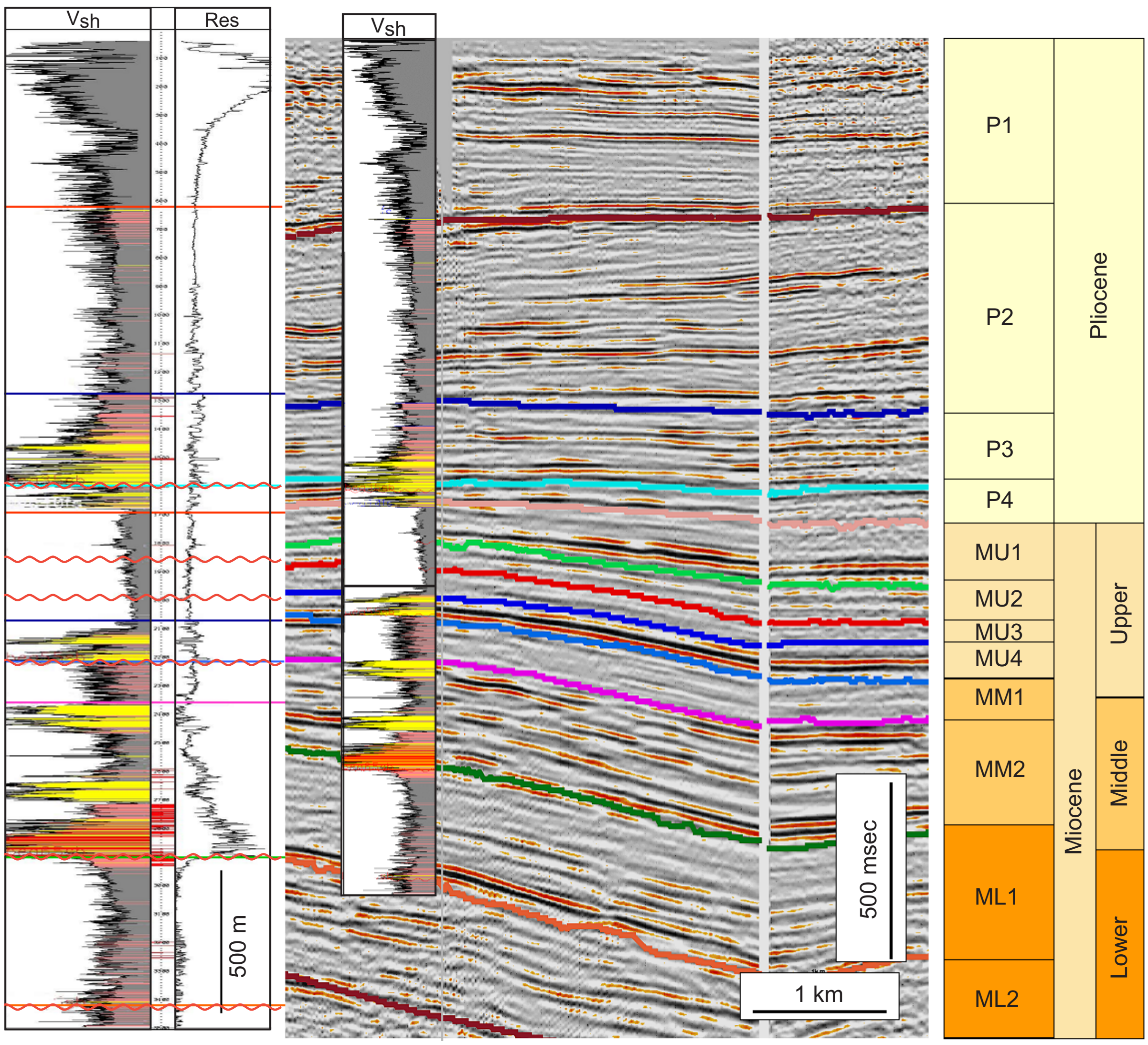

Figure 3. Type well, characteristic 2-D seismic data, and stratigraphic-correlation framework. Good correlation exists between sandstone and strong amplitude. Possible sequence boundaries occur at the base of stacks of thick-bedded, locally conglomeratic (red), sandstone units (yellow). Shaly zones (gray) are calibrated to low-amplitude seismic facies. Age associations are tied to an extensive biostratigraphic database. Location of well is shown in Figure 1.

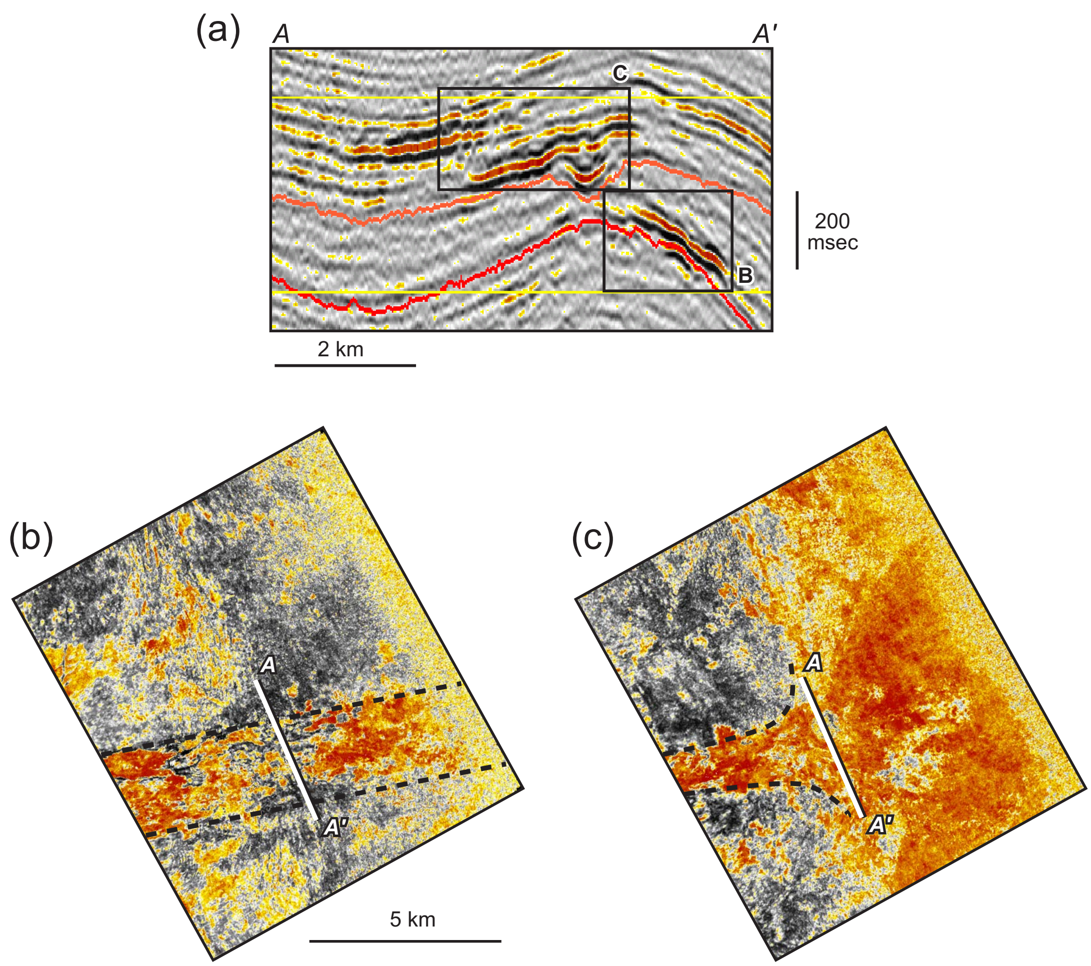

Figure 4. (A) Seismic profile and amplitude extractions of lower Miocene channelized deposits, Cocuite 3-D survey. (B) The linear pattern implies that the change into unconfined fan deposits occurs basinward of the survey. (C) A channel complex develops into a distributive fan. This change marks the slope-to-basin-floor transition. The toe of slope is mapped to shift landward throughout the Miocene.

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We constructed a total of nine depositional systems maps (two lower Miocene, one middle Miocene, three upper Miocene, and three Pliocene) by combining well-log data, seismic facies, amplitude, and isochron (Fig. 6). Each Miocene map shows a system composed of two main facies belts: one of confined channel complexes and one dominated by basin-floor fans. Proximal features consist of long-lived canyons and smaller, erosional gullies. These channel-fill deposits are mainly thin, coarse grained and locally conglomeratic. The transition from confined channels into less-confined fan facies is evident in each Miocene depositional system (e.g., Fig. 4). Lower Miocene fan deposits are thick and generally predate structural growth in the basin. The middle and upper Miocene fan deposits are strongly affected by growing structures, particularly in the south part of the basin (Fig. 6). Also from middle Miocene to recent, deposition was strongly affected by growth of the outboard volcanic centers.

The Pliocene depositional system contrasts with the onlapping Miocene system. Pliocene sedimentation rates exceeded basinal accommodation, and prograding clinoforms dominate the fill. The discretely mapped, highly erosive channel complexes observed in the proximal Miocene facies belts are replaced by nonerosive channelized slope complexes that fed smaller basin-floor fans. Proximal reservoirs in the Pliocene are narrow, sinuous channels, and basinal reservoirs are fan successions (Fig. 7). Pliocene fan deposits are more limited in extent than Miocene fans.

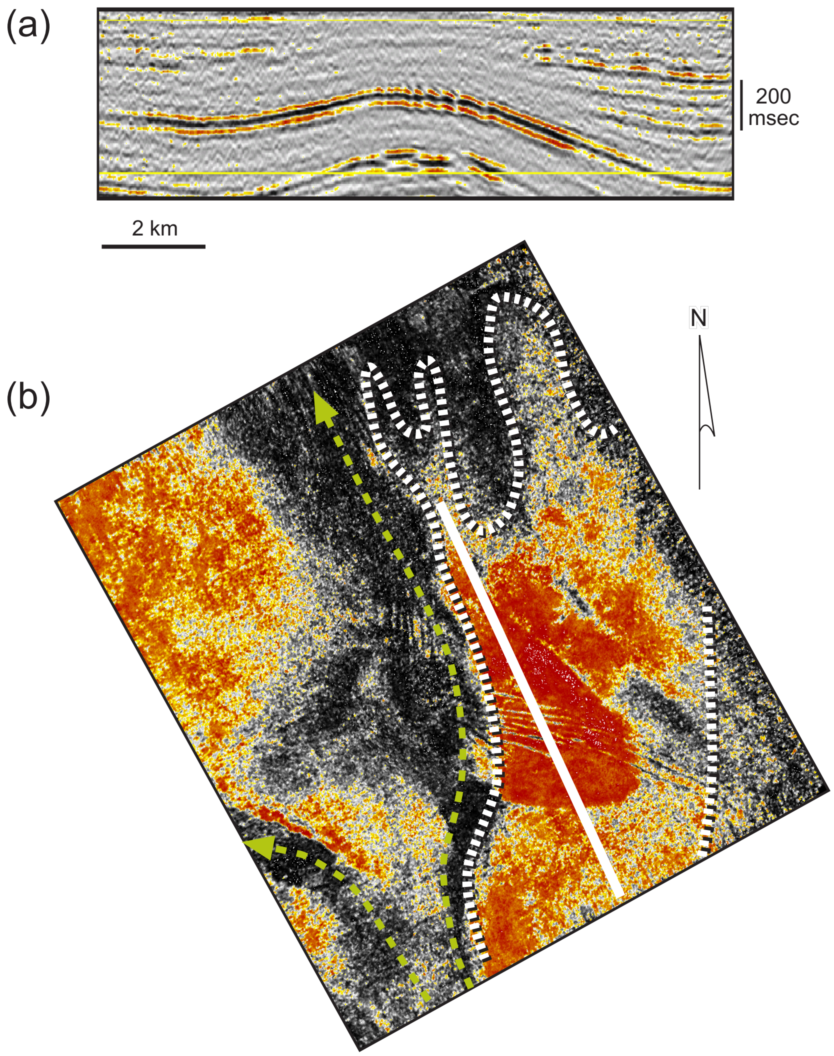

Figure 5. Sandy fan deposit, Cocuite field. (A) Seismic profile across a sheet-like sandstone in the lower part of the upper Miocene. High amplitude and continuous seismic facies correlate to sandstone occurrence. (B) Amplitude extraction of the sheet sandstone. The west margin of the amplitude is sharp and interpreted to be eroded by younger flows. The unit is interpreted to shale out to the north.

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Trap

Closure

The basin is located along the tectonically active southwest margin of the Gulf of Mexico at the convergence of several tectonic plates. This convergence gave rise to numerous pre- and syndepositional transpressional and transtensional structures that were variably active throughout the Neogene to recent. Reconnaissance of the producing fields and undrilled amplitude anomalies in the 3-D surveys indicates production from several reservoirs of differing stratigraphic age, with most of the gas coming from channel-dominated reservoirs whose traps have a partial to strong stratigraphic component. Overall, the dominant trap styles observed in the basin are four-way (domal) closures, three-way closures with updip fault seal, three-way closures with updip stratigraphic pinch-out, and pure stratigraphic traps. Three-way traps that require sealing faults have not yet been encountered.

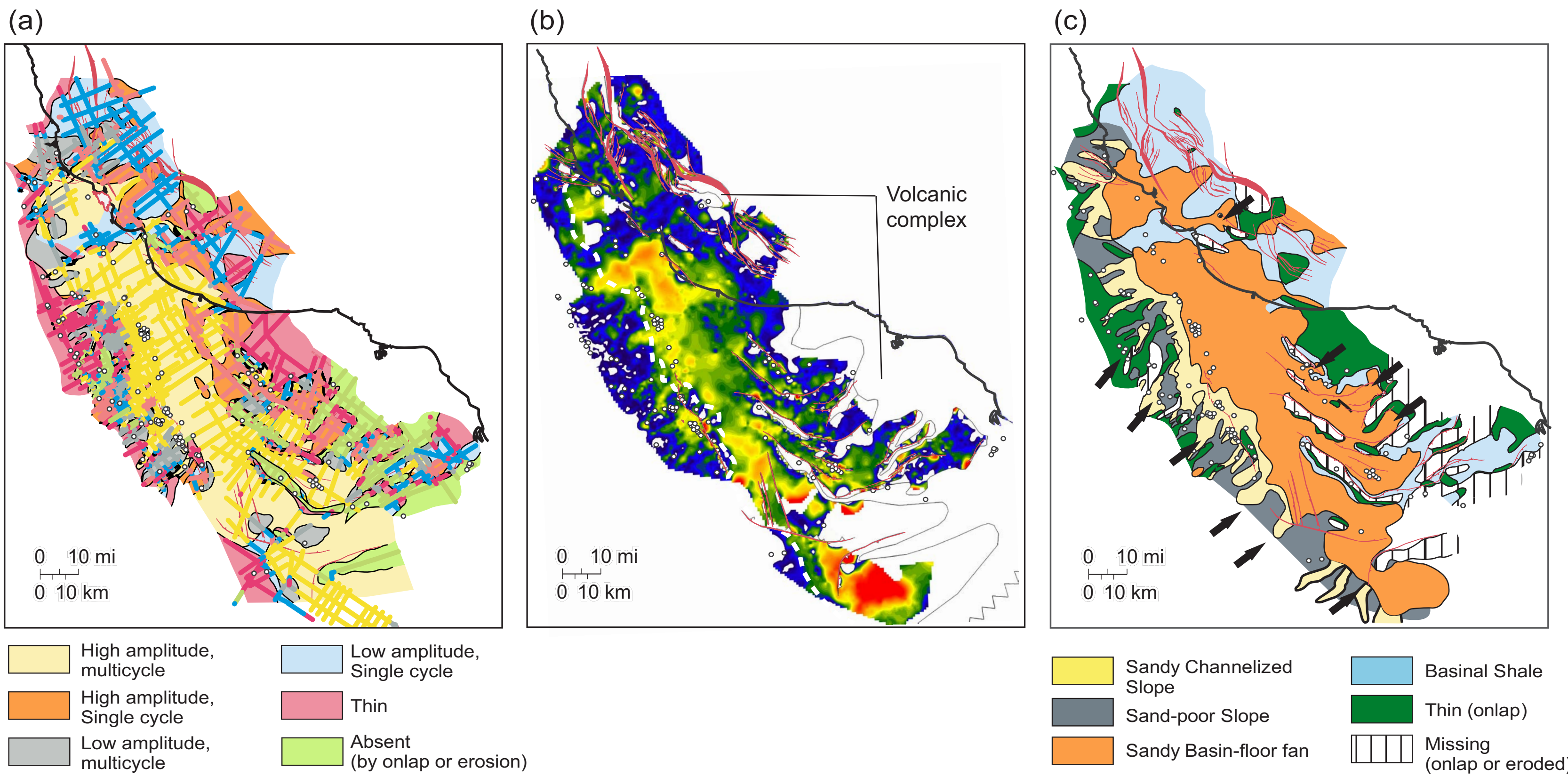


Figure 6. Middle Miocene depositional-systems map. Interval is the MM2 (Fig. 3). (A) Seismic facies ribbon map based on manual, line-by-line analysis. (B) Isochron map (reds=thicks, blues=thins). (C) Depositional environment interpretation.

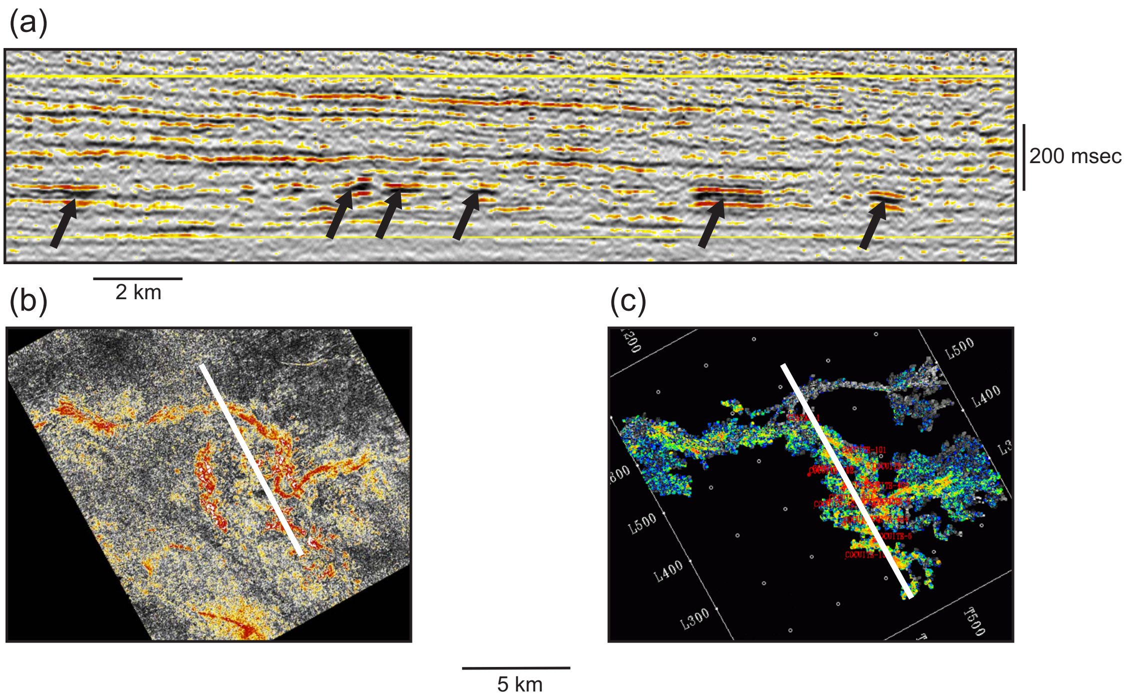


Figure 7. Seismic characteristics of a sinuous channel from the lower Pliocene. (A) Seismic profile showing a discontinuous array of high amplitude due to channel sinuosity. (B) A windowed extraction highlighting the channel pattern and possible splay channels. (C) A directed or piloted seed picked amplitude map showing splays and distributaries at the channel termini.

Seal

Many large structures in the basin have experienced complex and long-lived structural deformation. Many anticlines in the basin display closely spaced extensional faults on their crests. These closely spaced faults may compromise the ability of overlying shale beds to hold large gas-column heights. At least two gas chimneys are recognized on two separate 3-D surveys (Jennette et al., in review). These features record the vertical leakage of gas from deeper, higher pressured reservoir zones. A mixture of more deeply sourced thermogenic and locally sourced biogenic gases is found in Pliocene reservoirs around the Cocuite chimney.

Source

Confident understanding of the source play element suffered somewhat from paucity of data from the interior of the basin. Most of the source-rock data came from a few wells drilled along the basin margin, and most aspects of the source play element are based on forward modeling of these observations in more basin-centered positions. The basin-margin wells indicate that excellent quality source rocks occur in the Upper Jurassic/Lower Cretaceous, and secondary source rocks are encountered in the lower Tertiary. These units are the source of nearly all of the oils, condensates and thermogenic gas in the Veracruz Basin and surrounding area (Talukdar et al., 2002, for summary). Given that these source rocks are interpreted to be present across the basin, the thermal maturity, source quantity, and source quality are generally considered adequate for gas over the total extent of the Tertiary basin study area. (Talukar et al., 2002). In addition, biogenic gas is common in many upper Miocene and lower Pliocene reservoirs, suggesting an additional local source for dry gas in these intervals.

Migration Pathways and Timing

Numerous deep-seated thrust and strike-slip faults indicate that pathways are probably adequate for thermogenic gas (e.g., Fig. 2). Surface seeps and abundant gas shows indicate that hydrocarbons are migrating through the Tertiary section today.

Timing is a poorly quantified play element for our study of the Veracruz Basin. One positive aspect is that many structures have been in existence since the middle Miocene. One possibly negative aspect is that a peak in structural activity occurred in the latest Miocene (circa 5–7 m.y.a.). Early-migrated thermogenic gases may have leaked from these traps during this phase of deformation. In addition, the intensity and longevity (middle Miocene to recent activity) of structuring in the Coatzacoalcos Reentrant and Anton Lizardo strike-slip trend may affect the adequacies of several play elements.

Play Types and Play Mapping

Plays were defined by combining three criteria: stratigraphic age, reservoir type, and trap type. Nine reservoir intervals were combined into four composite units on the basis of distribution and reservoir style: (1) lower Miocene, (2) middle and lower upper Miocene, (3) uppermost Miocene, and (4) Pliocene (Fig. 8). Each of the four composite maps was then divided into channel-dominated and fan-dominated play areas, and the resulting eight facies/age play areas were measured. We assumed that the 4 main trap types occurred in each of the 8 play areas, bringing the possible number of plays to 32. Several more trap types were identified during this exercise (e.g., subunconformity traps), but their numbers were relatively small for establishing a statistical sampling.

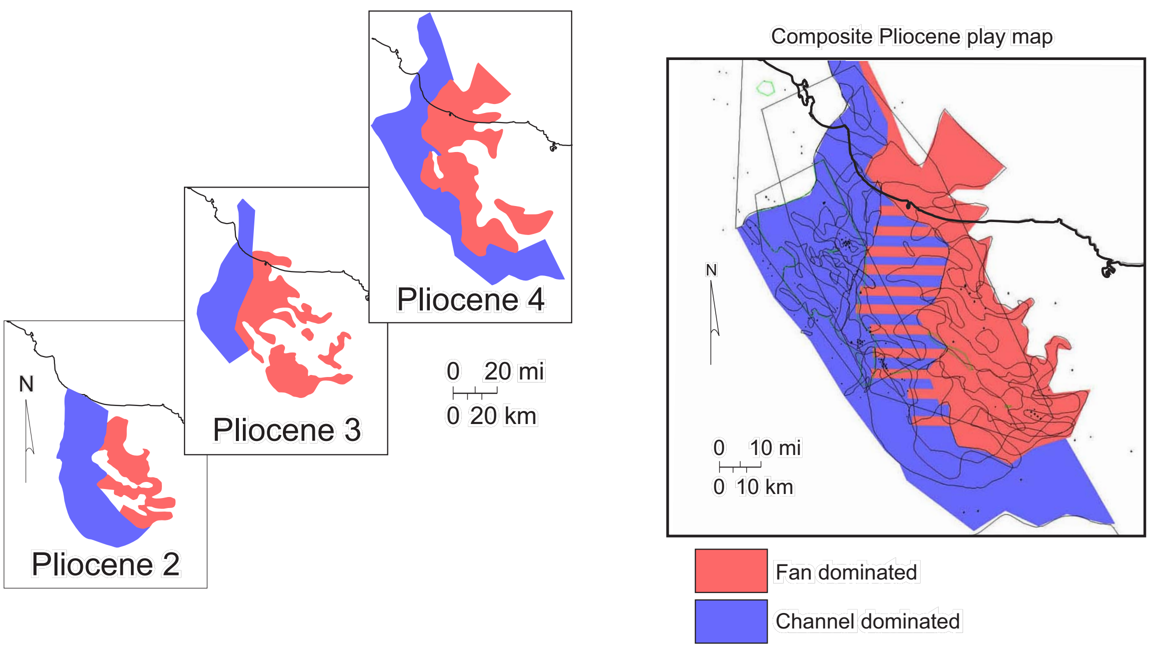


Figure 8. Example of multiple facies belts merged and combined into a single play area for the composite Pliocene play. Blue areas are dominated by channelized slope facies, and basin-floor fan deposits dominate the reddish areas. The striped area indicates the area where younger Pliocene channelized slope facies overlie older Pliocene basin-floor fans.

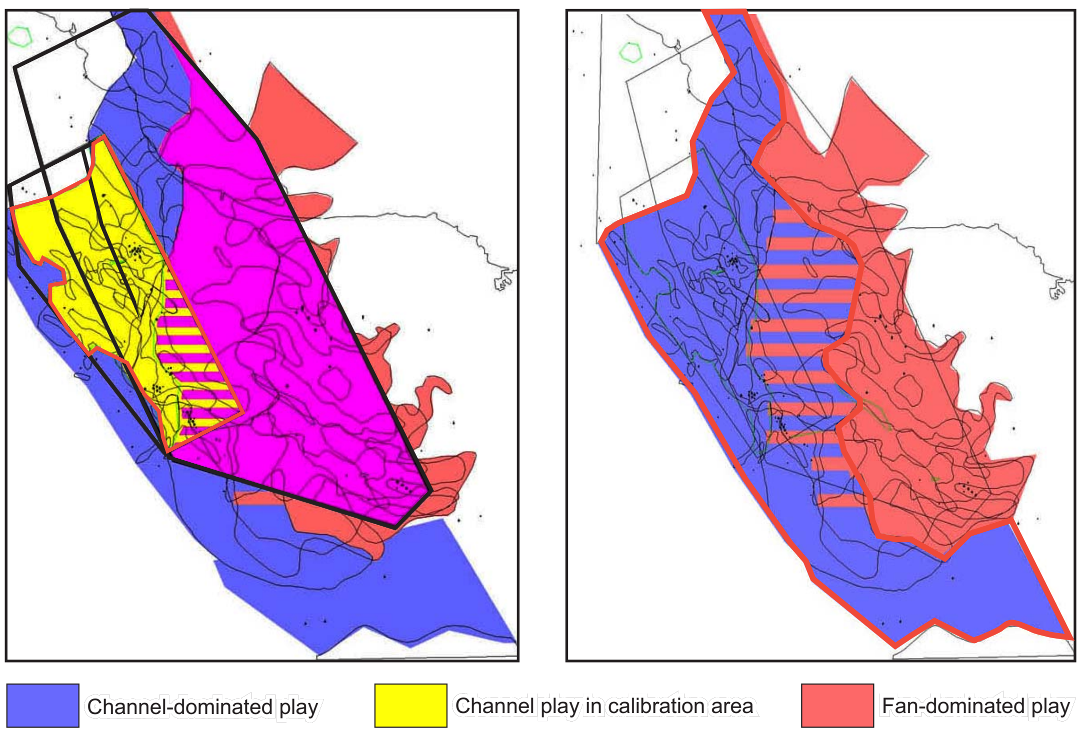
Field-Size Areas of Future Fields

Given the paucity of producing field volumes, we generated a postulated field-size distribution by mapping the limits of existing fields, undrilled prospects, and amplitude anomalies. This mapping was conducted in two calibration areas that had better data quality and quantity. One calibration area helped define stratigraphic traps associated with channelized reservoirs and fan pinch-outs. This area included the Novillero and Cocuite 3-D surveys and the region of higher quality 2-D seismic between these surveys. A second, larger calibration captured large four-way closures. A cumulative plot of the trap areas fits a log-normal curve. A hypothetical trap density (traps per unit area) was next determined for each play and then simply extrapolated to the entire play. This procedure is illustrated in the following equation (Fig. 9):

Future number of fields = (gross play area) / (play area in calibration area) × (number of traps in calibration area).

As a result of this analysis, we found that 11 of the 32 original plays had a trap density sufficient to merit further volumetric characterization, including construction of volumetric parameters (porosity, net pay, saturation, geometric correction factor), development of play chance and a future-success ratio for each play, and estimation of recovery efficiency. Positive covariant relationships were implemented for porosity and gas saturation, net pay thickness and reservoir area, and reservoir area and recovery efficiency. A Monte Carlo simulation was run for the high-data-confidence area and for the low-confidence area. Results were then summed to obtain gas-resource distribution for the whole play.

Unrisked reserves, risked reserves, and risked recoverable reserves based on the volumetric input were generated. Four-way closure plays compose a large part of the total in-place volume because these plays have larger trap areas and pay thickness has the potential to be great. Stratigraphic traps in both channelized and fan-dominated facies also compose a substantial part of the assessed volumes. Specific results are not presented in this paper because of confidentiality.



Play type	Traps in calibration area	Play area within calibration area (ac)	Trap density in calibration area (acres per trap occurrence)	Total play area (ac)	Total traps (postulated & mapped)	Traps outside calibration area
Paleocene stratigraphic channelized	16	430,000	26,875	1,500,000	56	40

Figure 9. Trap-density calculation for the Pliocene stratigraphic traps in the channelized facies belt. Sixteen traps were identified in the calibration area (430,000 acres) (yellow polygon). The entire play measures 1,500,000 acres. Using the trap density value from the calibration area, 56 total traps are postulated for this play, 40 of which lie outside the calibration area.

Conclusions

The main goal of this study was to determine the future gas potential of a relatively untested, structurally complex basin. This paper outlines methods and results of assessing play-element adequacy and determining play types, their areas, and future number of traps. Our understanding of the basin's potential has changed as a result of new 3-D surveys, which are providing new insight into the seismic expression of gas-filled reservoirs, deepwater reservoir facies and architecture, and the multiple trap styles that occur in this dynamic depositional and tectonic system. We conclude that

- Miocene and Pliocene reservoirs consist of deepwater deposits. Proximal reservoirs range between lower quality conglomerates and poorly sorted channelized sandstones (Miocene), to sandy, high-quality sinuous and narrow channels (Pliocene). The difference in depositional styles coincides with the change from a steep, tectonically accentuated slope to a constructional slope dominated by progradational clinoforms.
- The basin was differentially active throughout the Miocene and Pliocene, and six structural trends capture most of the pre- and syndepositional transpressional and transtensional structures in the basin. Top-seal adequacy over many tight folds is deemed an important geologic chance factor because of high geopressure and complex and long-lived structural deformation. Gas chimneys indicate vertical gas movement from deeper, possibly large reservoirs.
- Source-rock maturity, distribution, and quality are considered adequate for gas plays over the basin. Biogenic gas is prevalent in many upper Miocene and lower Pliocene reservoirs. Numerous deep-seated thrust faults and strike-slip faults serve as adequate pathways for thermogenic gas.
- The methodology could be used to combine deterministic and stochastic input parameters. Thirty-two plays were identified on the basis of age, depositional facies, and trap type. Mapping existing prospects and leads and new anomalies helped us to generate a postulated field-size distribution. We determined the total future prospect number for each play using the trap density value of a calibration area then extrapolating for the entire mapped play area.

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