Genetic Facies Analysis Using Seismic Geomorphology and Seismic Attributes in the Continental Shelf of Eastern Mexico

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Abstract

Methods for generating seismic facies maps have developed significantly in the last decade. These methods include facies mapping based on seismic geomorphology and sequence attribute extractions (Posamentier and Kolla, 2003). The results of these methods are used to define depositional systems, erosion, paleotopography, and inferred lithology estimation.

The seismic geomorphology technique is similar to back-stripping of a geologic sequence that represents a certain time-stratigraphic surface. We analyze depositional features from timeslices and windowed attribute extractions in a flattened volume within a stratigraphic sequence. Facies can be inferred from the resulting interpreted maps, which basically confine the variation in seismic reflections. Such variation, caused by geology change within seismic sequences and systems tracts, is expressed by change in reflection pattern, amplitude, and frequency (i.e., chaotic, hummocky, continuous). This technique produces quick and efficient results that capture the lateral changes in reflection pattern geometries.

In this article, we demonstrate how we deployed seismic geomorphology and attribute extraction to build out the facies in a third-order sequence. We show an example in the Laguna Madre area, a 3-D cube that extends over 2000 km^2 southeast of the Tuxpan Platform. This research is part of a study done by the Bureau of Economic Geology to investigate Neogene hydrocarbon plays in the Tuxpan area.

Geologic Setting and Sequence Stratigraphy

The Neogene sediments in the Laguna Madre area provide an excellent opportunity for studying lithofacies where they are well expressed seismically along the shelf margin of eastern Mexico. The lower and middle Miocene rocks comprise mostly lowstand prograding deltaic wedge, slope-fans, and basin-floor-fan deposits. In contrast, the upper Miocene and lower Pliocene rocks record more landward systems tracts. Landward sediments are characterized by cyclic on-shelf highstand and transgressive tracts to prograding wedges in the proximal parts.

Sequence and facies recognition was interpreted on the basis of the integration of well logs and cores, seismic data, and volume attributes (Risch et al., 1996). Robust sequence stratigraphic interpretation was performed to define the main third-order depositional cycles.

Multiple east-dipping, synthetic growth faults that sole into a single detachment are the principal structural features. The growth faults are commonly inferred to be the result of depositional loading triggering subsequent gravitational sliding of strata basinward.

Sequences in the Laguna Madre–Tuxpan (LM–T) area are bounded by unconformities and defined in the manner described by Van Wagoner et al. (1990). The timing of principal drivers of these unconformities is mainly ascribed to relative fall of sea level enhanced by local tectonic activity.

In this study we will show selected examples from shallow-water facies in the upper Miocene to lower Pliocene and deepwater facies in the middle Miocene deposits.

During the early Pliocene to the late Miocene an abrupt increase in sediment supply and accommodation rates occurred that resulted in remarkable sigmoidal clinoforms (fig. 1). The thick aggrading sediments and the prograding wedges suggest that the sedimentation rate slightly exceeded the accommodation space during this time. The upper Miocene section as defined in this report is enveloped by two surfaces, a regional sequence boundary (SB43) and a maximum flooding surface (FS40). This interval comprises several smaller depositional cycles defined by the stratigraphic marker beds FS42 and SB41, recognized from seismic data in the study area. The high-amplitude packages above unconformities SB43 and SB41 are represented on well logs as sand-rich intervals. These two unconformities exhibit very little or no detectable relief on the shelf. For example, the SB43 unconformity is expressed in seismic data with virtually undetectable erosional relief in the area of Well-1, and the SB41 unconformity is expressed in seismic as a bright amplitude having 10 to 25 ms of relief, representing limited incision of valley-fill systems on the shelf.

The middle Miocene sediments are complex deepwater fan systems. The transgressive-regressive cycle of the middle Miocene is defined by two surfaces. The first is an erosional surface, SB55, underlying the high-amplitude single- to multiple-cycle basin-floor-fan deposits. The second is a maximum flooding surface, FS50, representing termination of a transgressive episode that marks a rapid decrease in sediment supply.

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Sequences and Lithofacies

Three cores from the interval between FS40 and SB43, were analyzed. Dominant composition is massively burrowed siltstone and very fine grained sandstone in slightly upward coarsening successions. Sandstones typically are poorly sorted owing to significant amounts of muddy matrix introduced by burrowing. Sandstones in the FS40 to SB43 interval may easily be interpreted as shelf bars because they are intensely burrowed and have a fine-grained, slightly upward coarsening grain-size profile. However, a shelf-bar genesis for these sand bodies on the outer shelf is problematic, considering that the shelf is typically a muddy, sediment-starved system (Kulm et al., 1975). A hypothesized origin for these “shelf” sandstones is that they are reworked transgressive deposits from earlier highstand and lowstand progradational episodes. During highstand before the creation of the SB43 unconformity, sandy sediment was delivered to the outer shelf. These deltaic and shoreface deposits were then reworked and subsequently stranded on the shelf during transgression, after which they were thoroughly burrowed by organisms.

Logs and Seismic Patterns

The Pliocene and upper Miocene sections are penetrated in a number of wells in both the inner- and outer-shelf areas. This section exhibits cyclic on-shelf highstand and transgressive systems tracts, which are characterized by strong parallel seismic reflections dipping slightly seaward. Many incised valleys mark the top of the highstand systems tracts, particularly in the Pliocene section, typically represented by muddy transparent amplitude reflections. In some instances, the localized valley fills encompass single to multiple cycles of high amplitudes commonly interpreted to represent sandy sediments.

Wireline logs of the Pliocene and upper Miocene sections display thick coarsening and upward-shallowing highstand sandstone and siltstone intervals alternating with thin intervals of shaly transgressive upward-fining (backstepping) successions. The highstand sediments in this section are characterized on seismic by moderate-strength parallel reflections that range from continuous to discontinuous. Transgressive facies, however, are represented by thinner, more continuous parallel seismic reflections. Major flooding surface FS40 in Well-1 is a high-gamma ray, low-resistivity shaly zone near the top of the sandy succession overlying the SB43 unconformity. Seismic reflection patterns of the FS40 to SB43 show the presence of multiple transgressive-regressive depositional cycles on a ramplike shelf. Flooding surfaces in the FS40 to SB43 interval occur within thin (commonly <100 m), low-amplitude condensed sections that cap high-amplitude zones.

Basinward, the lower and upper Miocene strata are lowstand prograding wedges. These wedges are mostly muddy and are characterized by sigmoidal shapes with weak progradational seismic reflections and transparent amplitudes. Basin-floor-fan deposits are also spread at the toe of these clinoforms, where they are commonly characterized on seismic by bidirectional downlap reflections.

The middle Miocene deepwater facies are characterized by high-amplitude continuous and discontinuous reflections. These fan deposits can be classified as either confined (canyon, channels) or unconfined (sheet, lobes) geometrical bodies. Map patterns of the extracted amplitudes suggest that the fans are high-impedance sediments.

Stratal Surface Methods

Stratal surface interpretation techniques were used to determine facies distribution. Stratal surfaces are sheetlike rock units whose seismic signatures reflect the acoustic impedance boundary associated with surrounding strata. Maximum flooding surfaces (MFS), pervasive throughout the area, served as useful surfaces for flattening the seismic volume. These were subsequently used to define upper and lower limits of the stratigraphic cycle. The analysis carried out from horizon slicing and attribute extraction in the 3-D survey revealed a number of possible sand geometries in the Neogene section. Facies maps that were generated at specific intervals represent a specific systems tract. Also, facies-sensitive seismic attributes were extracted from the flattened volume within a narrow window (10 ms) within a specified vertical (geologic time) zone of interest (Taner et al., 1994). The extracted attributes were then draped on top of the structure horizons in 3-D perspective.

Reservoir Occurrences and Sand Geometries

Map patterns of extracted amplitudes selected at specific zones of the upper Miocene and lower Pliocene exhibit a wide variety of on-shelf depositional systems ranging from wave- and fluvial-dominated deltas to lagoonal and transgressive-shoal systems. Amplitude patterns selected within the middle Miocene section define the shape of a toe-slope-fan complex.

Growth faulting resulted in a narrow linear intraslope subbasin that was filled during the late Miocene and early Pliocene. A stratal slice map at SB43 displays two principal pre-SB43 sources of fluvial sediment and a wave-dominated delta system with strong strike-oriented (northwest-southeast-trending) coastal sandstone facies of strandplain or barrier-bar systems (fig. 2). A river-dominated delta system to the south was inferred from east-trending, narrow amplitude patterns. The continental margin north of Well-1 and Well-2 was intensively faulted, but to the south, where a river-dominated delta system existed, it was a structurally stable ramp area. Along the more intensively faulted shelf margin, lowstand delta systems and basin-floor fans were linked to wave-dominated delta systems and strike-aligned barriers.

Transgression that followed SB43 significantly redistributed the sandstone facies of the wave-dominated delta system. A large lagoon formed in the area of Well-1 and Well-2 landward of transgressive barrier islands.

An amplitude-slice map at the SB41 unconformity is shown in fig. 3. This interval is restricted mostly in the south part of the study area. Seismic facies and wireline-log patterns resemble those described earlier for the FS42 to SB43 interval. Figure 3 displays the distribution of lowstand systems deposited on SB41, in addition to the underlying eroded highstand tract below the unconformity.

Another amplitude-slice map higher in the FS40 to SB43 interval is from the FS40 to SB41 interval. This interval displays parallel, mixed high- and low-amplitude reflections in shelf areas and progradational clinoform facies basinward of its associated growth fault. There is also a linear intraslope subbasin that was the site of a basin-floor-fan system and lowstand deltaic deposition. A stratal slice slightly higher in the section at the FS40 maximum flooding surface documents the starved basin and flooded, on-shelf coastal systems.

A similar procedure of attribute extraction from multihorizon flattening of seismic volume was applied to the middle Miocene interval between FS50 and SB55. The amplitude-slice map shows a diverse spectrum of bright amplitudes, continuous and discontinuous. Map patterns define the geometry of a complex fan that was cut from the north by the major growth fault (fig. 4). Because the area is in the vicinity of the Mexican Volcanic Belt, it is possible that these infill sediments of the fan, characterized by bright amplitudes, are related to volcanic materials. However, if these deepwater sediments have some porosity, these facies could represent potential reservoirs. Detailed analysis of these amplitude anomalies needs to be performed, in conjunction with our detailed facies maps, to test the probability of hydrocarbon occurrence.

Conclusions

We demonstrated an integrated approach using well logs, cores, and seismic geomorphology to illuminate spatial distribution of important facies in a selected 3-D area southeast of the Tuxpan Basin. Marker events at the inner shelf sites represented by the aggradational systems tract provide key horizons for mapping depositional packages. These surfaces are flat and continuous, and they overlie sigmoidal facies. Therefore, they are excellent candidates for stratigraphically flattening seismic data volumes. The facies map images depositional systems and reflects the preserved geometry of the systems. Relative impedance contrasts assist in discriminating sandstone and shale sediments.

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Genetic Facies Analysis Using Seismic Geomorphology

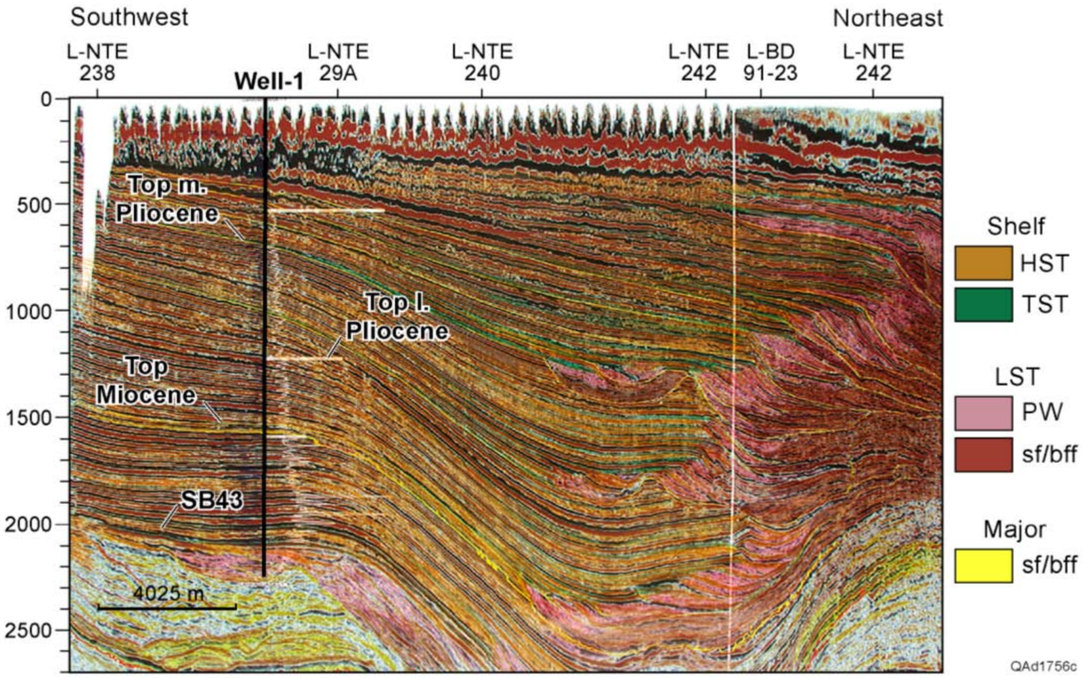

Figure 1. Arbitrary line from the Lankahuasa 3-D survey, showing sequence-stratigraphic framework of the upper Miocene FS40 to SB43 and Pliocene. Abbreviations are HST=highstand systems tract, TST=transgressive systems tract, PW=prograding wedge, sf=slope fan, and bff=basin-floor fan. Prograding wedges mark shelf breaks downdip of shelf systems.

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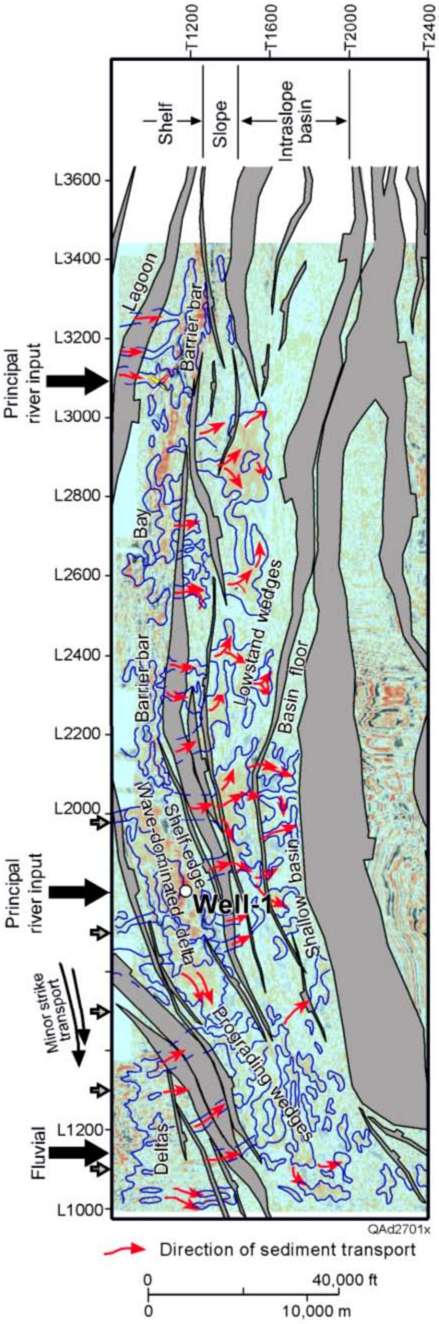

Figure 2. Amplitude-slice map on near top of SB43 (5.73 Ma) showing highstand shelf sediments and postunconformity prograding wedges and basin-floor-fan deposits.

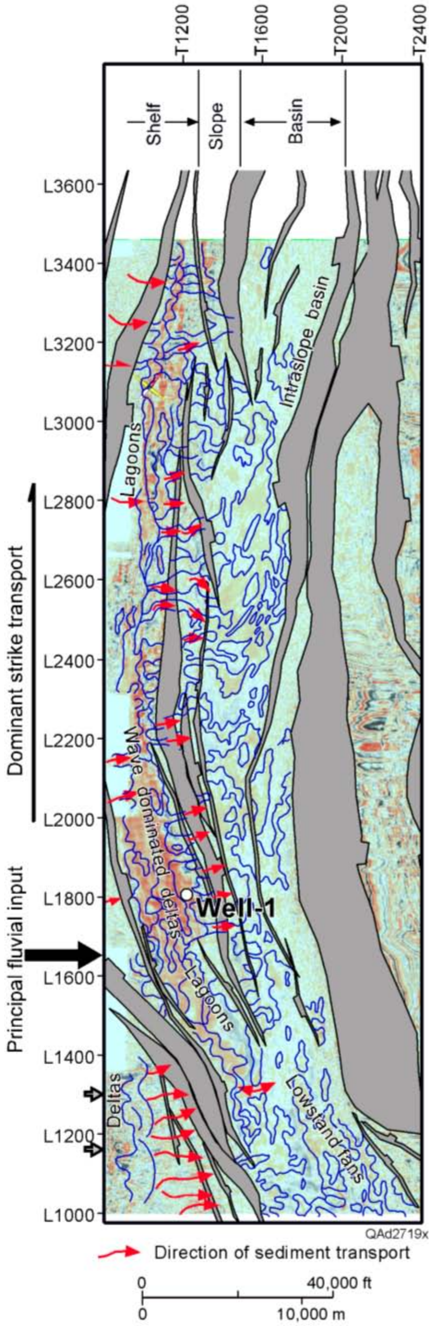

Figure 3. Amplitude-slice map on near top of SB41 (5.5 Ma) showing highstand shelf sediments and postunconformity prograding wedges and basin-floor-fan deposits.

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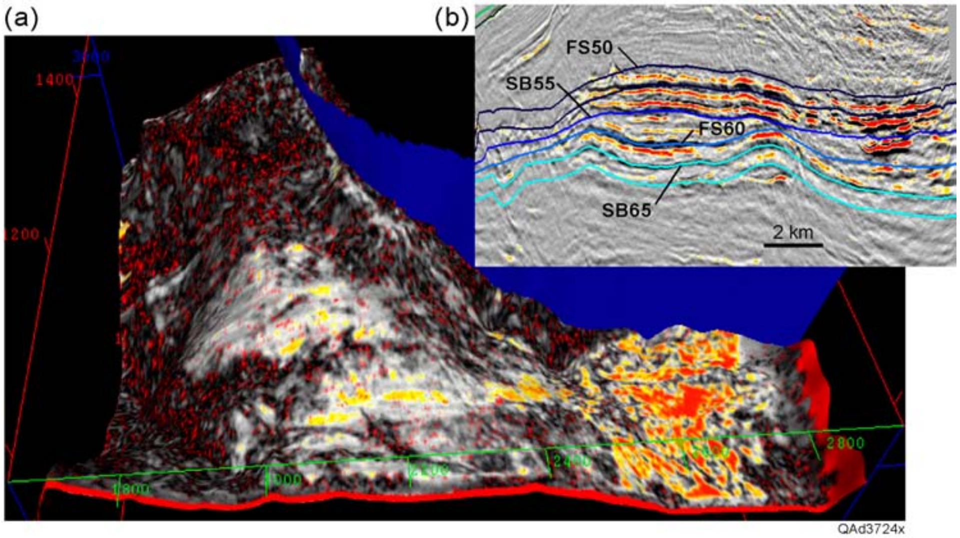

Figure 4. (a) Absolute-amplitude map extracted from flattened volume within the middle Miocene between SB65 and FS50, showing limits of fan at south part of Lankahuasa survey. (b) Seismic line 1100, showing fan deposits.