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High-Resolution Seismic Stratigraphy of a Late Pleistocene Submarine Fan Ponded by Salt-Withdrawal Mini-Basins on the Gulf of Mexico Continental Slope

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Abstract

The late Pleistocene Brazos-Trinity Fan, a structurally ponded fan completely exposed and undisturbed on the seafloor, was mapped with a combination of conventional and high-resolution seismic data. This fan occupies three salt-withdrawal mini-basins (I, II, IV) and a graben (III), each filled with an onlapping package consisting of alternating bedded and non-bedded units evident on high-resolution data. Basins I-III are filled to their topographic spill points; the onlap-fill succession of each is incised by a channel system which bypassed sediment to the next basin(s) downdip. Seismic continuity generally increases distally in the system and within individual basins, believed to reflect the increasing prevalence of turbidity currents over high-density sediment gravity flows.

Introduction

A late Pleistocene submarine fan system linked to a shelf-margin delta of the Brazos and Trinity Rivers (**Fig. 1**) was ponded on the upper Texas continental slope during the last glacio-eustatic lowstand of sea level by three salt-withdrawal mini-basins (**Fig. 2, 3**). Such ponded fan systems are abundant in the subsurface of the Gulf of Mexico continental slope, but only the Brazos-Trinity fan is still exposed intact on the seafloor. Shell Development Company and Shell Offshore, Inc. conducted a high-resolution seismic stratigraphic study of the Brazos-Trinity fan to provide an analog for more deeply buried and less well-imaged ponded fans.

The Brazos-Trinity fan was previously recognized by Gardiner[1] and Satterfield and Behrens[2] on the basis of seafloor fan channels seen on seismic profiles. Earlier studies[3,4] had depicted this system simply as chaotic fill, similar to the chaotic facies comprising the East Breaks Slide[5,6] associated with the late Pleistocene Colorado River and shelf-margin delta (**Fig. 1**). Published seafloor maps[7,8,9] are insufficiently detailed to show these channels, but they are apparent on recent NOAA multibeam data (**Fig. 4**).

Paleogeography of the eastern Texas continental shelf and slope during the last glacio-eustatic lowering of sea level was compiled from several sources[2,3,4,10,11,12,13,14] and summarized in **Fig. 1**. From the Ingleside strandline of the preceding highstand[11], the shoreline migrated 75-200 miles southward to the shelf edge. The Trinity, Neches, Sabine, and Calcasieu (not shown) Rivers became entrenched and joined on the inner shelf to form a single river which extended southward toward the shelf margin[12]. Near the shelf margin, this "greater Trinity" river was joined by the Brazos River[14]. This combined river system ultimately built a deltaic complex at the shelf margin[3,4,10,13,14]. Suter and Berryhill[10] mapped two discrete shelf-margin deltas ("A" and "B" in **Fig. 1**), whereas this study recognized a single, continuous shelf-margin delta complex whose maximum progradational extent occurs at the head of the Brazos-Trinity fan system (**Fig. 1**).

Prior to high-resolution seismic acquisition, gross features of the fan system Fig. 3) were mapped using conventional 2D seismic profiles (**Fig. 5, 6**). Basins I, II, and IV are typical bowl-shaped salt-withdrawal basins, while Basin III is a graben. Basins I, II, and III are each filled to their bathymetric spill points with onlap-fill sequences. Each of these onlap-fill packages is incised by a surface channel system which bypassed sediment to the next basin(s) downslope. In contrast, Basin IV is only partly filled with an onlap-fill sequence and represents the ultimate terminus for the surface channel complex. Basin V is a sediment-starved basin south of Basin IV, from which it is separated by a 1500-ft high ridge (**Fig. 7**). In addition to these fan components, a chaotic slide extends southwest from the shelf-margin delta along strike from Basin I (**Fig. 1**).

Data Acquisition and Processing

Approximately 800 miles of high-resolution seismic data were acquired in 2000 ft x 4000 ft grids in Basins II, II, and IV and in a sparser grid in Basin I. Grids were oriented to optimize migration of surface channels as mapped from conventional 2-D data. Data were acquired using the Tricluster-80 array acquisition system of SeaScan, Inc., which employs a center-weighted array of 8 10-in^3 sleeve guns synchronized with an Aircon control module. Twenty-four channels were recorded at a cable depth of 10 ft with a maximum source-receiver offset of 2469 ft. However, due to excellent signal/noise obtained under near-calm conditions, the optimum stack was obtained using only the near 6 channels, recorded 1/4 msec, with a maximum offset of 265 ft. Data were depulsed based on independent source signature measurements, followed by adaptive deconvolution. Based on preliminary tests, the best quality migration was obtained with a constant-velocity frequency-domain (k-f) algorithm using water velocity, which is valid for this combination of deep water, shallow depth of investigation, and low-velocity sediments.

Frequency content in the upper 200 msec below the water bottom is typically in the range of 100-500 Hz (**Fig. 8, 9**), an order of magnitude higher than with conventional seismic data. High-resolution data were less useful than conventional data only in the deeper part of Basin I (**Fig. 6**), where a combination of thick basin fill and out-of-plane scattering of seismic energy by chaotic stratigraphy resulted in inadequate signal/noise. Within the onlap-fill sequences that comprise the Brazos-Trinity fan, high-resolution seismic data made it possible to differentiate chaotic and layered facies and to resolve the internal geometry of layered facies, including levees, fanlobes, and basin-margin onlap.

Description

Surface Channels. Surface channels in the Brazos-Trinity fan are first evident on NOAA multibeam data at a water depth of ~1000 ft (**Fig. 4**), and become mappable on 2D seismic data at ~1500 ft (**Fig. 2**). In the updip part of Basin I, they constitute an anastamosing complex of moderately sinuous, low-relief channels without levees (**Fig. 4**). Farther downslope in Basin I they coalesce to form a single, increasingly incised channel with low sinuousity and scalloped walls (**Fig. 4**). At the southern end of Basin I, additional tributaries enter from either side, resulting in considerable dissection at the seafloor (**Fig. 3**).

About one mile down the slope between Basins I and II, the single channel becomes shallow again and begins to develop levees. Levees flank the channel until it turns abruptly to the southeast to drop into Basin III. Again, it becomes deeply incised and tributary channels join it from either side. Levees are again present between the two facing fault scarps that define Basin III (**Fig. 3**).

The channel continues down the slope to Basin IV, developing a levee on only the west side as it enters the basin. It changes morphology rapidly to a complex of low-relief channels which are difficult to map even with closely-spaced seismic profiles. The mapped channels probably include the most recently active distributaries for the terminal lobe of the fan system, and possibly remnants of slightly older channels that have been partly buried. A second channel (West Channel) connects Basins II and IV. It originates in the subsurface of the Basin II onlap-fill, and debouches in the subsurface of Basin IV.

In summary, the surface channel complex begins as multiple shallow channels at or near the shelf edge. These coalesce in a tributary pattern into a single channel, which alternately deepens and shallows before reaching its termination as shallow, ephemeral, distributary channels on the fanlobes of Basin IV. The tributary style of multiple small feeder channels seen in Basin I contrasts with the more conventional notion that submarine fans are sourced from single submarine canyons deeply incised at the shelf edge. However, there are modern analogs for this style of feeder system in the modern Homathko and Klinaklini deltas[15]. The Homathko delta contributes to active turbidite sedimentation on the floor of Bute Inlet[16] via several shallow channels which originate at the delta front, coalesce, and deepen downslope[15].

Basin I. This basin contains both shelf-margin delta and upper slope deposits. In the northern part of the basin oblique clinoforms grade downdip into a choatic facies (**Fig. 6**). Farther to the south seismic continuity increases again and coherent reflections onlap the mini-basin margin. The onlap surface defines the base of the ponded seismic sequence. The basal sequence boundary is underlain by high-continuity hemipelagic sediments that extend up the basin flanks and are readily apparent on high-resolution profiles. The chaotic facies in the northern part of the basin can be resolved in places into updip listric normal faults and downdip thrust faults, with a detachment surface cutting down through the base of the sequence. Disturbance by slumping, together with a strong water-bottom multiple (**Fig. 6**), precludes recognition of the sequence base in the northern part of the basin and beneath part of the delta (**Fig. 3, 6, 7**). The surface channel complex described in the previous section is incised into the top of Basin I onlap fill.

Basins II & III. The channel system that originates in Basin I extends across Basins II and III. In Basins II and III the channel is slightly sinuous (**Fig. 4**)and flanked by levees which grade laterally into overbank deposits (**Fig. 8**). Piston cores described by Satterfield and Behrens[2] indicate the presence of sparse, thin sand beds in this unit. Below the levee deposits in Basins II and III are alternating bedded and chaotic to transparent deposits, evident only on high-resolution seismic data (**Fig. 8**). Core and log data acquired during this study indicate that the bedded deposits are more sand-prone, including both massive amalgamated sands and interbedded sand and mud. The chaotic/transparent zones are tabular and span the width of the basin; in cores they are heterolithic and internally deformed. Basin flanks consist entirely of dipping, undeformed hemipelagic strata of essentially constant thickness (**Fig. 8**) Therefore, the only plausible source for the onlap fill is the single feeder channel from Basin I. Both layered and chaotic facies in the onlap fill are believed to be sourced from the shelf margin.

Basin IV. The eastern channel from Basins II and III debouches in a fan with low-relief channels at the northern corner of Basin IV (**Fig. 3**). This fan corresponds to the uppermost unit of onlap fill, which thins toward the south (**Fig. 9,10**). In the northern part of the basin this upper unit is characterized by moderately continuous, subparallel reflectionss, similar to the more sand-prone facies in Basin II, and interpreted as fanlobe deposits. This unit grades southward into a very continuous, parallel-bedded facies which onlaps the basin margins, and is interpreted as outer fan deposits (**Fig. 9,10**).

An underlying unit of alternating layered and transparent to chaotic facies (**Fig. 9**) appears to be sourced from the West Channel, based on structure, isopach, and facies mapping. Below that are chaotic and layered facies ("Pre-fan" in **Fig. 9**) whose distribution indicates a source from the oversteepened eastern flank of the basin (**Fig. 3**). As in Basin II, the entire onlap-fill unit and basin flanks are underlain by hemipelagic deposits of essentially constant thickness, geometry, and reflection character.

Basin V. This is a deep intraslope basin with steep, deformed flanks. In contrast to Basin IV, access by downslope sediment transport from the shelf margin is blocked by a high sill (**Fig. 7**). On high-resolution seismic profiles, onlap fill in this basin consists mostly of chaotic units with hummocky tops, interpreted as slump masses derived from the basin flanks. A layered seismic facies occurs at the surface in the very center of the basin. E. W. Behrens (1990, personal communication) reported that piston cores obtained from the hummocky chaotic facies consist of distorted mud and mud-pebble conglomerate, while a single core obtained from the layered facies contains graded beds of mud and foraminiferal sand. These observations indicate that near-surface onlap fill in Basin V is entirely of local derivation.

Discussion

This study demonstrates that submarine fans on the Gulf of Mexico slope can consist of isolated bodies of sediment-gravity-flow deposits completely encased in hemipelagic deposits. Feeder/bypass channels for these isolated sedimentary bodies can be fairly small, in this case 1000-2000 ft wide. On the uppermost slope, feeder channels for a single fan system can be numerous but small, shallow, and anastamosing (**Fig. 4**), virtually precluding recognition in the subsurface. Single channels incised deeply into onlap fill are much more likely to be detected seismically after deep burial.

The Brazos-Trinity fan contains the expected components of a fine-grained submarine fan, including incised feeder channels, aggradational channel-levee complexes, fanlobes with shallow, ephemeral channels, and a smooth outer fan. Overall, it lacks a true fan morphology due to the influence of pre-existing high-relief topography, which is in turn structurally contolled. In the upper unit of the fan system (**Fig. 10**), the channel-levee complex is mostly detached from the fanlobe and outer fan facies because of this structural/topographic control. During the life of such a ponded fan system, the distribution of these components may shift suddenly as basins overtop their topographic spill points and switch locally from aggradation to incision and bypass. Repeated adjustments of channel grade and base level can occur independently of sea-level control.

In the Brazos-Trinity fan, onlap-fill in Basin I either predates or is contemporaneous with progradation of the shelf-margin delta (**Fig. 6**), although the actual feeder channels have not been identified. On the other hand, onlap-fill deposits in the downdip basins were supplied by the surface channel system which developed at or near the end of progradation (**Fig. 4,6**). On the whole, the timing of fan deposition is indistinguishable stratigraphically from the timing of deltaic progradation. Quite possibly, deposition of the entire fan was contemporaneous with deltaic sedimentation, similar to the modern Homathko Delta-Bute Inlet system[15,16].

Despite many local complexities, the Brazos-Trinity fan displays an overall, large-scale trend revealed by high-resolution seismic data: internal continuity increases distally, both within individual basins and on the scale of the fan system as a whole (**Fig. 11**). This can be attributed to the relative influence of turbidity currents (which create bedded onlap fill) and higher-density mass flows such as slides, slumps, and slurries (which create more chaotic or nonreflective onlap fill). Turbidity currents become more prevalent at the expense of other sediment gravity flow deposits with increasing distance from the shelf edge. Exceptions to this pattern occur where sediment is derived from oversteepened basin flanks, as on the eastern margin of Basin IV and sediment-starved basins such as Basin V.

Acknowledgments

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SI Metric Conversion Factors

ft x 3.048 E-01 = m
mi x 1.609344 E+00 = km
in^3 x 6.102374 E-02 = cm^3

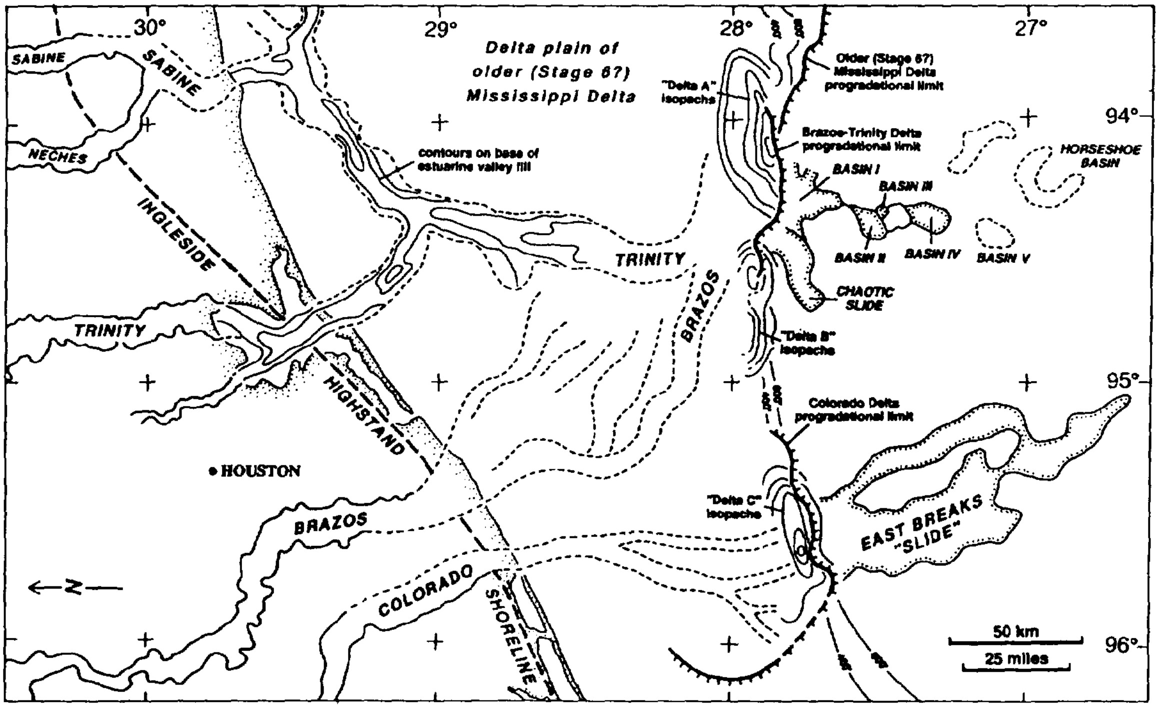

Fig. 1.--Paleogeographic features of offshore eastern Texas associated with last Pleistocene lowering of sea level. Compiled from Ref. 2,3,4,5,10,11,12,13,14. Deltas A-C from Ref. 10; valley fill contours from Ref. 12.

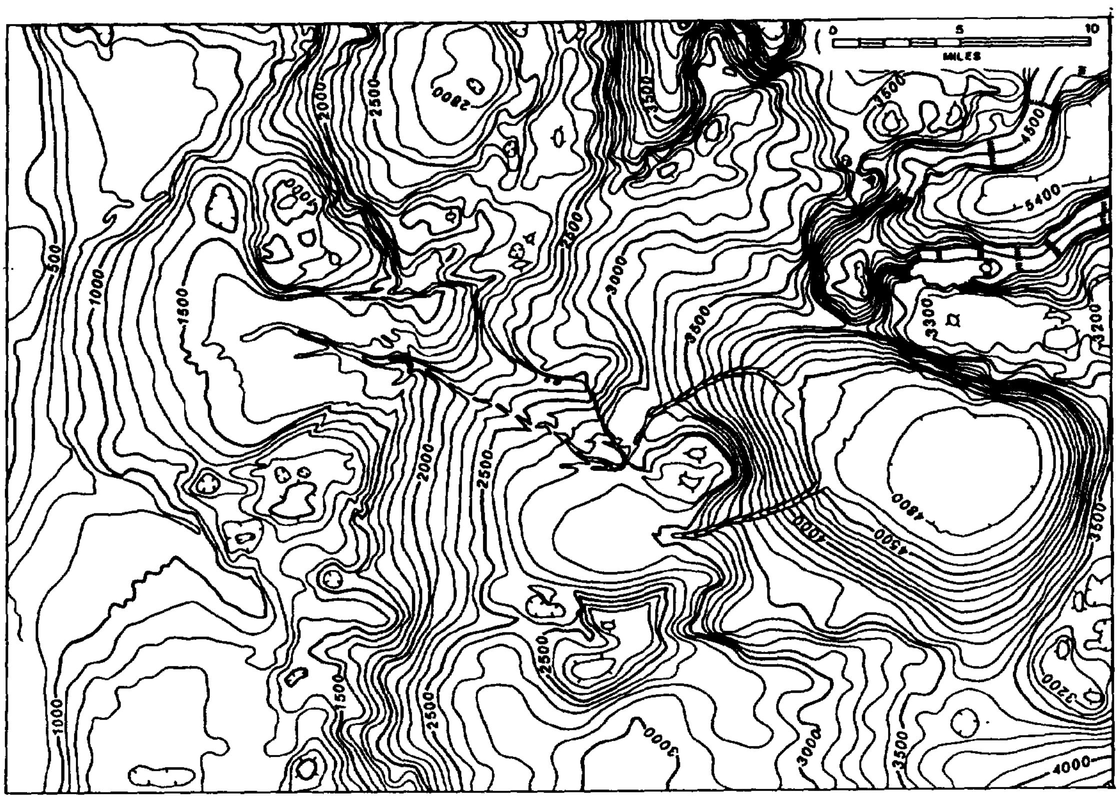

Fig. 2.--Bathymetric map of the study area, hand-contoured from 2-D seismic water-bottom picks. Contour Interval = 100 ft.

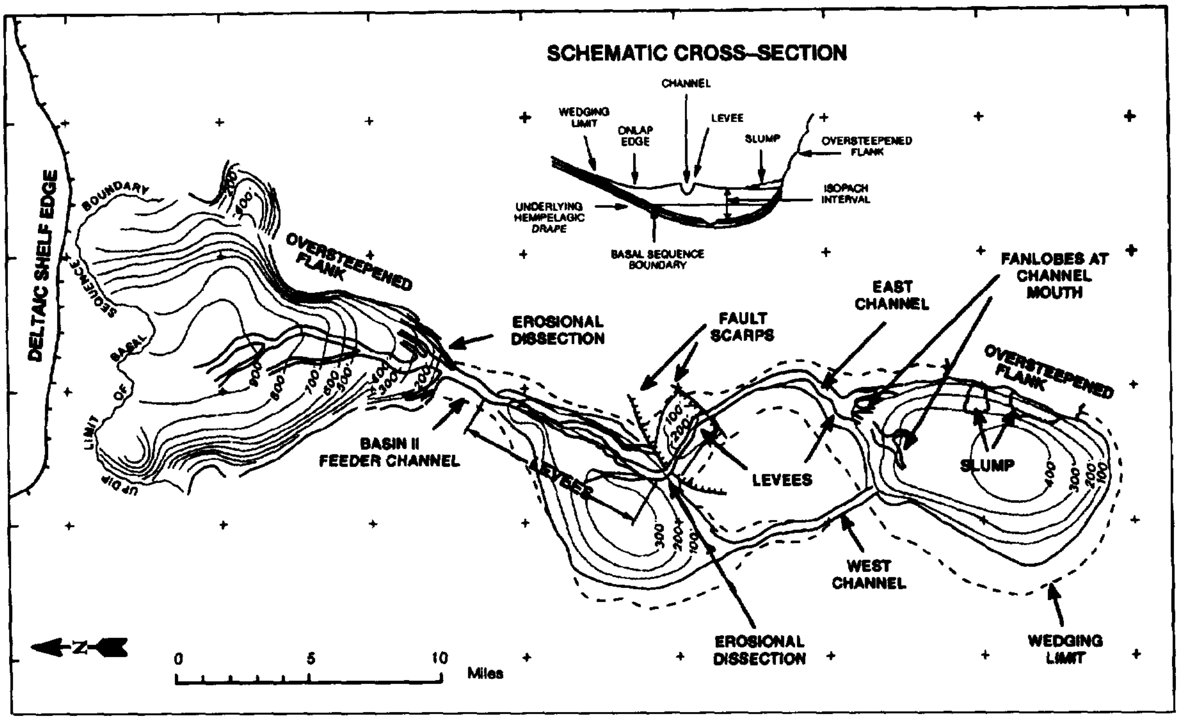

Fig. 3.--Isopach map and seismic-stratigraphic features of the Brazos-Trinity Fan.

Fig. 4.--Rendered seafloor map generated from NOAA multibeam data, showing details of fan channels in Basin I (left) and Basin II (right). Illumination from west (below). Contour interval = 200 ft.

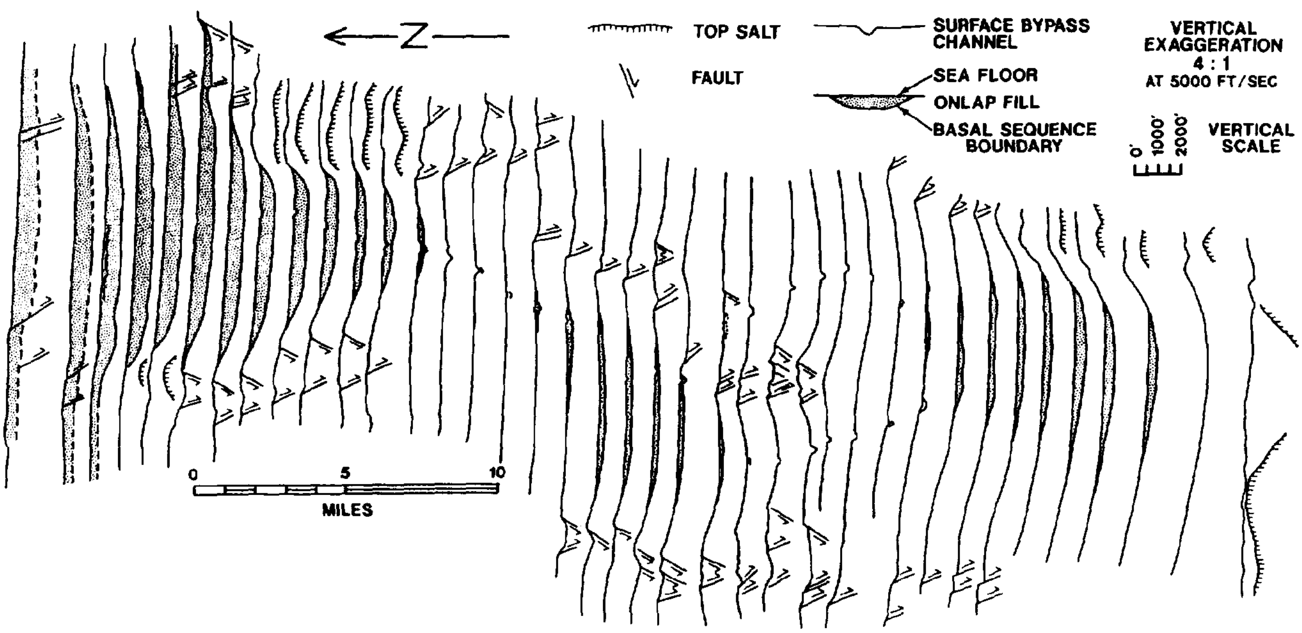

Fig. 5.–Tracings of east-west seismic profiles (conventional 2-D) spaced one mile apart, illustrating external geometry of the Brazos-Trinity fan in Basins I (left), II (center) and IV (right), in relation to faults and shallow salt.

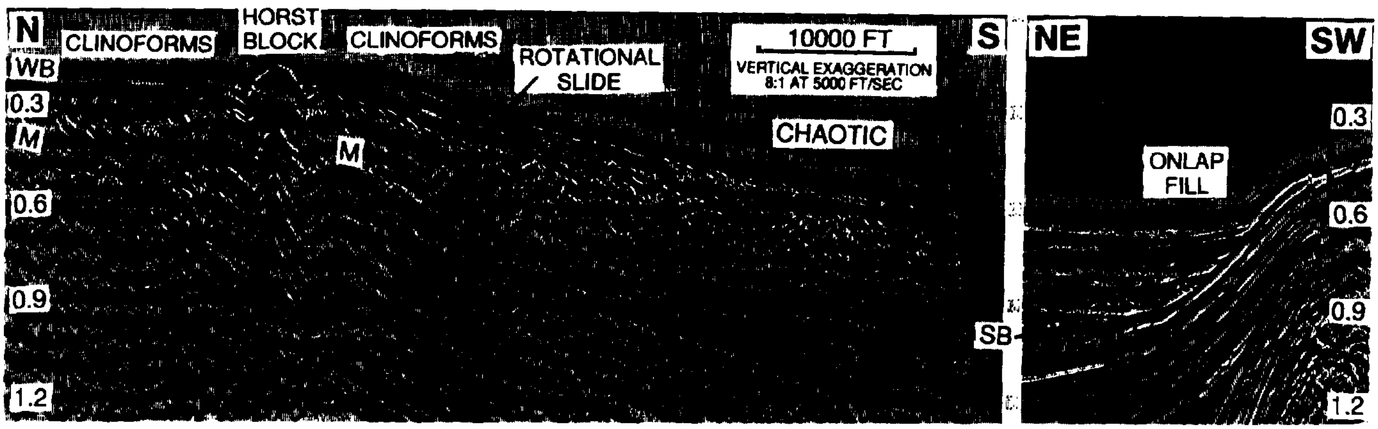

Fig. 6.–Composite conventional seismic dip profile of Basin I. WB=water bottom; M=water-bottom multiple; SB=basal sequence boundary.

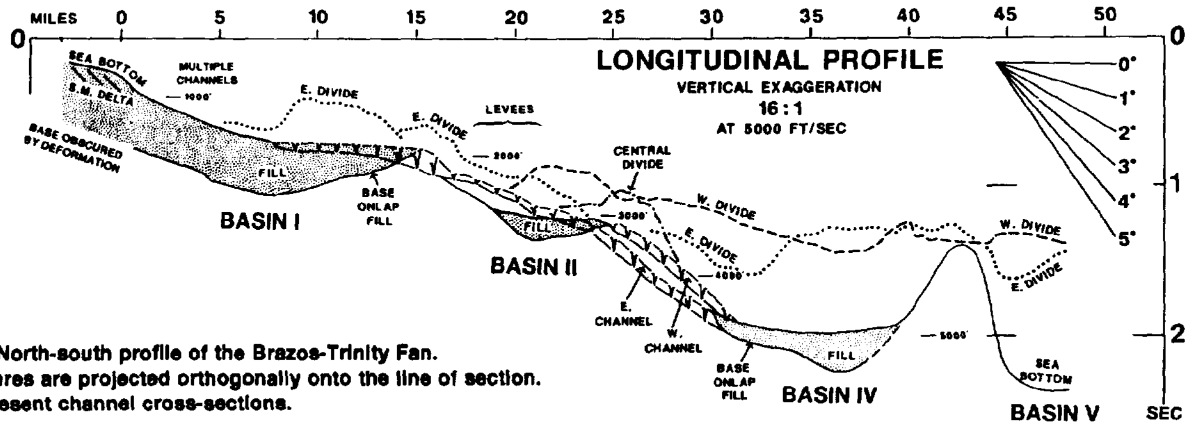

Fig. 7.–North-south profile of the Brazos-Trinity Fan. All features are projected orthogonally onto the line of section. V's represent channel cross-sections.

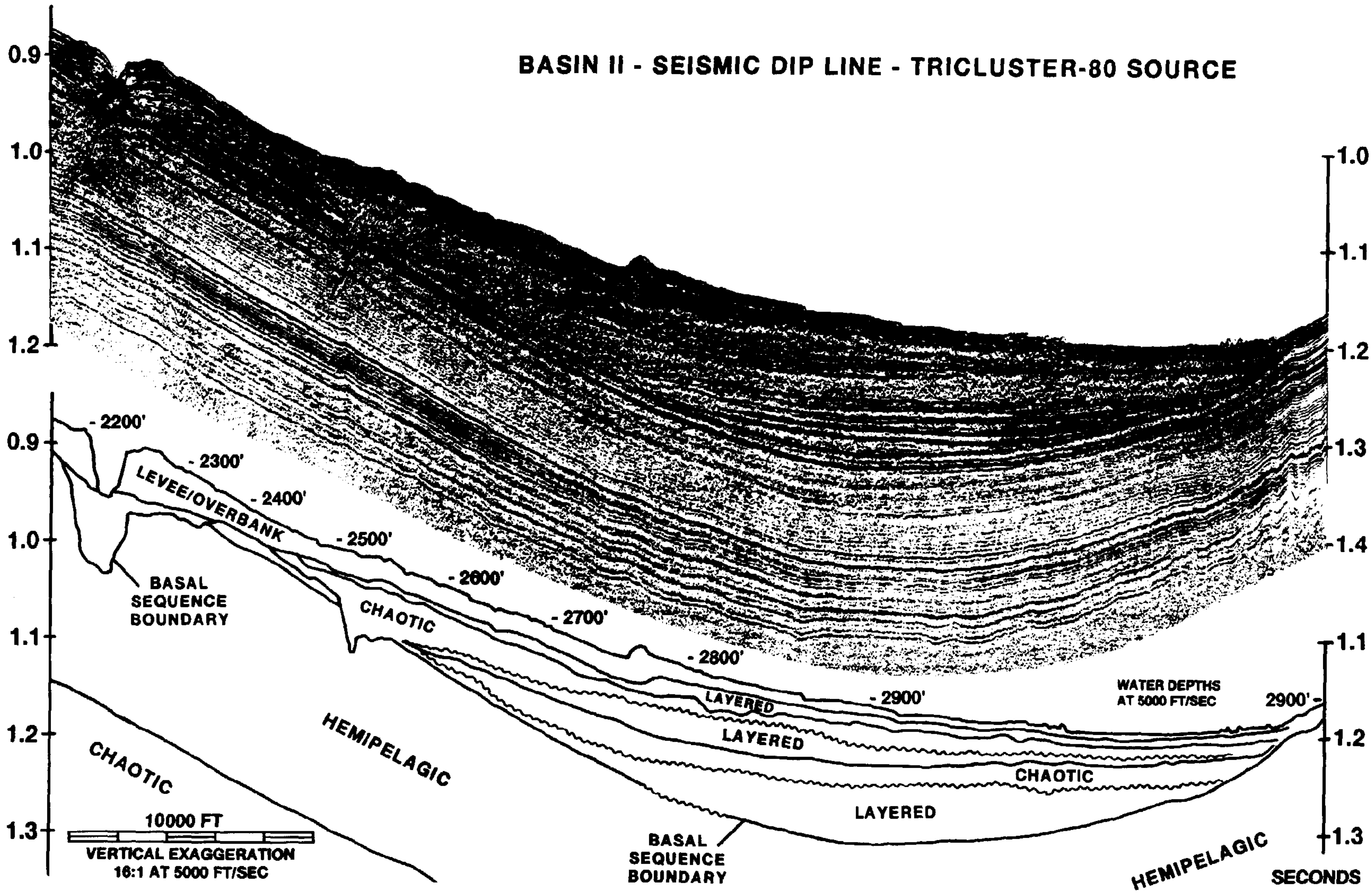

Fig. 8.—High-resolution seismic dip profile of Basin II, showing differentiation of major seismic facies. The levee-overbank unit is depicted in Fig. 10.

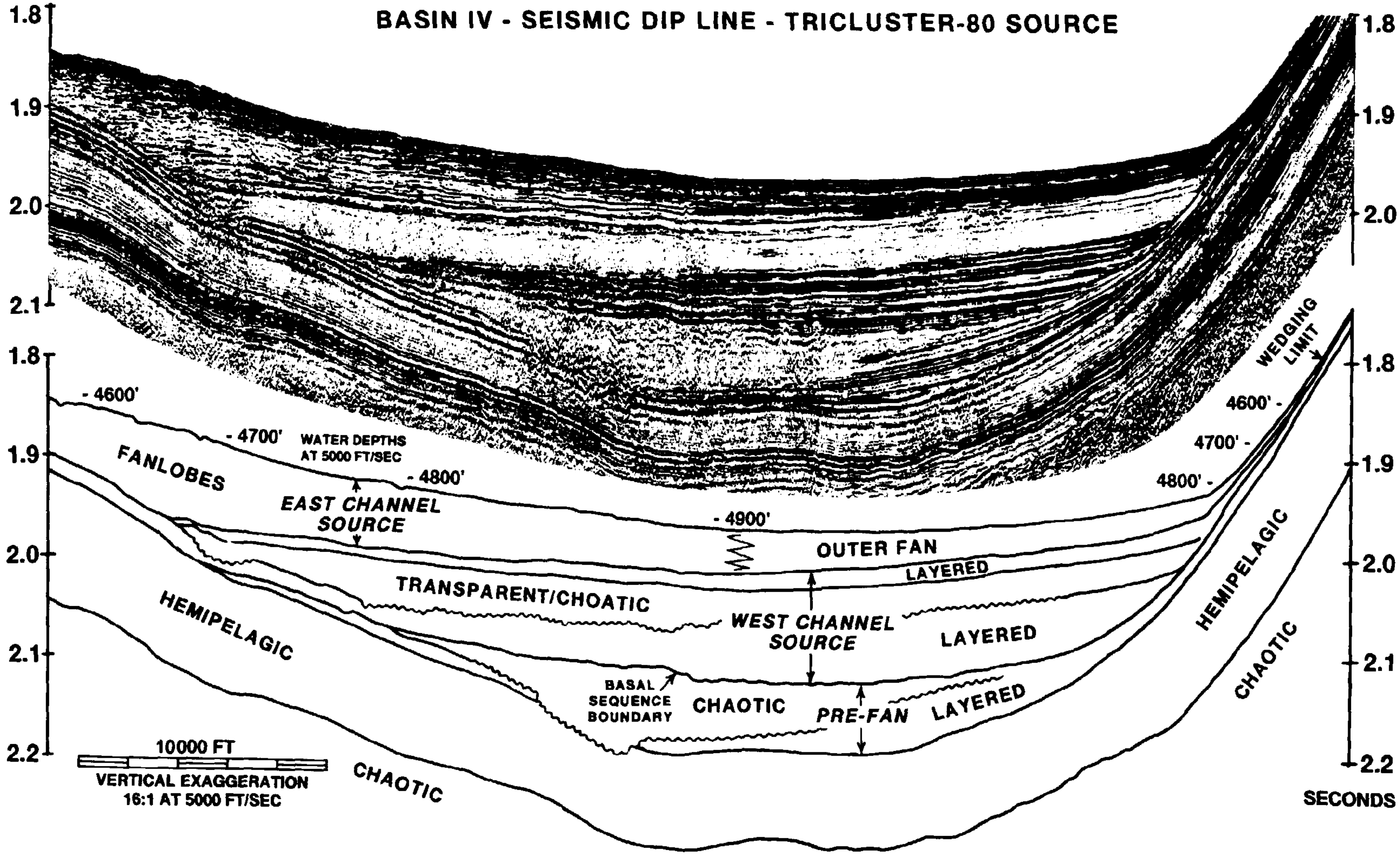

Fig. 9.--High-resolution seismic dip profile of Basin IV, showing differentiation of major seismic facies. Units are defined on the basis of apparent source area; "pre-fan" was probably derived from eastern basin flank. Fanlobe and outer fan facies from the "East Channel source" unit are depicted in Fig. 10

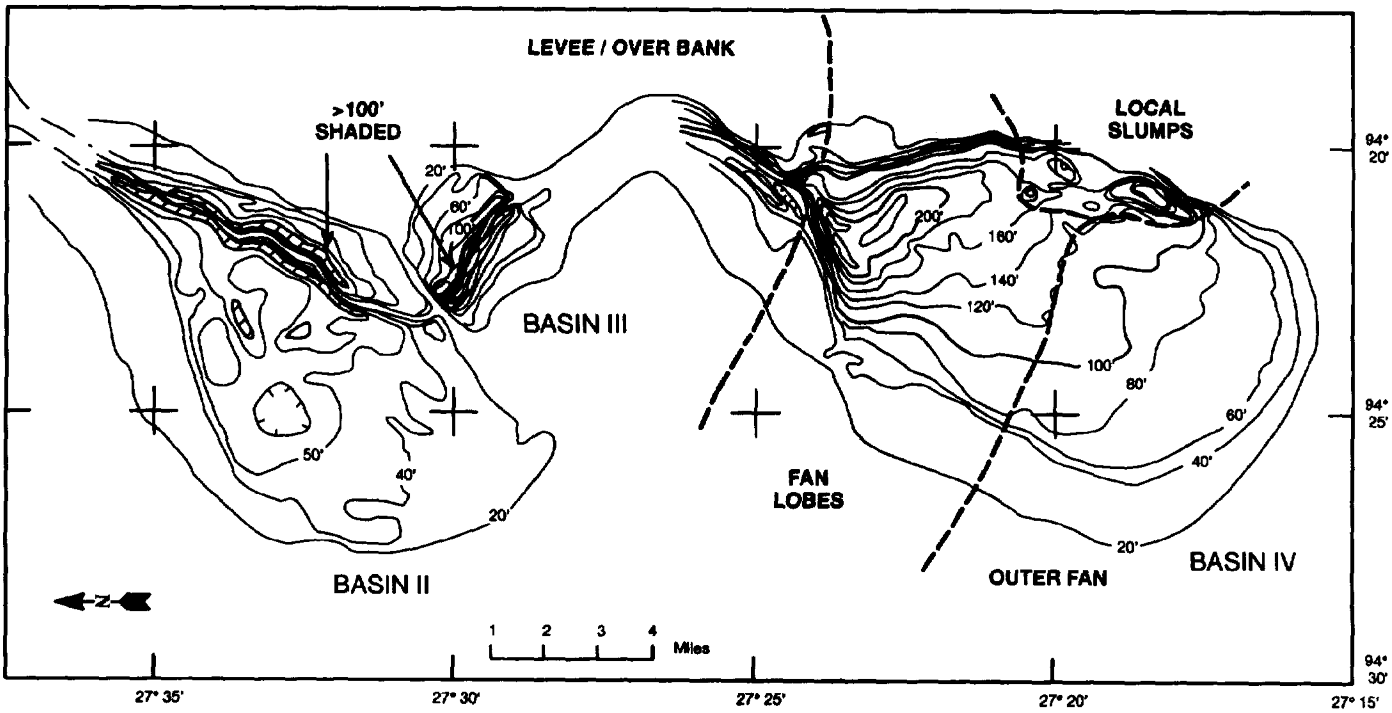

Fig. 10.--Isopach map of the uppermost unit in the Brazos-Trinity Fan (levee/overbank in Fig. 8; fanlobes and outer fan in Fig. 9).

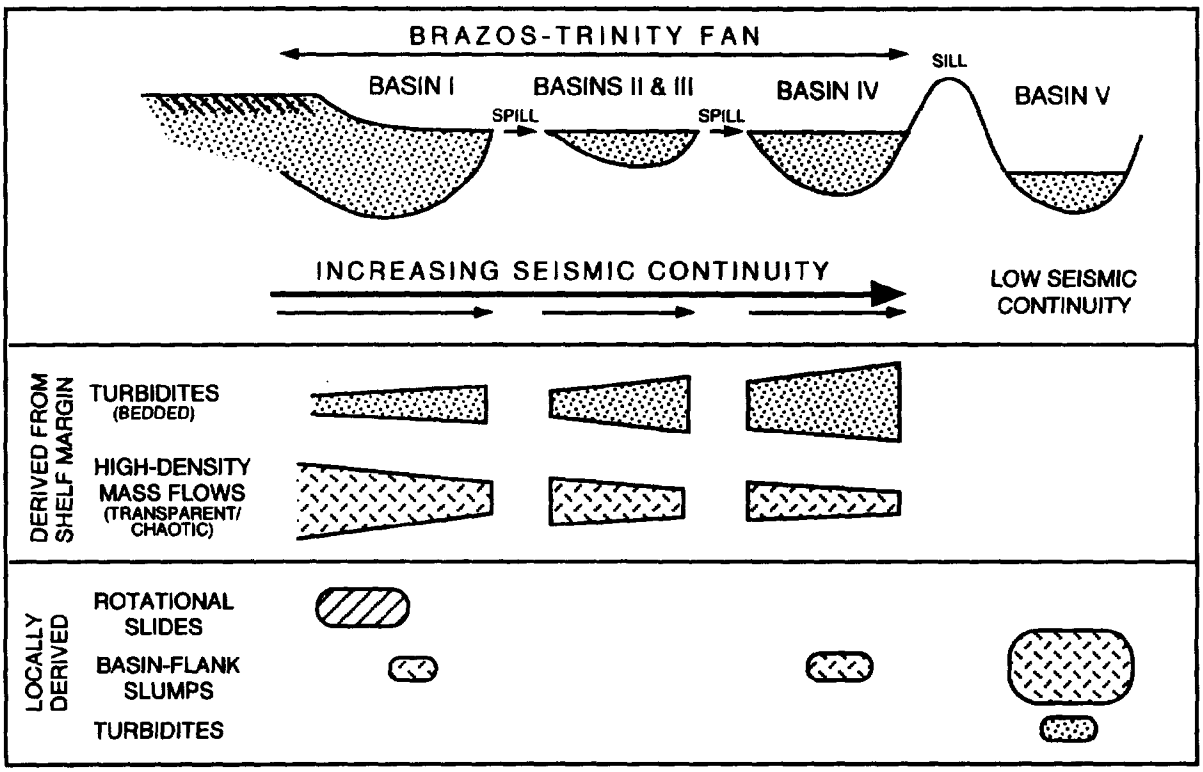

Fig. 11.--Conceptual model for distribution and relative importance of various types of sediment gravity flows in the Brazos-Trinity Fan.