Report of Investigations No. 152

DEPOSITIONAL SYSTEMS AND OIL AND GAS PLAYS IN THE CRETACEOUS OLMOS FORMATION, SOUTH TEXAS

Noel Tyler
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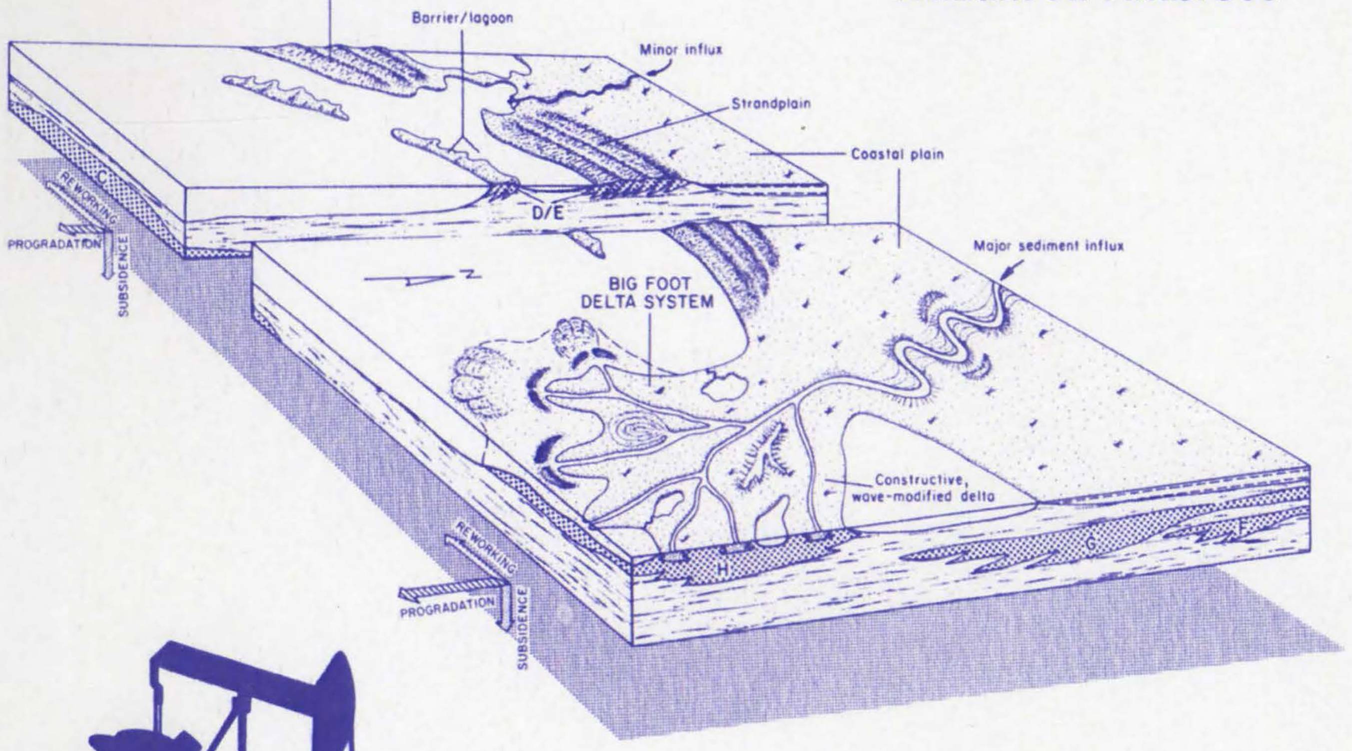

1986

BUREAU OF ECONOMIC GEOLOGY
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Plate 1 (in pocket)

ABSTRACT

The Upper Cretaceous Olmos Formation in South Texas continues to be an active exploration target 60 years after oil was first discovered in this clastic assemblage. The shallow, oil-bearing formation was deposited on a broad, wave-influenced shelf. Sand accumulated in two depocenters. Initial deposition took place in a western depocenter during an early phase of wave-dominated deltaic sedimentation. Deposition of the strike-elongate delta preceded two cycles of high-constructive deltaic deposition, during which time sediments prograded seaward over the Lower Cretaceous shelf edge. These three deltaic complexes together compose the Catarina delta system. The focus of sedimentation then shifted eastward to the Big Foot delta system, where again wave-dominated deltaic sedimentation was followed by two episodes of high-constructive but wave-modified delta formation. Sands not retained in the Big Foot delta system migrated alongshore to the west, where they formed a thick retrogradational coastal/interdeltaic complex, named the Rocky Creek barrier/strandplain system. Regional uplift with concomitant erosion removed much of the updip facies tracts of the Olmos. This truncated section was then unconformably covered by Escondido shelf mudstones, thereby creating conditions favorable for stratigraphic entrapment of hydrocarbons migrating updip from the deeper basin through permeable deltaic sandstones.

The resulting stratigraphic trap play is the most prolific of the seven oil and gas plays in the Olmos Formation. Six other plays produce oil and gas from a variety of structural traps, but most of the remaining oil production is from the Charlotte Fault Zone. Youthful shelf-edge gas, condensate, and oil plays are highly productive, and together with wildcat prospects further basinward offer the best potential for continued high-level production from this mature province.

KEYWORDS: Maverick Basin, Olmos Formation, Cretaceous, Gulfian, deltas, barrier/strandplains, oil and gas, Charlotte Fault Zone.

INTRODUCTION

The Olmos Formation is one of three Upper Cretaceous (Gulfian) terrigenous clastic wedges deposited in the Maverick Basin of the Rio Grande Embayment in South Texas. In ascending order, the clastic units are the San Miguel Formation, the Olmos Formation, and the Escondido Formation. The San Miguel contains a spectrum of wave-modified and wave-dominated deltaic sandstones (Weise, 1980) as does the Escondido (Pisasale, 1980). In contrast, the Olmos Formation contains a broad range of sandstone facies, including wave-dominated to high-constructive deltaic, barrier/-strandplain, and coastal plain and fluvial deposits.

Although the Olmos Formation has been actively drilled for oil and gas since the mid-1920's, little has been published about the origin and regional distribution of Olmos sandstones. Early papers dealt primarily with oil and gas production (Dunham, 1954; Glover, 1955, 1956). More recent studies focused on local areas in Zavala County (Indest and McPherson, 1983) and Webb and La Salle Counties (Snedden and Kersey, 1982). The present regional study of the Olmos covers an eight-county area in South Texas and includes almost the entire subsurface extent of the formation from outcrop in Maverick County to the Cretaceous shelf edge in Webb and La Salle Counties (fig. 1).

The Olmos Formation is an economically important oil- and gas-bearing unit. In addition to conventional oil and gas fields, the Olmos also contains small deposits of tar and heavy oil and is designated a tight gas formation by the Railroad Commission of Texas.

Structural Framework

The Olmos Formation was deposited in the Maverick Basin, a restricted depression in the Rio Grande Embayment (fig. 2). This embayment probably formed as an aulacogen resulting from the breakup of Pangea during the Triassic (Walper, 1977). Lower Cretaceous sedimentation in the embayment was dominated by carbonate deposition. Continued subsidence accompanied by renewed tectonism in western and northwestern source areas led to sediment influx into the structurally negative area from adjacent highlands.

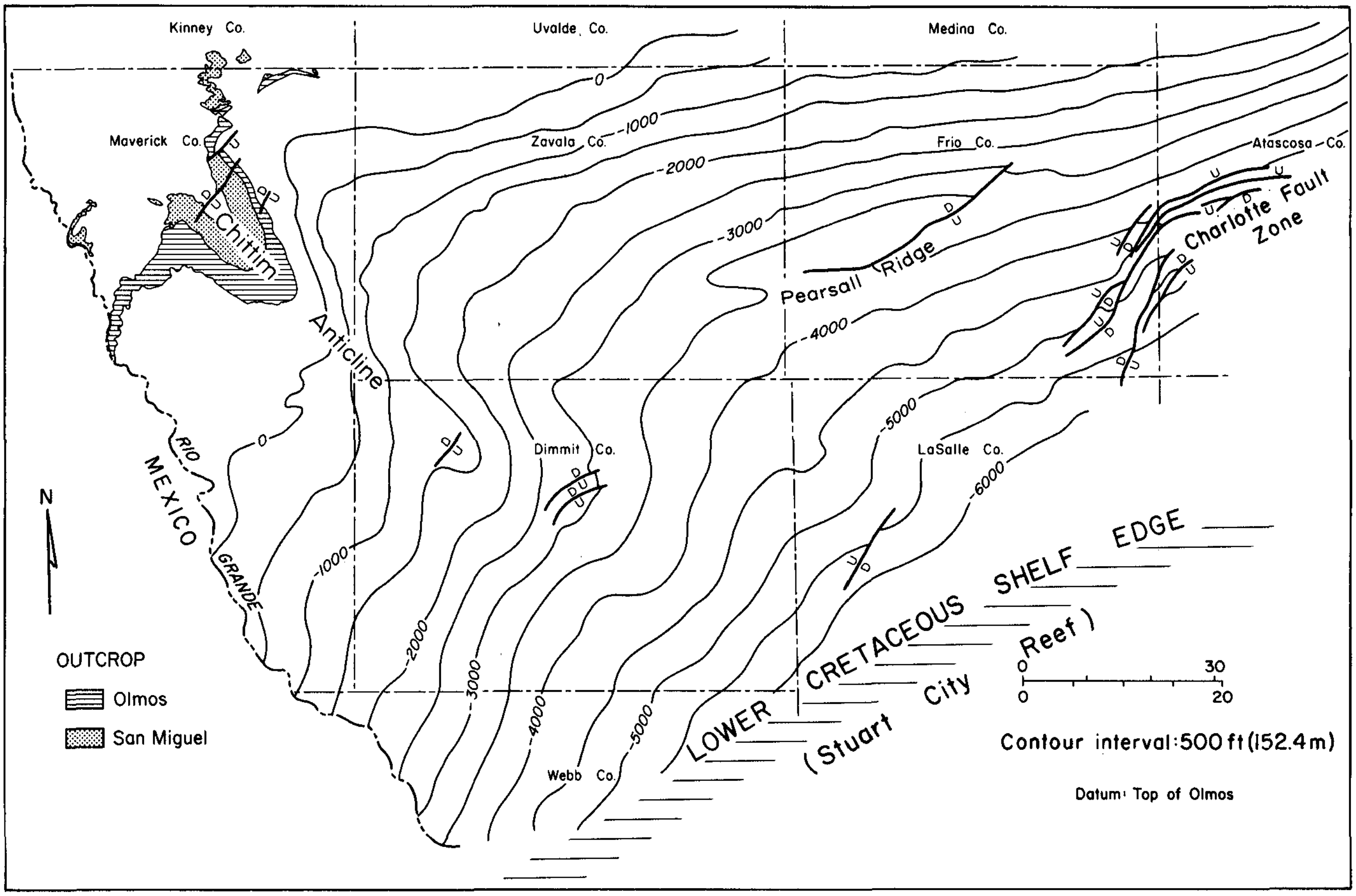

FIGURE 1. Regional structure map of the Maverick Basin contoured on the top of the Olmos Formation. Modified from Weise (1980).

The product of this synsedimentary tectonism is a thickened Upper Cretaceous terrigenous clastic sequence in the Maverick Basin and in other parts of the Rio Grande Embayment (Murray, 1957; Weise, 1980).

The Maverick Basin is bounded to the east by the San Marcos Arch, which acted as a mildly positive structure that subsided at a slower rate than did adjacent basins during Cretaceous sedimentation. To the west, the Salado Arch separates the Maverick Basin from other basins in the Rio Grande Embayment (fig. 2). The Devils River Uplift and Balcones Fault Zone compose the northwestern and northern limits of the basin, respectively. Contours on the map of the Olmos Formation (fig. 1) indicate a regional southeast to east-southeast gulfward dip. Postsedimentation second-order structures affecting the Olmos are the Chittim anticline, which plunges southeastward parallel to dip, and several long-lived fault systems including the Charlotte Fault Zone (fig. 1). Minor faults and folds that are indistinguishable at this scale of mapping are also present in downdip parts of the Olmos. The faults resulted from displacement along the Stuart City shelf margin (Snedden and Kersey, 1982). These structures act as traps for Olmos oil, condensate, and gas.

The Olmos Formation is folded over numerous small basaltic volcanic plugs in the northern Maverick Basin, particularly in Zavala County. Differential compaction and small tensional structures exist over the plugs. Volcanic mounds are the prevalent trap type in the updip San Miguel and Olmos Formations. Postdepositional elevation and erosion of the updip Olmos took place during a depositional hiatus between the end of Olmos sedimentation and the beginning of Escondido deposition. Deeper in the basin, sedimentation was uninterrupted. The Escondido Formation is unconformably superposed over progressively older units of the Olmos and San Miguel toward the northwest (fig. 3).

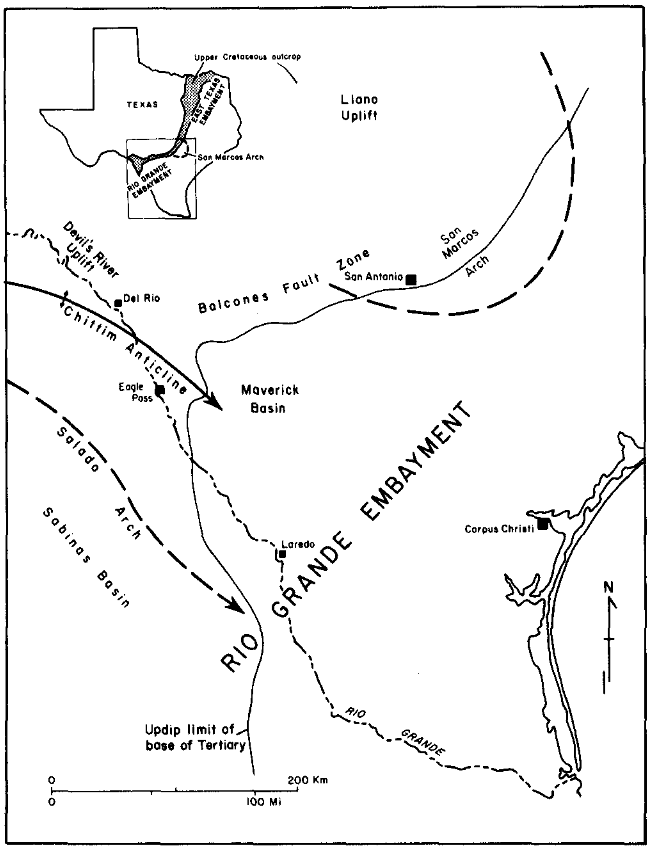

FIGURE 2. Structural framework of the Maverick Basin. From Weise (1980).

Stratigraphy and Depositional Systems

The Late Cretaceous depositional history of South Texas consists of an early phase of carbonate sedimentation followed by terrigenous clastic deposition. Upper Cretaceous sedimentation took place on a broad carbonate platform that existed late in the Early Cretaceous (Comanchean). The shelf edge during this time was marked by the Stuart City Reef (fig. 3), which serves as a useful reference for mapping the overlying sediments. Eagle Ford shelf elastics and carbonates are overlain by the Austin Chalk (fig. 3), which is a laterally extensive open-marine micrite. These carbonate mudstones form the floor upon which Anacacho shoal-water carbonates were deposited updip and Upson clays were deposited downdip (fig. 3). The Anacacho Limestone is a discontinuous carbonate bank composed predominantly of carbonate grainstones. The Anacacho grew as patchy biostromes on igneous intrusive and extrusive mounds. These reefs supplied abundant shell debris that was reworked into coquinoidal shoals and beaches that compose the dominant facies in the Anacacho (Luttrell, 1977; Wilson, 1983). Terrigenous shelf mudstones of the Upson Formation were deposited between and seaward of Anacacho depositional centers.

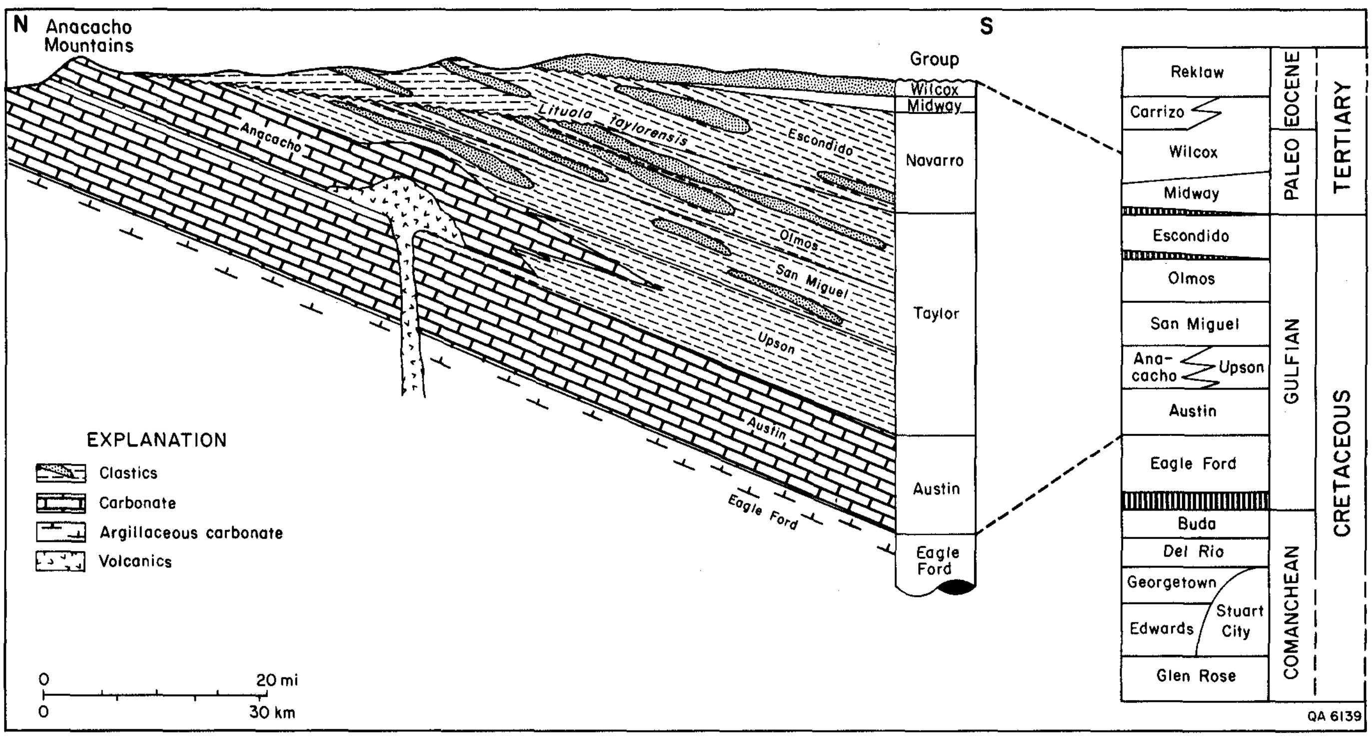

FIGURE 3. Schematic dip section through the Maverick Basin. Modified from Weise (1980) after Spencer (1965).

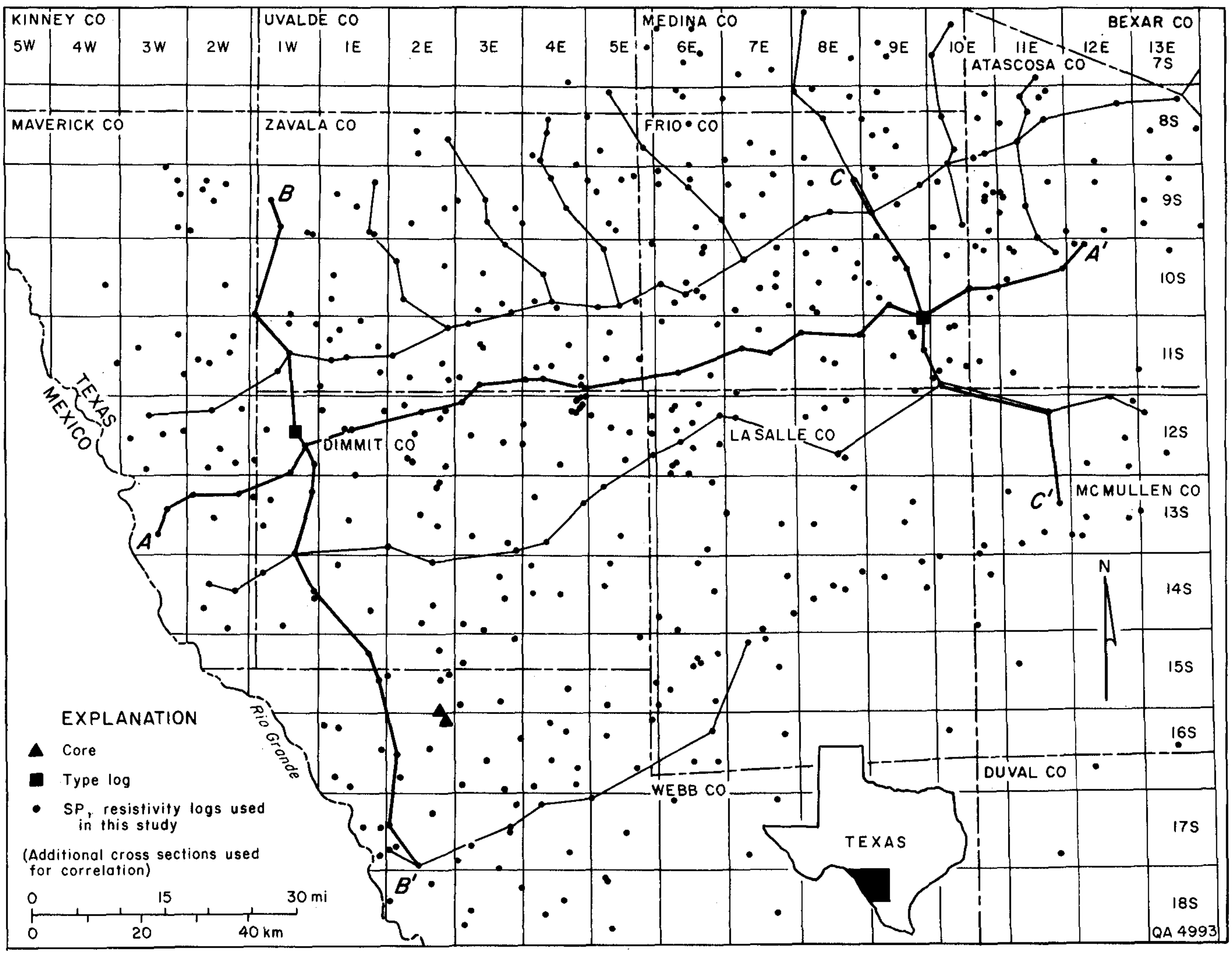

FIGURE 4. Well control and location of type logs and stratigraphic dip and strike sections.

During the latest stages of Cretaceous sedimentation, tectonic activity in the Laramide orogenic belt west and northwest of the Rio Grande Embayment resulted in an influx of terrigenous sediment and basinward progradation of deltaic and associated coastal plain and fluvial systems. Deposition of the San Miguel, Olmos, and Escondido Formations took place on a broad, stable, and shallow shelf. Low rates of sediment input allowed waves and currents to significantly influence the geometries of San Miguel and Escondido deltas. Olmos deposition, in contrast, was largely characterized by higher rates of sedimentation and fluvial dominance and the consequent formation of lobate to elongate delta systems (Tyler, 1983; Ambrose and Tyler, 1984).

Objectives and Methods

The principal objective of this study was to map major depositional units of the Olmos Formation in the Maverick Basin. Approximately 500 electric logs, mostly spontaneous potential (SP) and resistivity curves, were used in preparing 12 stratigraphic cross sections, 4 parallel to depositional strike and 8 parallel to depositional dip (fig. 4). Isopach, sandstone thickness, and percent-sandstone maps depict eight major units, informally named A through H. Whole cores from two wells facilitated detailed rock description, which was then related to SP log response. All eight units, A through H, displayed characteristic SP responses that can be directly related to widespread depositional systems in the Olmos. Hence, the SP curve was useful in determining depositional facies tracts within regional sandstone units. Downdip along the Cretaceous shelf edge, SP response was subdued and therefore useless for sandstone thickness determination and environmental interpretations. The resistivity curve, however, was useful in tracing the subunits downdip in La Salle and McMullen Counties. Synthesis of lithofacies, isopach, and SP-response characteristics facilitated the interpretation of the depositional history of the Olmos Formation.

Two further goals of this study were to relate oil and gas production to depositional systems and to characterize the reservoirs according to play type. Four principal play types account for most of the Olmos hydrocarbon production: (1) stratigraphic traps such as updip sandstone pinch-out against the pre-Escondido unconformity; (2) structural traps associated with the Cretaceous shelf edge, and the Charlotte and smaller updip fault zones; (3) combined structural/stratigraphic traps associated with the Chittim anticline; and (4) traps over volcanic plugs.

REGIONAL SEDIMENTARY PATTERNS OF THE OLMOS FORMATION

The Olmos Formation is a clastic wedge that gradually thickens southward from southernmost Medina and Uvalde Counties, where a partly to completely eroded section underlies the post-Olmos unconformity, to more than 1,000 ft (305 m) in Webb County (fig. 5). Sediments were transported from the north and northwest and deposited in two depocenters (fig. 6). A western depocenter in

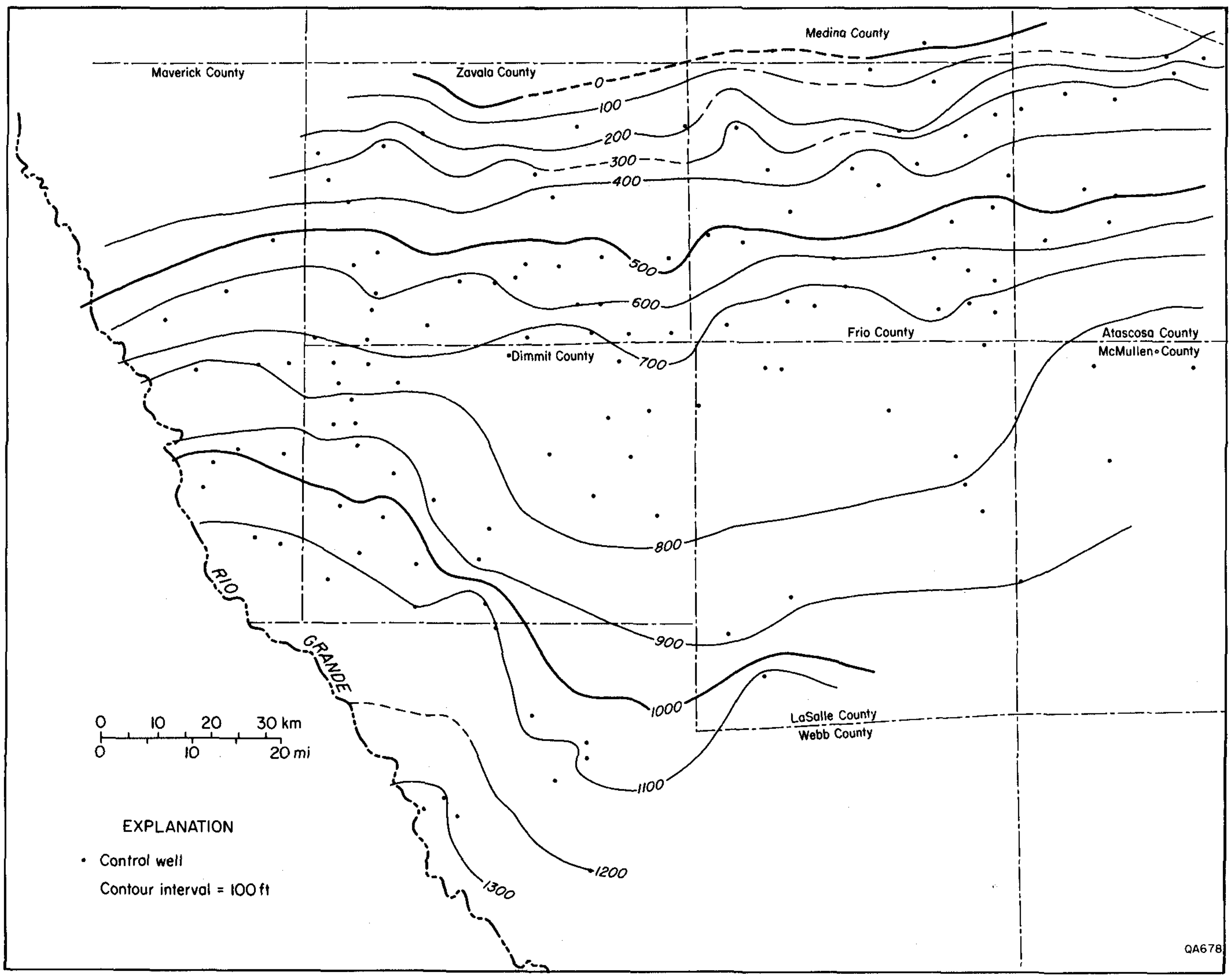

FIGURE 5. Isopach map of the Olmos Formation. The updip parts of the formation are erosionally truncated by a post-Olmos - pre-Escondido unconformity.

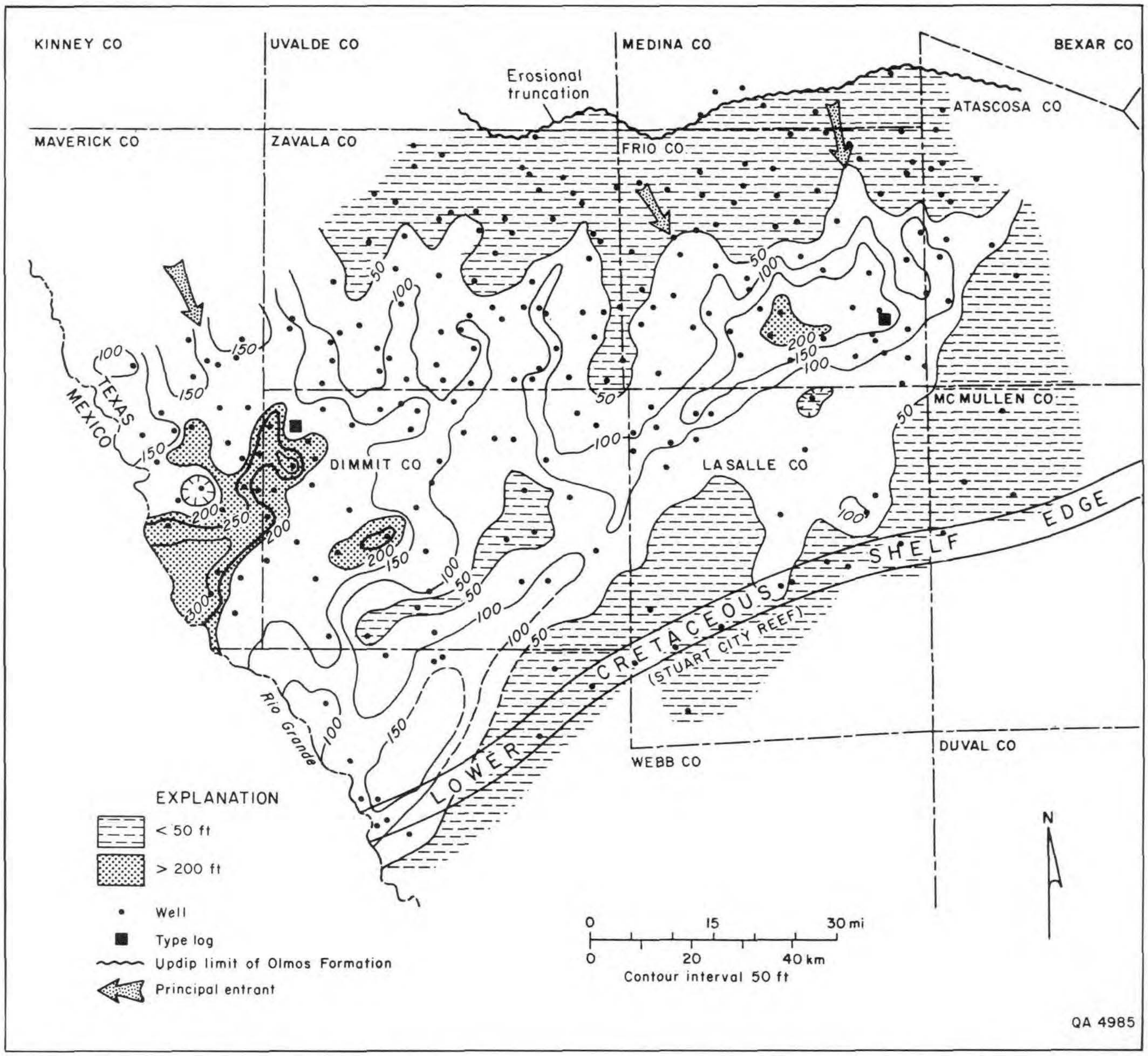

FIGURE 6. Net-sandstone map of the Olmos Formation. Sediments were transported from the north and northwest into an eastern depocenter in Frio County and a western depocenter in Maverick and western Dimmit Counties.

Maverick and Dimmit Counties displays a strike-elongate sand-rich belt containing more than 275 ft (84 m) of sand. In the eastern depocenter in Frio County, as much as 225 ft (69 m) of sand was deposited. More than 150 ft (46 m) of sand accumulated downdip along the Cretaceous shelf edge in Webb County near the present Rio Grande.

Western Depocenter

Five depositional units, A through E, are recognized in the western depocenter. These are informal designations that are not intended to replace older but also informal stratigraphic nomenclature. These units, shown on the type log (fig. 7), are generally less than 150 ft (46 m) thick and are bounded by shale breaks that are traceable across the depocenter (figs. 8 and 9). Electric log responses reflect a succession of delta types (units A, B, and C) and coastal-interdeltaic environments (units D and E). We propose the names Catarina delta system for deltaic units A, B, and C, and Rocky Creek barrier/strandplain system for shore-zone units D and E.

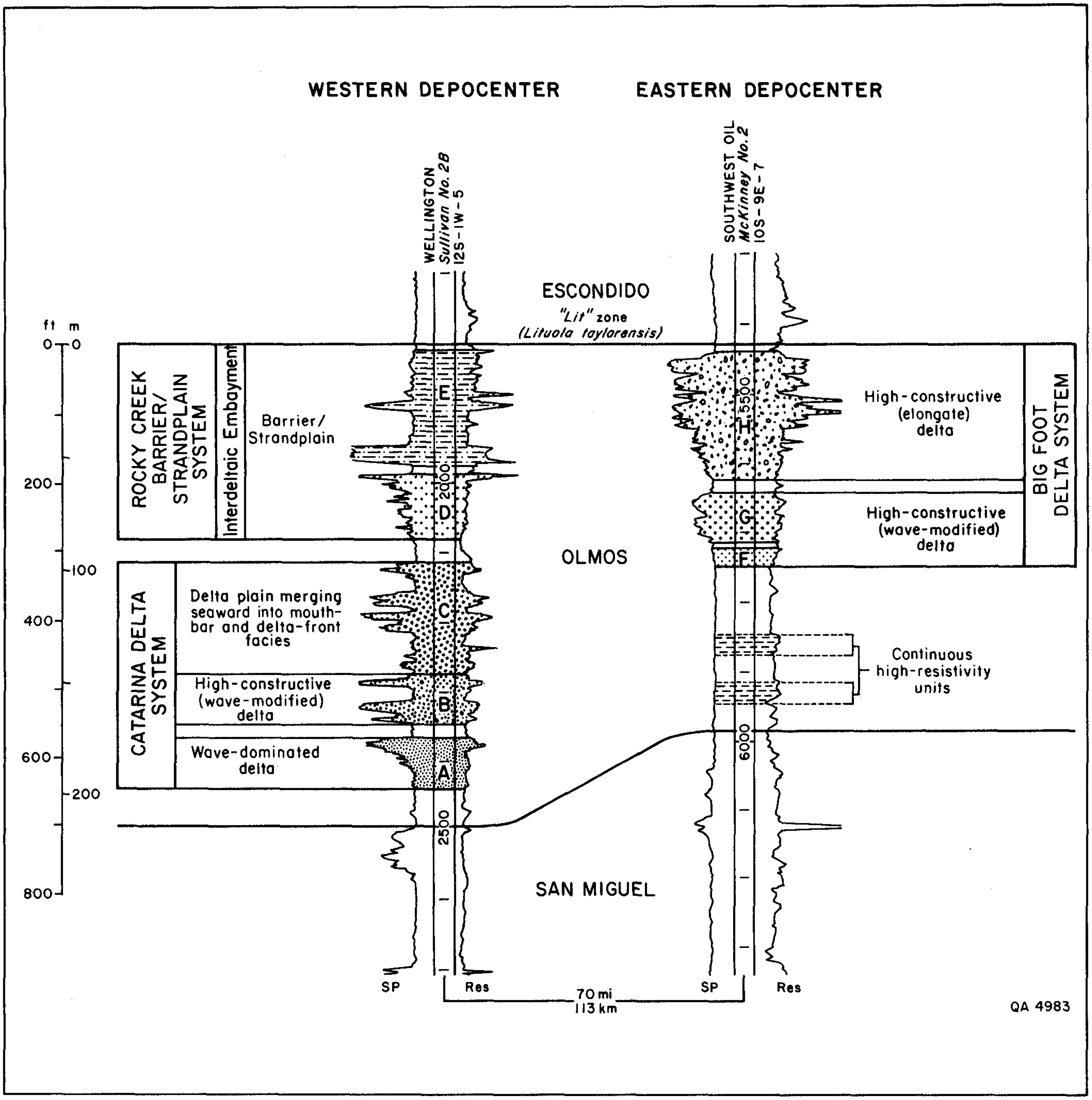

FIGURE 7. Type logs of the Olmos Formation from the eastern and western depocenters. Well locations shown in figure 4.

Eastern Depocenter

Three depositional units (F, G, and H) exist in the eastern depocenter. These units, commonly characterized by simple upward-coarsening SP log responses, are generally thicker (300 ft; 91 m) than those of the western depocenter (fig. 7). On the basis of interfingering relationships with units of the western depocenter (illustrated on stratigraphic strike section A-A′, fig. 8 and plate), units F, G, and H were deposited contemporaneously with units C, D, and E, respectively. We refer to deltaic units F, G, and H collectively as the Big Foot delta system. Two informal units older than unit F recognizable only by resistivity response are traceable across the downdip part of the eastern depocenter (figs. 8 and 10). Because of poor electric log characteristics these units were not studied in detail.

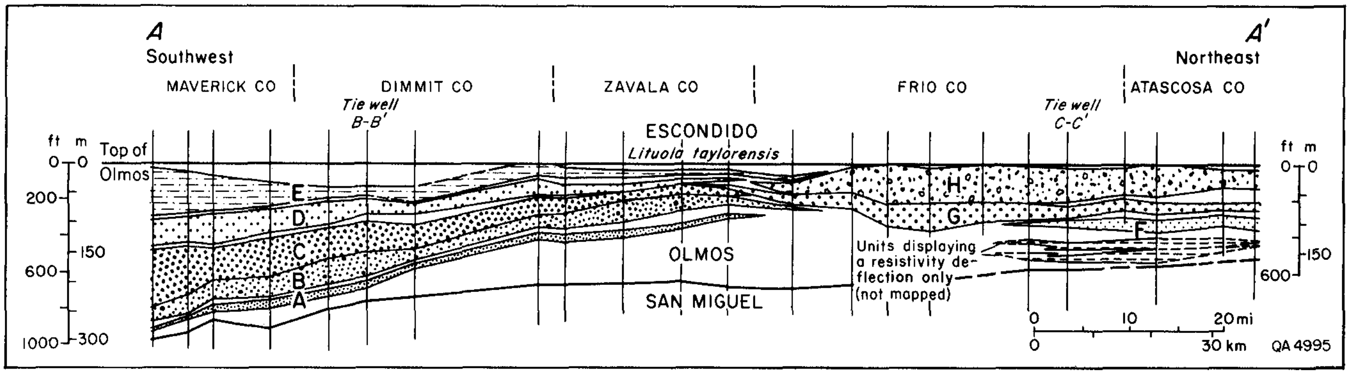

FIGURE 8. Simplified stratigraphic strike section A-A′. Modified from plate 1. Section location shown in figure 4.

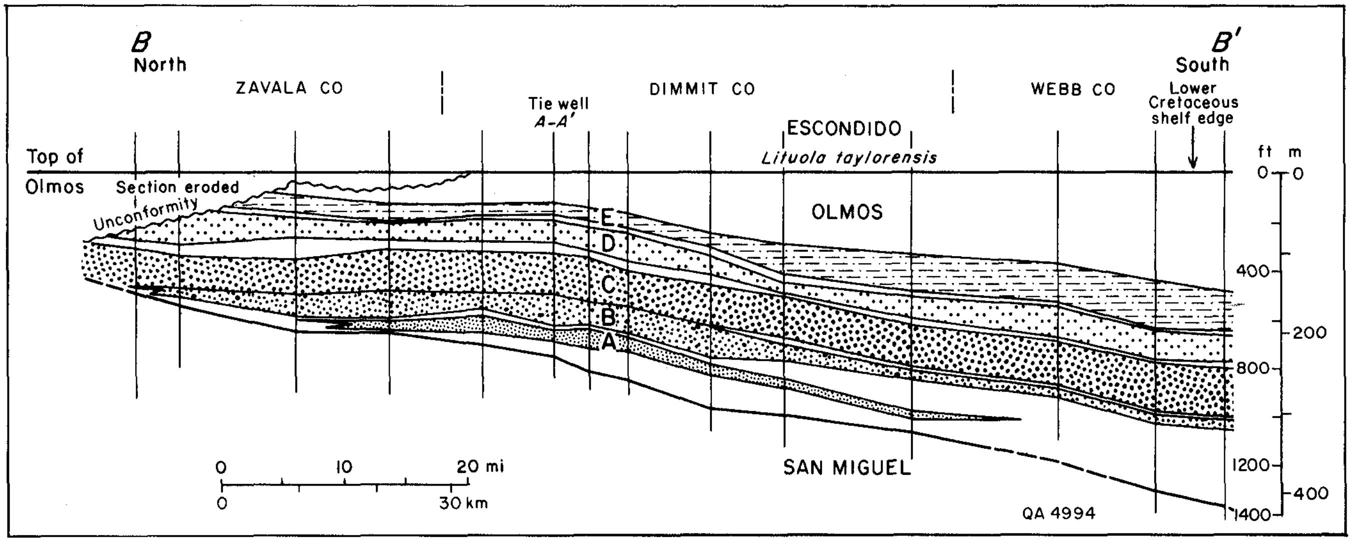

FIGURE 9. Simplified stratigraphic dip section B-B′ from the western depocenter. Units A-E become increasingly shaly downdip but are correctable. Modified from plate 1. Section location shown in figure 4.

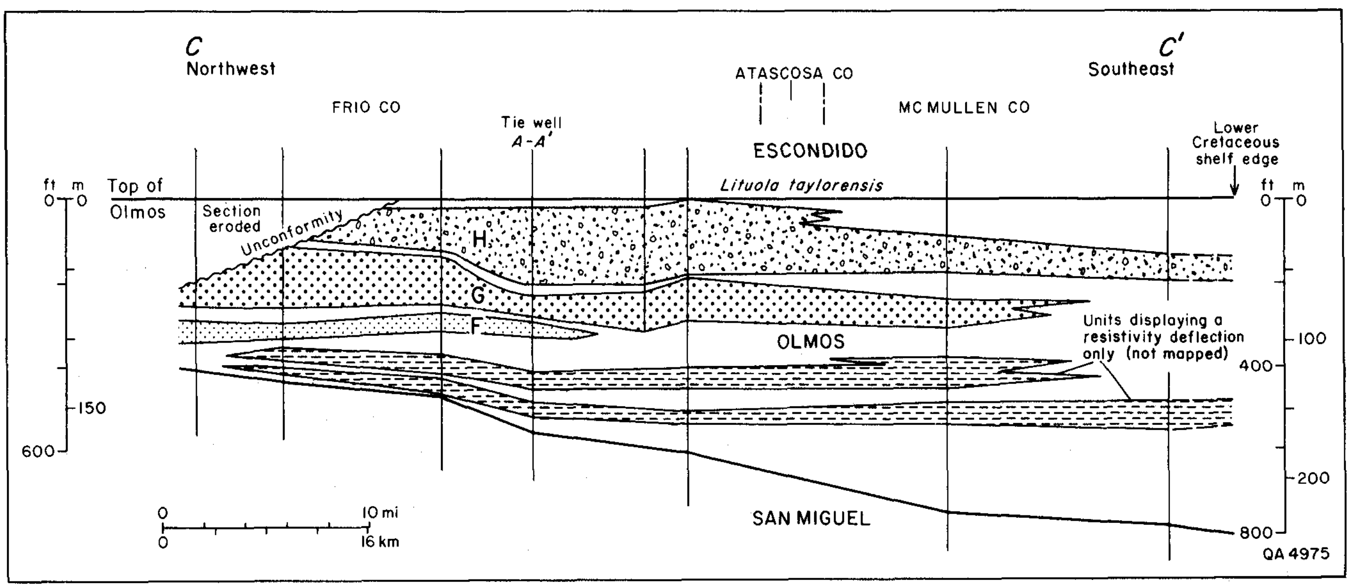

FIGURE 10. Simplified stratigraphic dip section C-C′ from the eastern depocenter. Modified from plate 1. Section location shown in figure 4.

Deltaic Unit A

Regional Extent

Unit A is the oldest and least widespread sandstone unit of the Catarina delta system; it is limited to Dimmit and Zavala Counties and part of southern Maverick County (fig. 11). It persists as far north as extreme southern Uvalde County, where it was truncated by pre-Escondido erosion, and pinches out downdip in southern Dimmit County 15 mi (24 km) north of the Lower Cretaceous shelf edge.

Sandstones of unit A were deposited in a northeast-trending elongate belt, at least 75 mi (121 km) along depositional strike (fig. 11). Maximum sandstone thickness (60 ft; 18 m) exists in southeastern Maverick and southwestern Dimmit Counties. A single dip-elongate sand belt lies on the northeast side of this sand body. A second and minor strike-parallel belt of sandstone only 20 ft (6 m) thick was truncated by the pre-Escondido unconformity in northern Zavala County.

Depositional Environments

Unit A sandstones are persistently characterized throughout the basin by simple upward-coarsening SP responses, an indication that they were deposited in a progradational setting. As shown by the limited sandstone distribution, strike-parallel

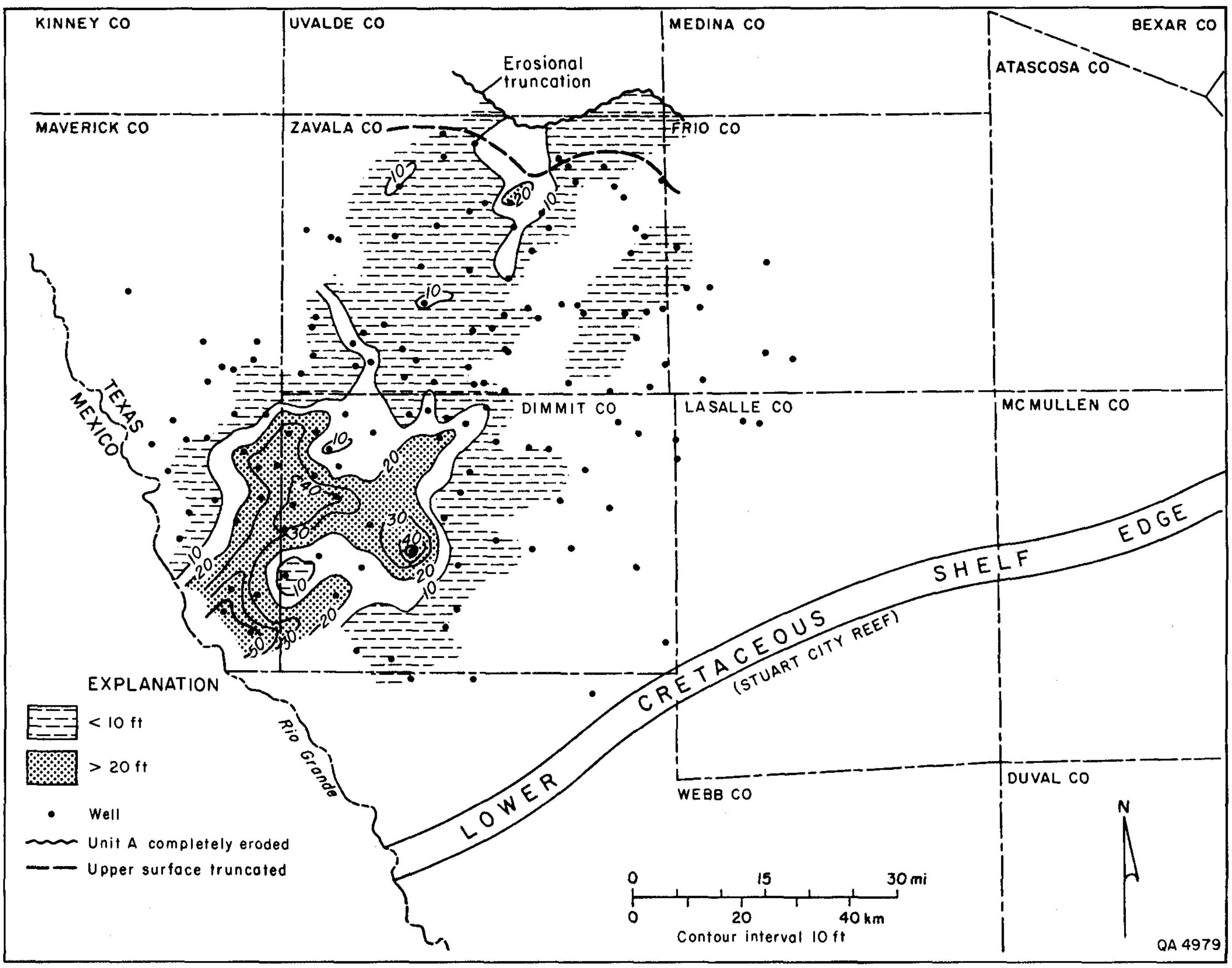

FIGURE 11. Net-sandstone map, unit A.

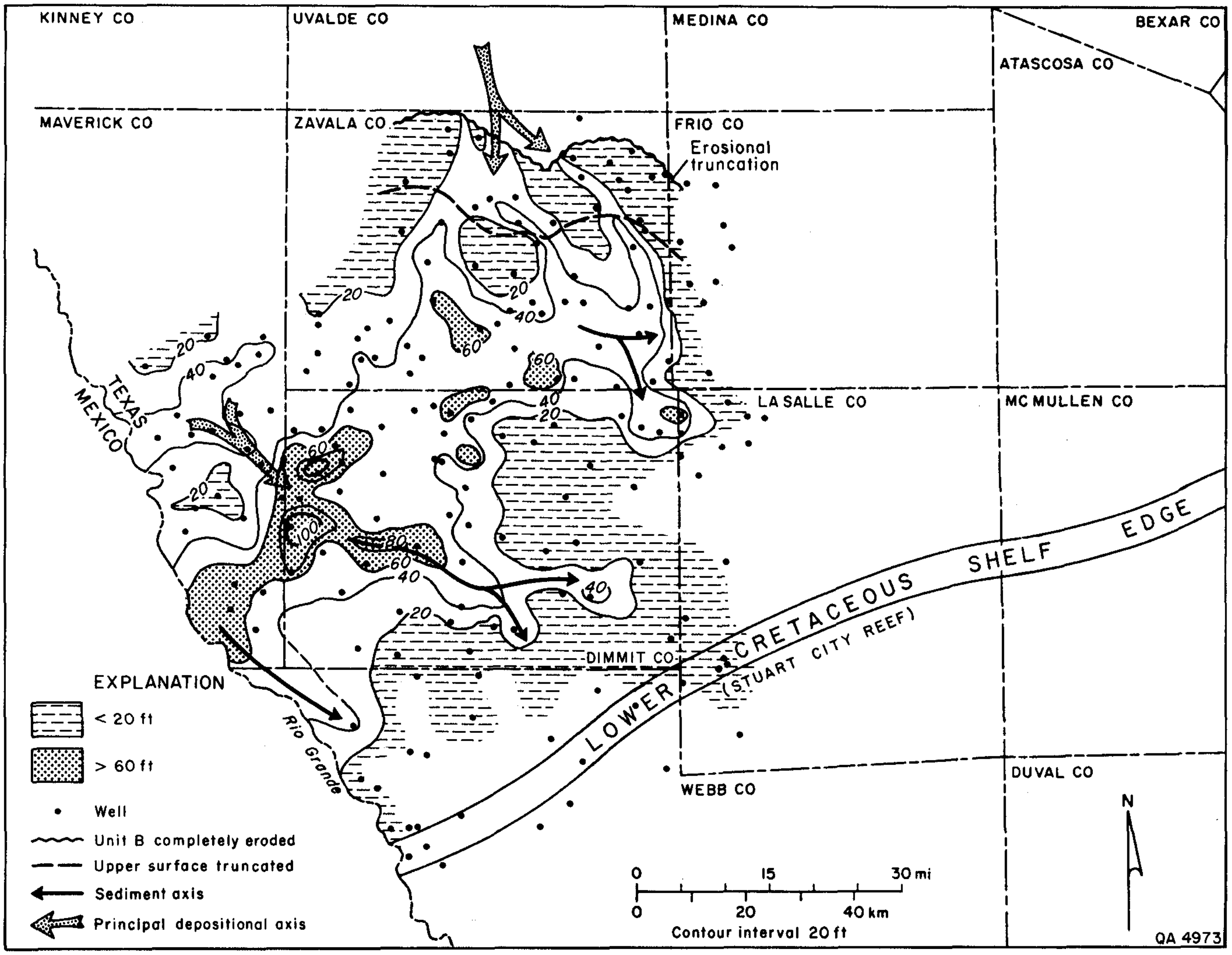

FIGURE 12. Net-sandstone map, unit B.

orientation of the unit, limited dip-elongate axes, and upward-coarsening trends, genetic unit A was deposited as a highly wave-reworked, strike-elongate deltaic sandstone on a wave-dominated coastline. Similar wave-dominated deltaic deposits characterize the underlying San Miguel Formation (Weise, 1980).

Deltaic Unit B

Regional Extent

Unit B, which overlies A, is much more widespread, covering approximately 3,500 mi^2 (9,065 km^2) and extending to the Lower Cretaceous shelf edge in La Salle and Webb Counties (fig. 12). Updip unit B strata are completely truncated in northern Zavala County. Sandstones in unit B display both lobate (southeastern Zavala and northeastern Dimmit Counties) and digitate (central Dimmit County) sand axes (fig. 12). Maximum sandstone development (120 ft; 36 m) occurs along a strike-parallel trend in Maverick and Dimmit Counties. Two dip-elongate axes diverging seaward from this belt indicate moderate fluvial influence during sedimentation. Sediment influx was predominantly from the northwest in Maverick County. A second but minor fluvial entrant is in northern Zavala County, where as much as 50 ft (15 m) of sandstone was truncated by pre-Escondido erosion.

Electric Log Response

Sediments in unit B are characterized by four basic SP responses: upward-coarsening, upward-fining, thick complex upward-coarsening, and mixed (upward-fining and upward-coarsening). The architecture of component facies is strongly dip directed (fig. 13), attesting to the fluvial influence on

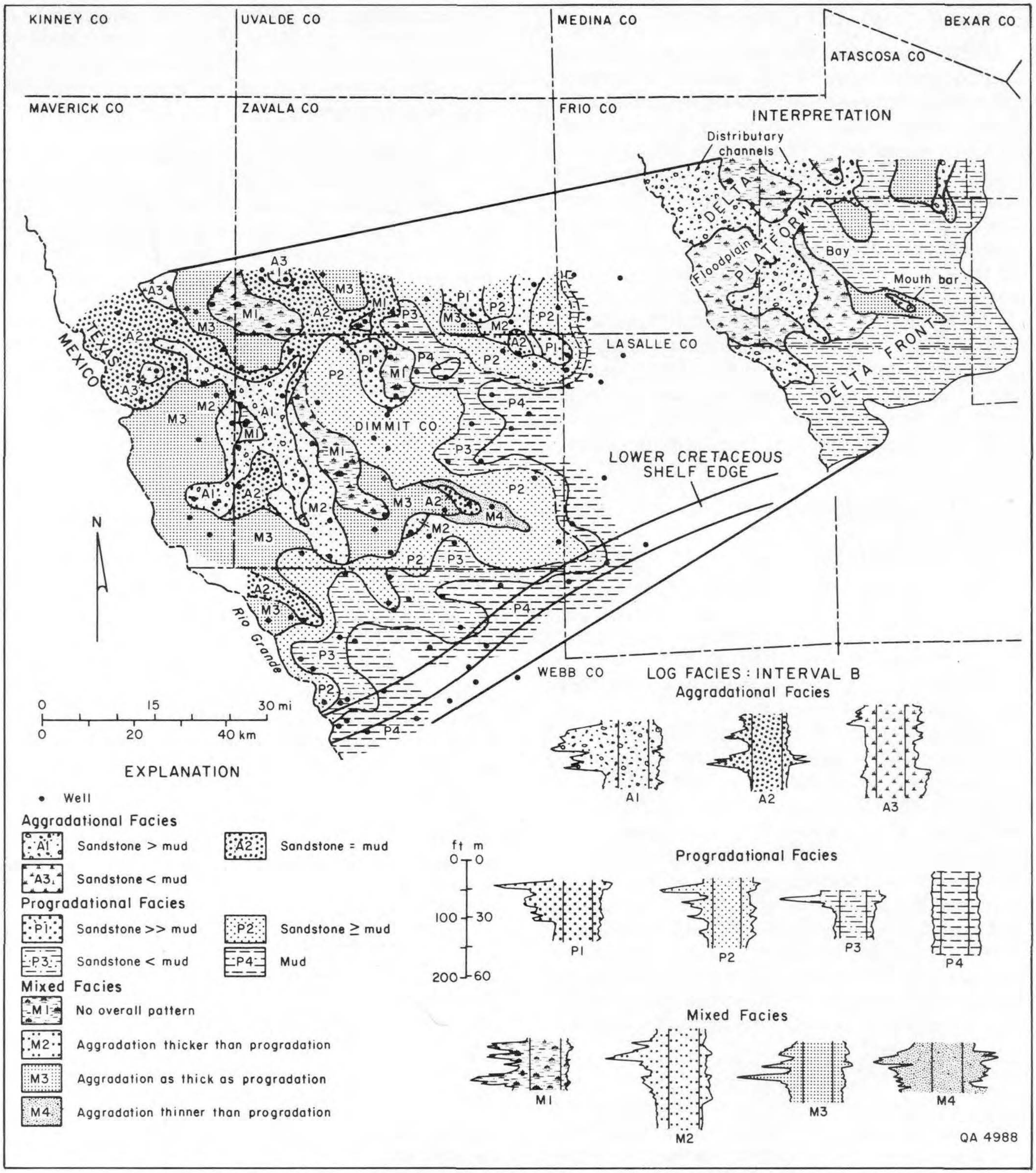

FIGURE 13. Map showing distribution of SP log facies and interpretation (inset) of unit B.

this unit. A simplified SP log facies map of unit B (fig. 13, inset) shows a system of upward-fining sandstones flanked by muddier sediments characterized by mixed SP responses. Downdip are dip-elongate sandstones characterized by complex upward-coarsening SP responses; these are associated laterally and seaward with simple upward-coarsening SP responses.

Depositional Environments

Unit B represents the initial stage of a major progradational pulse in the western depocenter; unit B delta-front sediments were deposited 20 mi (6 km) farther south than those of unit A and reached the shelf edge. The complex SP response of sandstones of unit B reflects diverse depositional environments on a wave-modified, fluvially dominated delta platform. An intricate, dip-elongate system of upward-fining channel sandstones (70 to 100 ft; 21 to 30 m thick) merged downdip with local upward-coarsening channel-mouth bar (20 to 50 ft; 6 to 15 m thick) and delta-front sandstones (fig. 13, inset). Interchannel and interdistributary areas were muddier, as reflected by baseline and serrate-pattern SP deflections. Downdip, strike-elongate mouth bar facies are poorly developed, indicating the predominance of fluvial over wave processes.

Deltaic Unit C

Regional Extent

The extensive deltaic progradation in the western depocenter culminated with deposition of unit C. It extends over a four-county area and covers approximately 3,900 mi^2 (10,100 km^2). In Webb County, unit C prograded as much as 20 mi (32 km) farther south than did unit B.

In Maverick, Dimmit, and Zavala Counties, unit C was deposited as a dip-elongate system containing a maximum of 80 ft (24 m) or 20 to 40 percent sandstone (fig. 14). This genetic unit lacks the well-defined sandstone thicks displayed by the older deltaic facies in the western depocenter. Rather, the updip deposits here show bifurcating and merging sandstone ribbons. Seaward, in Webb County along the Lower Cretaceous shelf edge, the dip-elongate system intersects a 100-ft (30-m)-thick strike-oriented belt composed of 50 percent sandstone. Here, strike-parallel sandstone thicks are arranged en echelon and are mostly oriented southwestward.

Lithofacies

Six distinct lithofacies of unit C appear in the Tesoro No. 3 Gates Ranch core. From bottom to top they are (1) upward-coarsening, burrowed siltstone, (2) upward-fining, crossbedded sandstone, (3) ripple-laminated, sparsely burrowed siltstone, (4) rooted, plane-bedded siltstone and coal, (5) upward-coarsening, ripple-laminated fine-grained sandstone, and (6) highly burrowed, plane-bedded siltstone. Features of lithofacies 1, 2, and 3 are illustrated by a 30-ft (9-m) core from the Tesoro No. 3 Gates Ranch well (fig. 15) in Webb County. Corresponding SP responses are shown on a column to the right of the section. In the following lithofacies descriptions, all thicknesses refer to the core descriptions only and do not imply regional thickness constraints.

(1) *Upward-coarsening, burrowed siltstone*

This lithofacies consists of more than 20 ft (6 m) of plane-bedded, sparsely burrowed (fig. 15A) siltstone. Grain size increases vertically, and bed forms show a transition from plane beds to ripples and small-scale crossbeds. Burrowing decreases upward. This lithofacies is interpreted as delta-front sediment that is erosively overlain by distributary-channel deposits.

(2) *Upward-fining, crossbedded sandstone*

Consisting of 15 to 20 ft (6 to 8 m) of fine-grained, crossbedded sandstone with clay rip-up clasts at the base, this lithofacies shows upward-fining grain-size trends and a progression in bed forms from crossbeds (fig. 15B) to low-angle inclined laminations. No burrows are present in these lithofacies, which are interpreted as distributary-channel deposits.

(3) *Ripple-laminated, sparsely burrowed siltstone*

This lithofacies, only 5 to 10 ft (1.5 to 3 m) thick, is found above lithofacies 2 and is composed of sparsely burrowed siltstone. Pelecypod shell fragments and horizontal burrows are more abundant at the top. In other cores these abandoned-distributary-channel deposits are overlain and eroded by the crossbedded fine sandstone of lithofacies 2. Lithofacies 4, 5, and 6 are also featured in the Tesoro No. 3 Gates Ranch core, 80 to 110 ft (24 to 34 m) higher in the section (fig. 16).

(4) *Rooted, plane-bedded siltstone and coal*

This lithofacies is composed of 5 to 10 ft (1.5 to 3 m) of muddy siltstone with abundant plant fragments. At the top of the section are vertically oriented, downward-bifurcating rootlets and thin (0.5 ft; 0.15 m) coal beds (fig. 16A) that formed in an interdistributary marsh environment on the delta platform of unit C.

(5) *Upward-coarsening, ripple-laminated, fine-grained sandstone*

Ranging in thickness from 7 to 12 ft (2 to 3.7 m), this lithofacies shows a succession of bed forms varying from horizontal laminations at the base to climbing ripples (fig. 16B) at the top. Roots and plant fragments are common in the section, especially at the top. Characteristic structures in this lithofacies are commonly found in crevasse splay and levee deposits.

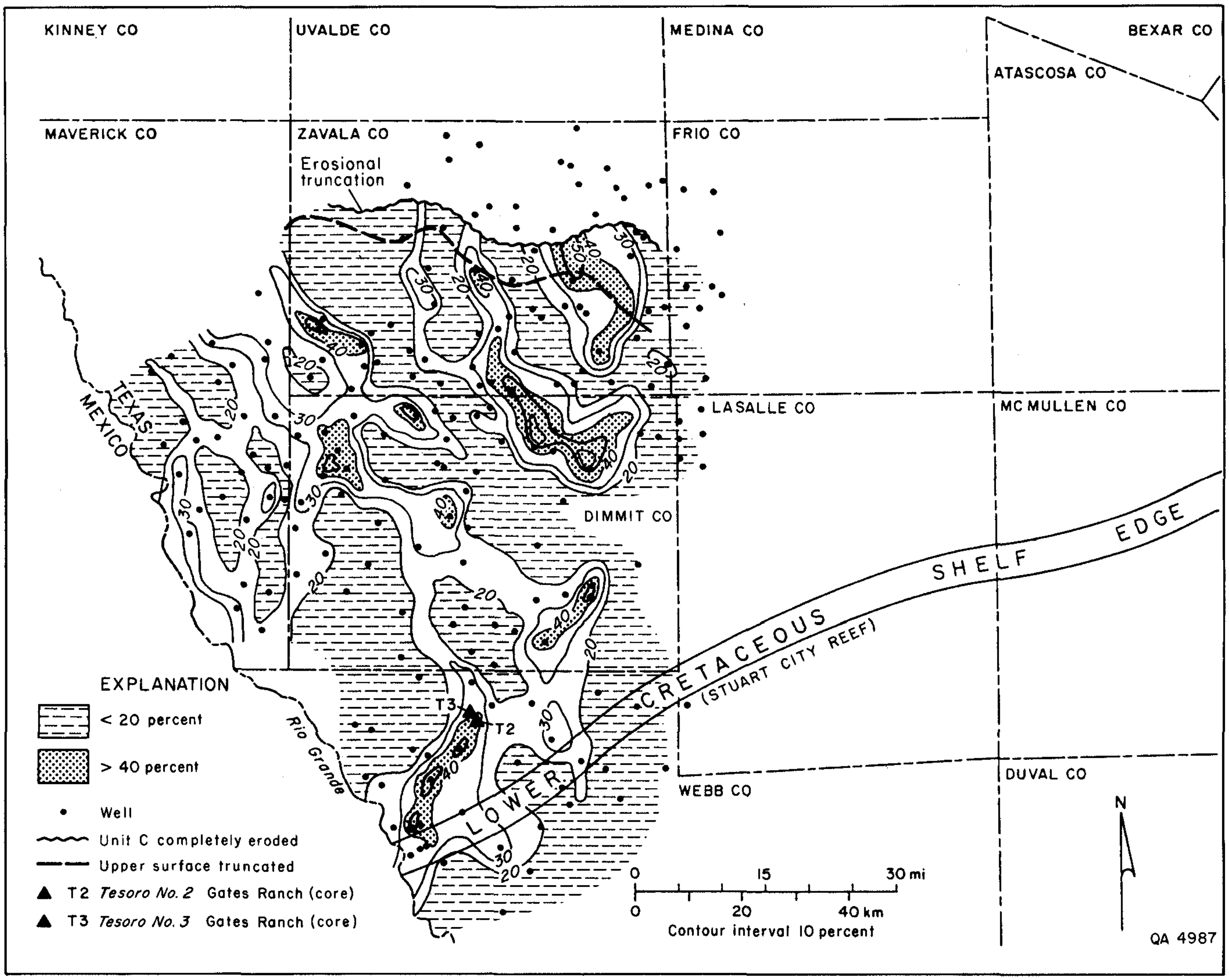

FIGURE 14. Percent-sandstone map, unit C.

(6) *Highly burrowed, plane-bedded siltstone*

This lithofacies is at the top of subunit C and is about 20 ft (6 m) thick. It consists of muddy siltstone with abundant horizontal burrows (*Planolites* and *Thalassinoides*) and scattered, less abundant pelecypod shell fragments. On the basis of its grain-size trend (fig. 16), faunal assemblage, and position in the stratigraphic column of unit C, the burrowed, plane-bedded siltstone represents shallow-shelf (abandoned-delta-lobe) deposits that formed after sediment supply was cut off from the C delta.

Electric Log Response

Facies motifs of unit C display the same spatial arrangement as those of unit B. Updip, aggradational facies with strong dip orientations merge laterally with mixed facies (fig. 17). Seaward, progradational facies assume greater prominence. Although the SP response map shows SP log facies that are generally similar to those of unit B, those of unit C differ in that the complex upward-coarsening facies is much more continuous along depositional strike.

Depositional Environments

Genetic unit C was the second major progradational wedge in the western depocenter. The C delta was more extensive seaward and laterally than the A and B deltas, reflecting the highly progradational nature of this delta system. Dip-elongate sand patterns and facies mapping attest to a strong fluvial contribution. Yet wave processes were active in the receiving basin; consequently, delta-front sandstones of unit C are well developed areally (fig. 17, inset).

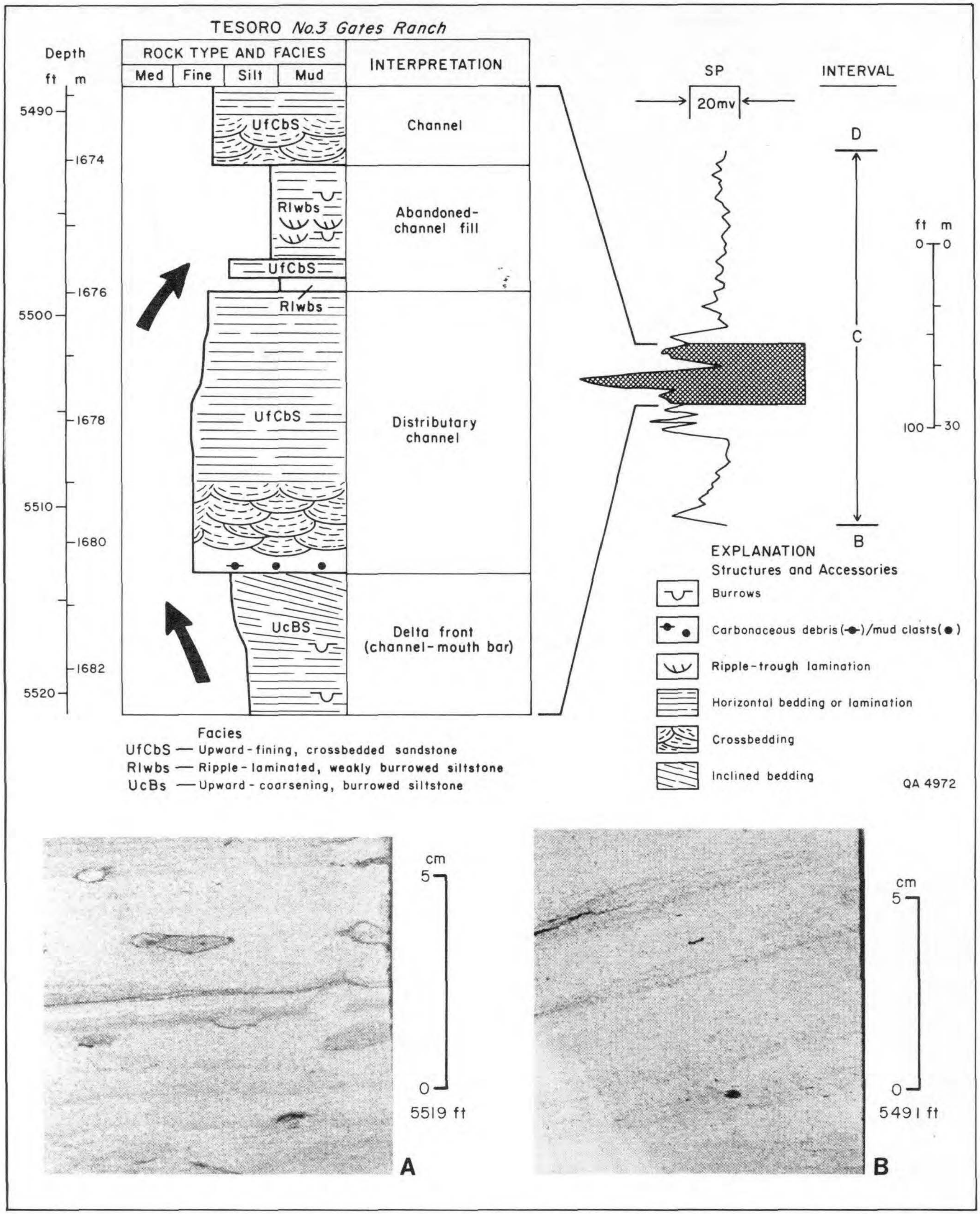

FIGURE 15. Channel-mouth bar, distributary-channel, and abandoned-channel-fill deposits of unit C, Tesoro No. 3 Gates Ranch core. Location of well shown in figure 14. A. *Ophiomorpha* and *Planolites* burrows in delta-front siltstone. B. Crossbedded fine-grained distributary-channel sandstone.

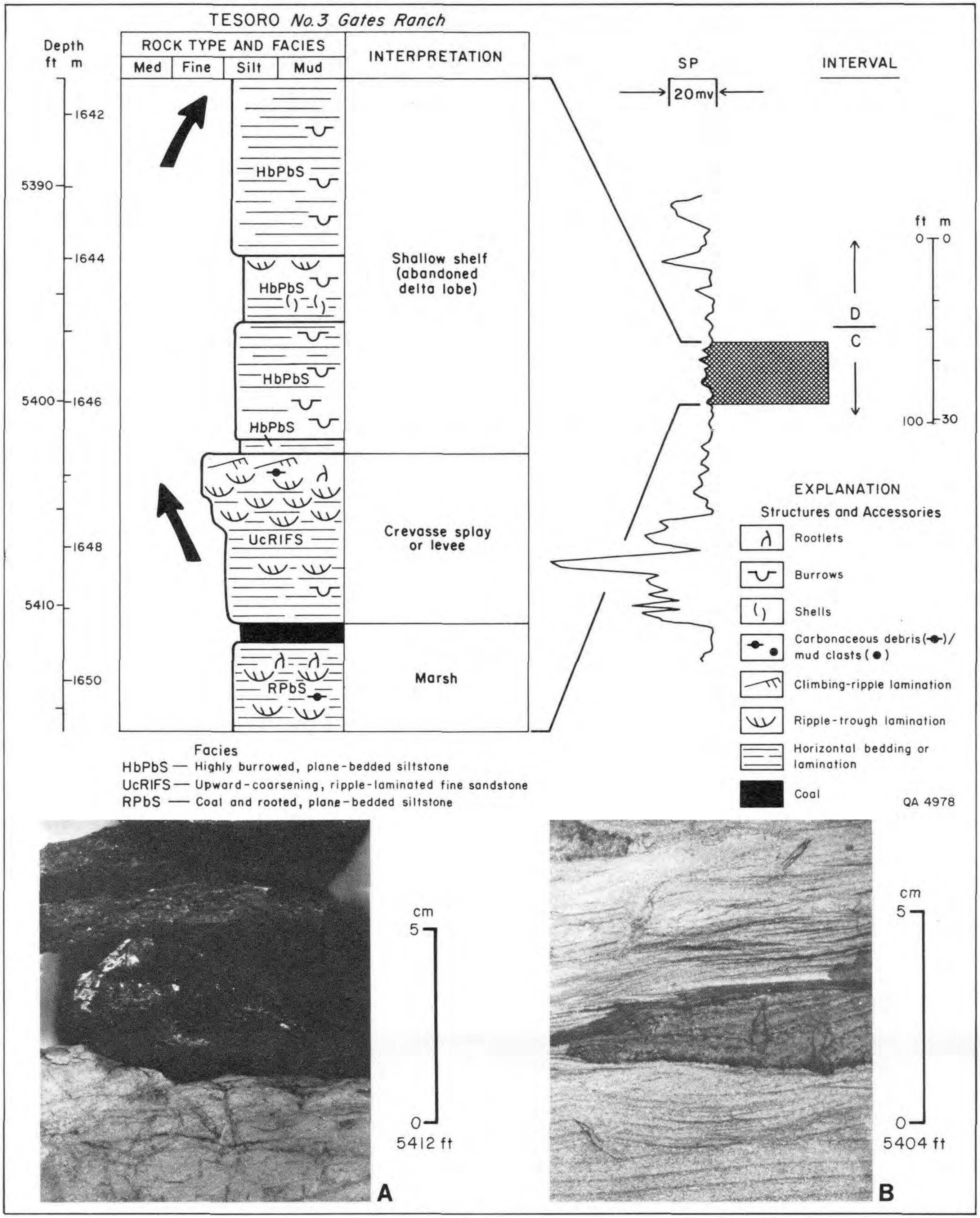

FIGURE 16. Crevasse splay sandstones interbedded with marsh and shallow-shelf (foundered delta) deposits of unit C, Tesoro No. 3 Gates Ranch core. Location of well shown in figure 14. A. Rooted, plane-bedded siltstone overlain by a thin coal seam. B. Climbing ripple lamination and rootlets in crevasse splay or levee siltstone.

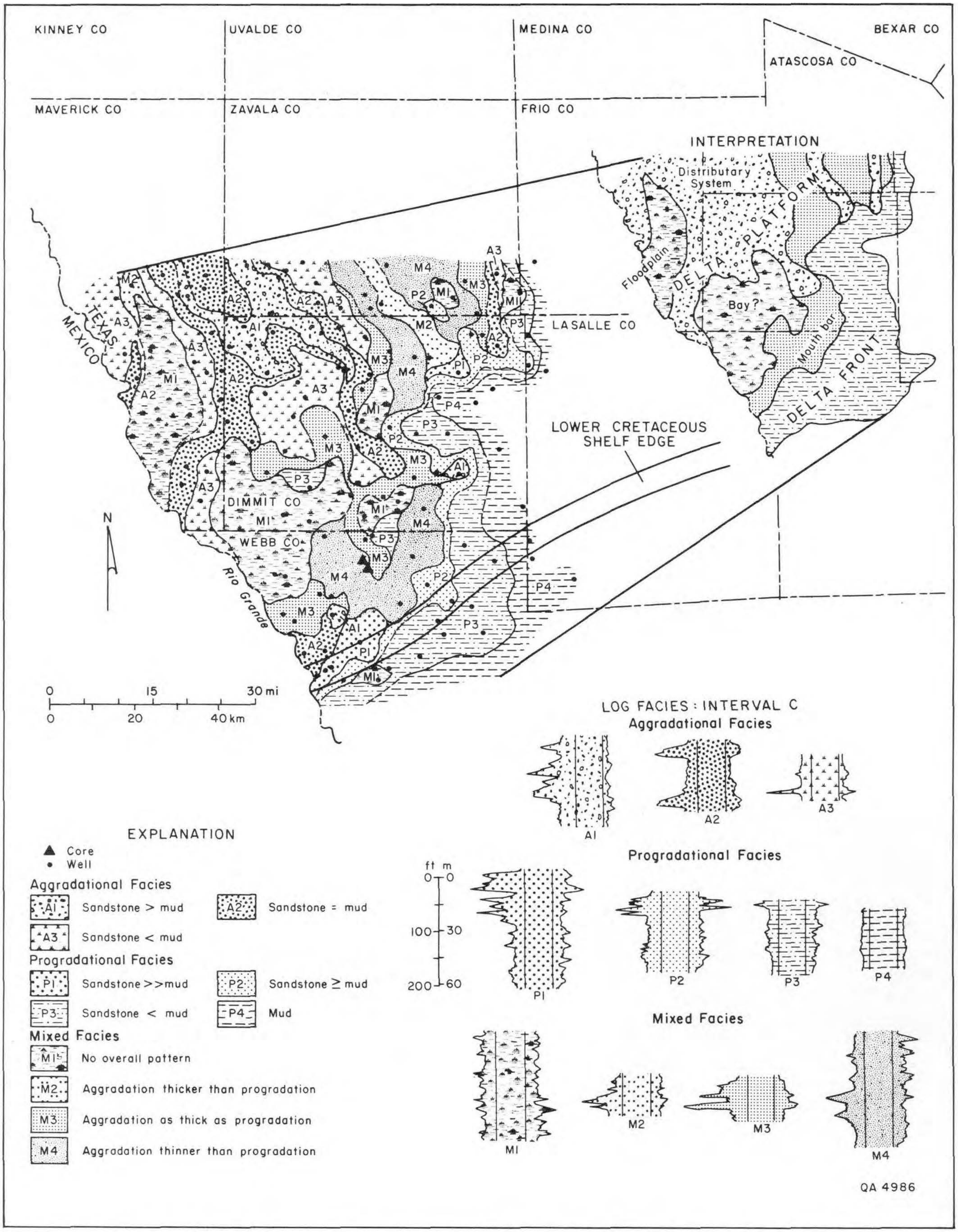

FIGURE 17. Map showing distribution of SP log facies and interpretation (inset) of unit C.

Thin (less than 1 ft; 0.3 m) coal beds were formed in interchannel floodplains on the extensive delta platform. Coal formation was interrupted by overbank deposition by crevasse splays during floods. As sediment supply to the western depocenter waned, the C delta foundered. It was then covered by shallow marine waters, as evidenced by the 20-ft-thick (6-m-thick), shell-rich, highly burrowed siltstone lithofacies at the top of unit C.

ROCKY CREEK BARRIER/STRANDPLAIN SYSTEM

Shore-zone Unit D

Regional Extent

At the end of progradation of the Catarina delta system, the western part of the Maverick Basin underwent marine inundation; unit D and E sandstones are oriented mainly along strike, reflecting the high marine influence. Unit D is extensively developed across the western depocenter. Sandstones of this unit exist as far south as west-central Webb County (fig. 18). To the east, unit D appears in La Salle County, where it interfingers with unit G of the eastern depocenter (stratigraphic strike section A-A´ in pl. 1 and fig. 8).

Depositional trends are bimodal, as indicated by net-sandstone patterns (fig. 18). A dip-oriented belt of poorly developed sand ribbons updip in Maverick, Zavala, and Dimmit Counties merges seaward in Webb County with a major strike-elongate belt that contains as much as 90 ft (27 m) of sandstone. Sandstone content decreases rapidly to the south of this strike sandstone body over the Lower Cretaceous shelf edge.

Lithofacies

Three lithofacies of unit D are recognized in cores from the Tesoro No. 2 Gates Ranch well (fig. 19). They are, from the base of the vertical section, (1) highly burrowed, rippled, sandy siltstone, (2) upward-coarsening, internally eroded sandstone, and (3) erosionally based, crossbedded sandstone.

(1) *Highly burrowed, rippled, sandy siltstone*

This lithofacies consists of up to 10 ft (3 m) of slightly upward-coarsening sandy siltstone, extensively burrowed at the top (fig. 19A) mainly by horizontal *Ophiomorpha.* Small pyrite nodules are common, especially low in the section. Toward the top, bed forms are dominated by climbing ripple and ripple-trough lamination. This lithofacies is interpreted as shallow-lagoonal sediment.

(2) *Upward-coarsening, internally eroded sandstone*

Less than 5 ft (1.5 m) thick, this lithofacies is found above the highly burrowed, rippled, sandy siltstone. It is characterized chiefly by numerous erosion surfaces (fig. 19B) and prominent small-scale trough cross-stratification. Rootlets (fig. 19C), shell debris, and plant fragments occur at the top of these units, which represent storm-washover sheets or fans.

(3) *Erosionally based, crossbedded sandstone*

This is the coarsest grained and thickest (up to 30 ft; 9 m) lithofacies of unit D. At its base are shale rip-up clasts and pelecypod shell debris. Fine-grained sandstone is markedly crossbedded throughout, especially at the base. Grain size decreases upward only slightly. This lithofacies was probably deposited as a transgressive barrier sequence.

Electric Log Response

Strata of interval D are characterized by a weakly developed dip-elongate belt of upward-fining sandstones interwoven with both upward-coarsening and mixed (upward-fining and upward-coarsening) sandstones in Maverick, Zavala, and Dimmit Counties (fig. 20). Downdip in Webb County is a strike-elongate system of sandstones having a "blocky" response—one showing no net upward-coarsening or upward-fining deflection. Seaward and to the east in Webb and eastern Dimmit Counties is a southwest-northeast band of upward-coarsening log facies.

Depositional Environments

Unit D was deposited in a complex, wave-dominated coastal system. An updip streamplain facies tract merged downdip with a large shallow lagoon or bay (fig. 20, inset). Progradational bay-head deltas were an integral component of the lagoon, seaward of which was a strike-elongate

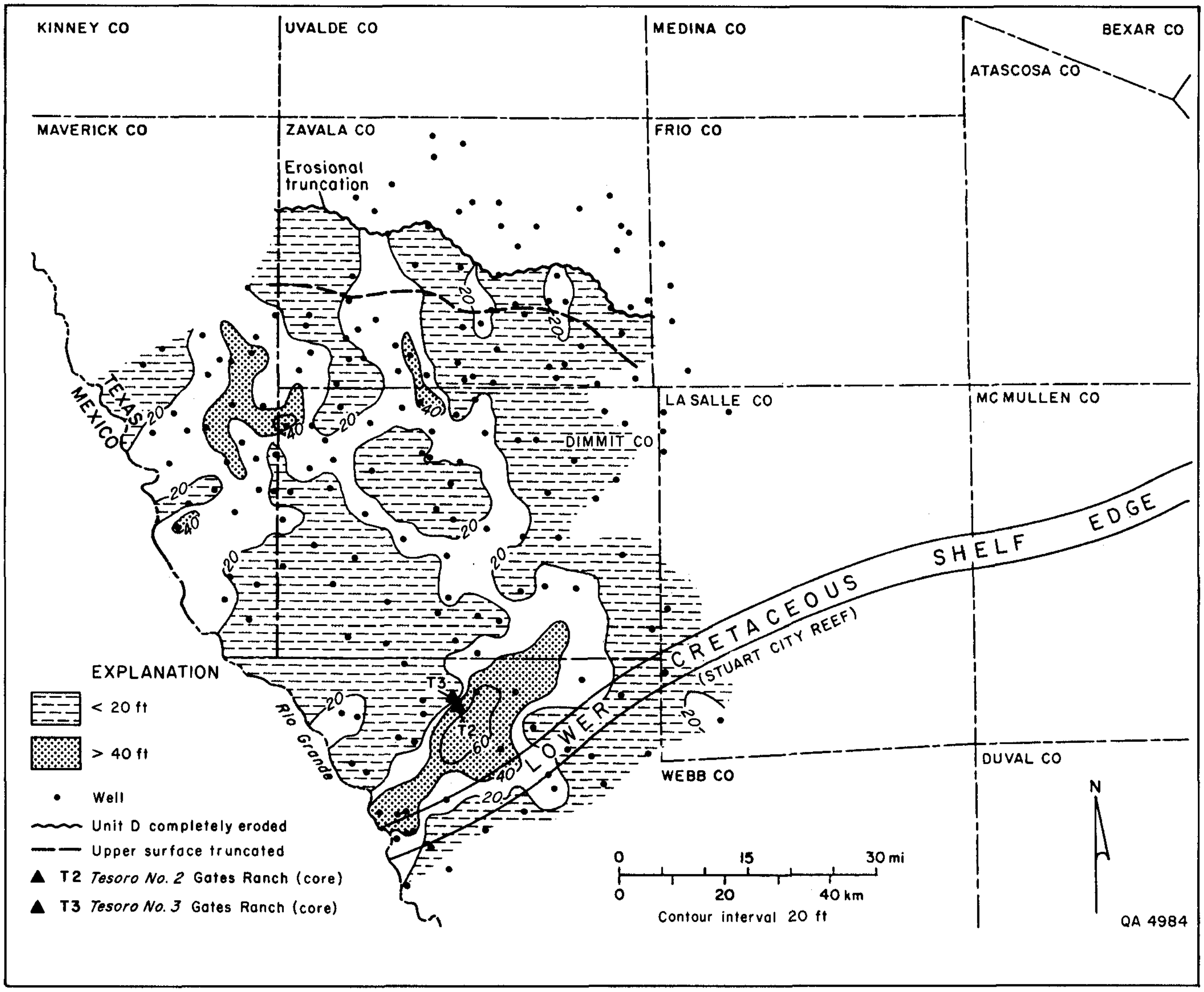

FIGURE 18. Net-sandstone map, unit D.

barrier. Associated with the barrier system were storm-washover fans and ephemeral back-barrier marshes, as indicated by thin organic layers preserved in the cores.

The unit D streamplain was minor compared with the well-developed C delta streamplain of the Catarina delta system: Unit D fluvial/streamplain deposits have less than 40 ft (12 m) of sandstone, contrasted with 60 to 80 ft (18 to 24 m) in unit C. This, coupled with the presence of the strike-elongate barrier system downdip, suggests that the main axis of sediment influx into the Maverick Basin shifted away from the western depocenter during deposition of unit D. A further line of evidence is the presence of a sizeable sandstone accumulation in the eastern depocenter after deposition of unit C in the west.

Thus, unit D marks the inception of an ongoing phase of coastal onlap in the western depocenter. The overlying barrier/strandplain sediments of unit E are offset landward of the principal area of shore-zone sedimentation of unit D. Furthermore, individual barrier sandstones in the cores are transgressive and rest abruptly on lagoon and washover-fan sediments (fig. 19). The source of the sandstone concentrated in the barrier system during this episode of marine inundation is somewhat problematic. Four sediment sources are possible. First, sands may have been supplied by streams feeding directly into the area from the updip streamplain. Yet this system was not well developed (as low sandstone content attests), although it may have acted as a conduit system through which the sands passed rather than as a sediment trap.

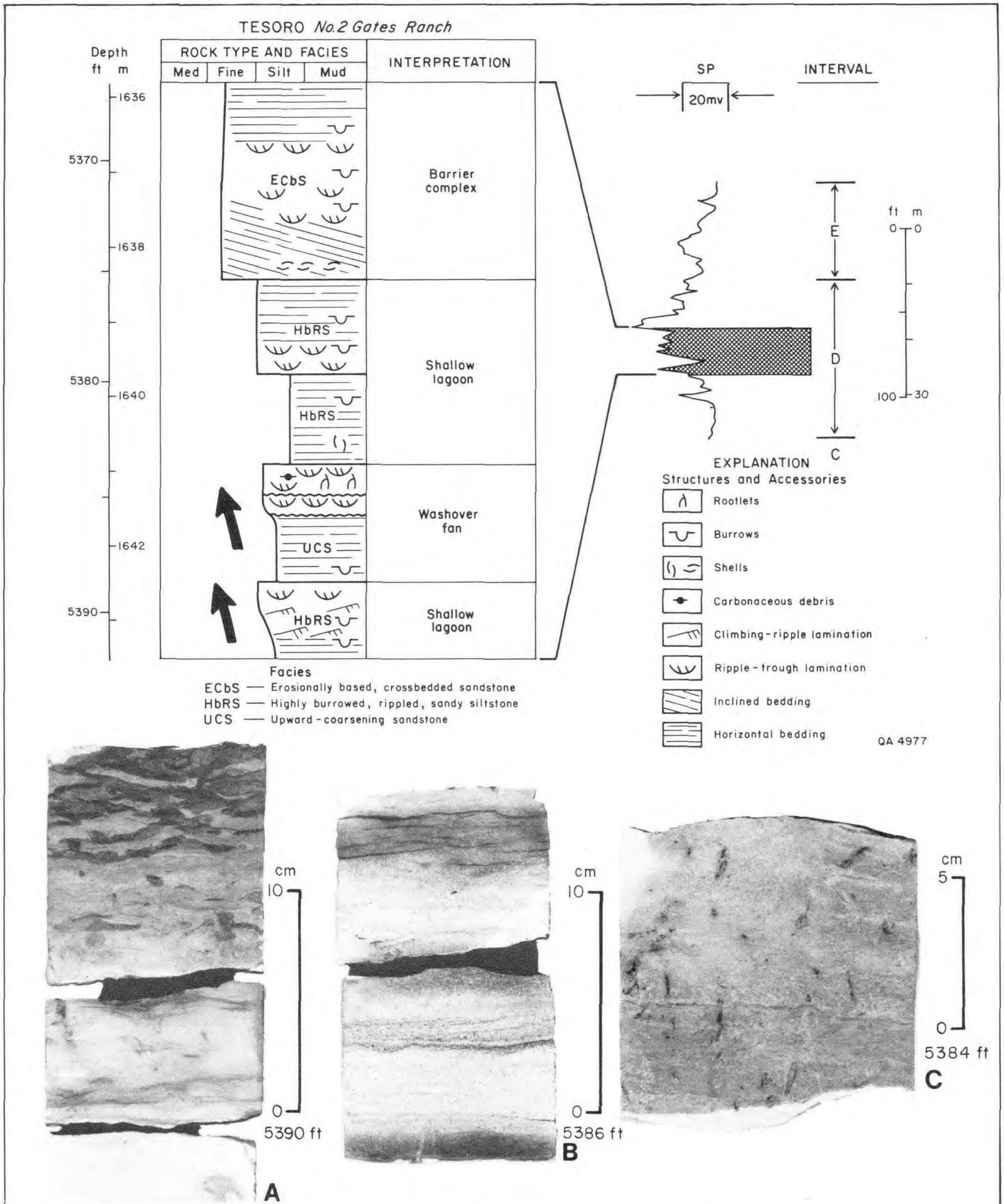

FIGURE 19. Barrier and washover sandstones interbedded with shallow-lagoon mudstones in unit D, Tesoro No. 2 Gates Ranch core. Location of well shown in figure 18. A. Gradational sequence in lagoon sediment showing an increase in horizontal *Ophiomorpha* toward the top. B. Graded cycles and erosion surfaces in upward-coarsening, internally eroded storm-washover sandstone. C. Rooted top of a storm washover.

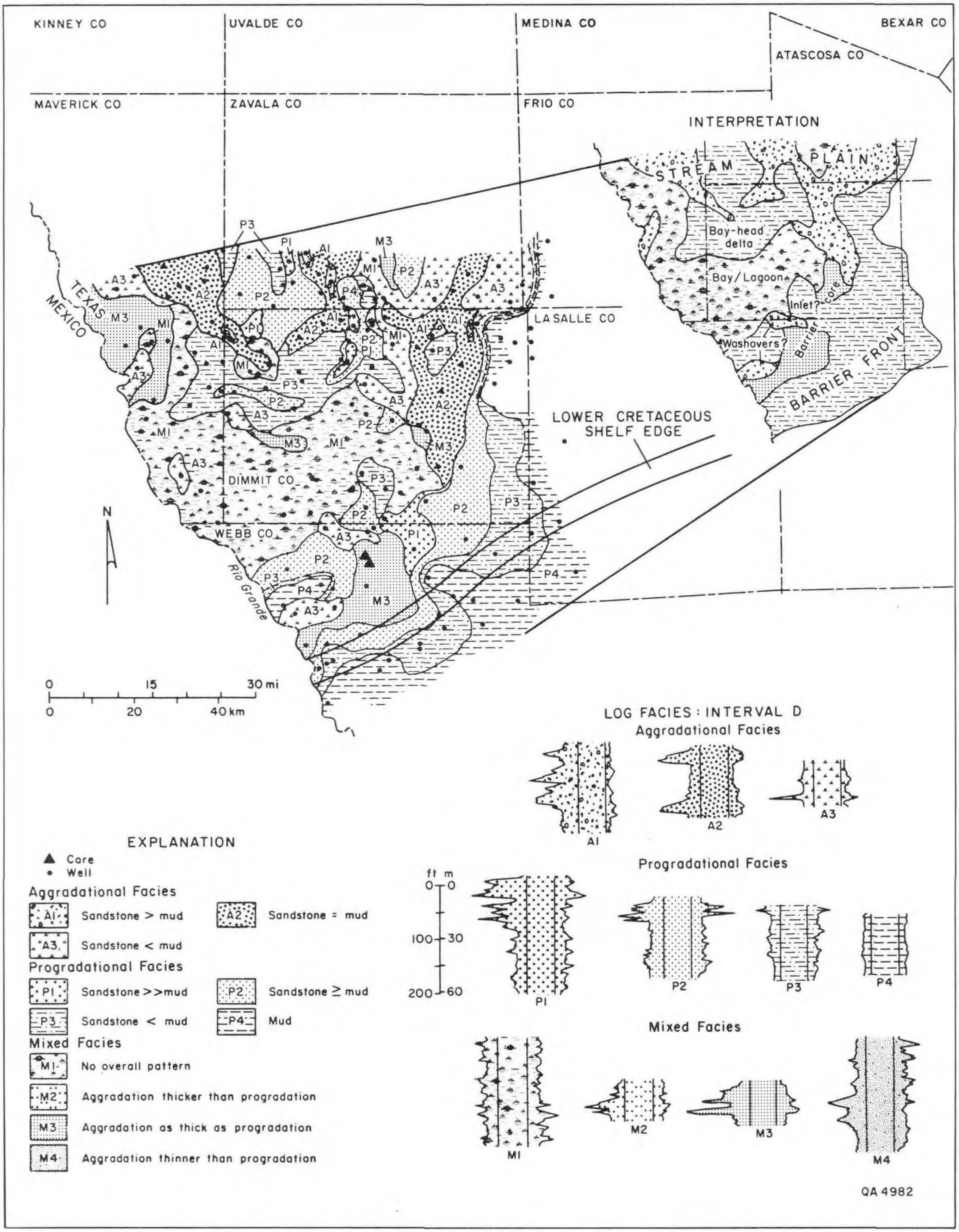

FIGURE 20. Map showing distribution of SP log facies and interpretation (inset) of unit D.

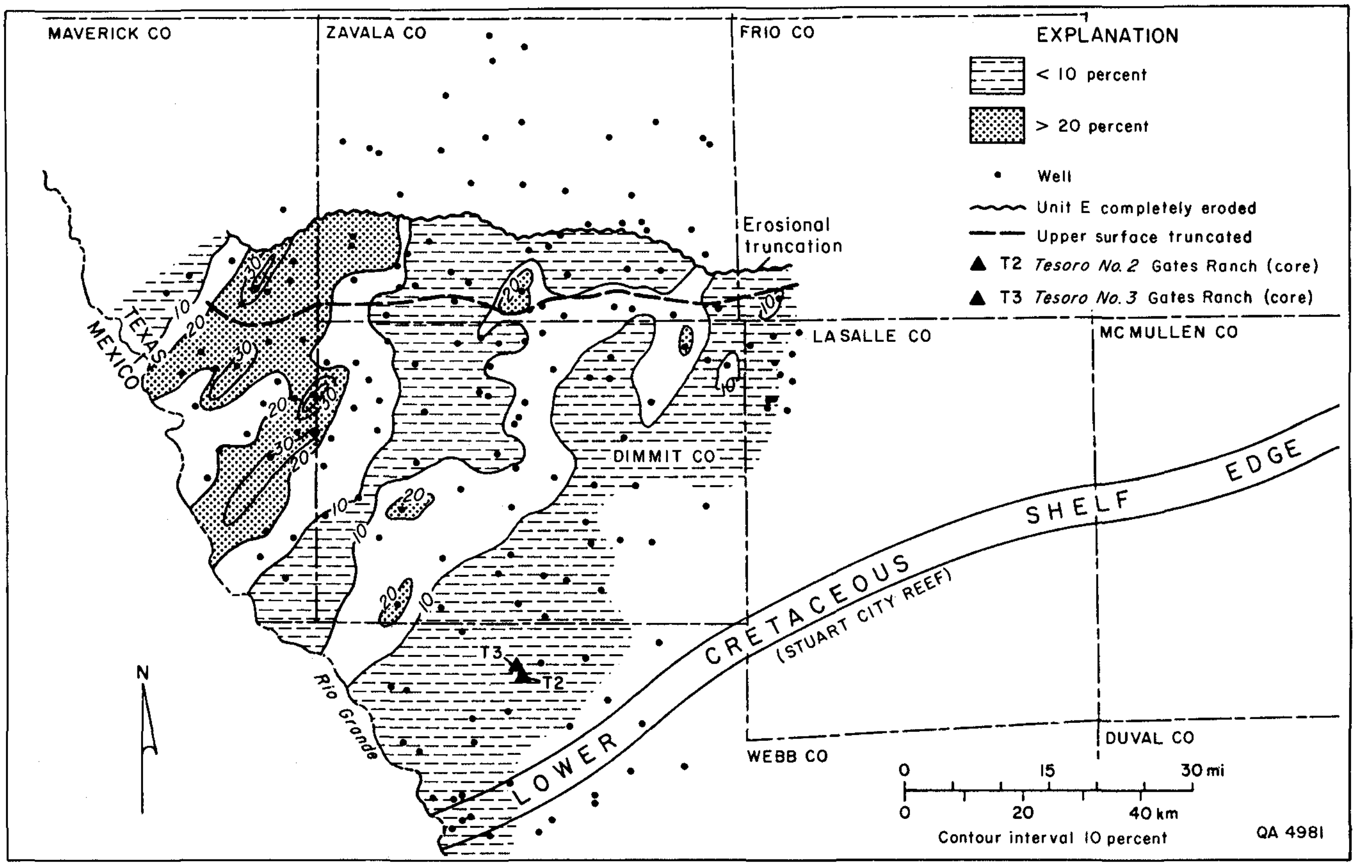

FIGURE 21. Percent-sandstone map, unit E.

Second, the underlying deltaic sands may have been reworked into the coastal barrier system, although delta-plain sediments of the underlying unit C are overlain and separated from unit D by a prominent (20- to 40-ft-thick; 6- to 12-m-thick) shelf mudstone that suggests burial and preservation of the foundered delta platform. Third, the large, high-constructive Big Foot delta system in the eastern depocenter may have been a source of sediment. The dominant direction of longshore drift in this Cretaceous basin was toward the southwest (Tyler and Ambrose, 1985); thus the D and E barrier strandplains lay downcurrent of and immediately adjacent to a major sediment source. Fourth, the source may have been to the west in Mexico. It is equally likely that, as a fifth alternative, all four of these systems may have provided some component to the D and E coastal systems.

Shore-zone Unit E

Regional Extent

Unit E, the youngest in the western depocenter, was deposited during continuing marine onlap. Deposits of unit E do not extend as far downdip as those of unit D. Updip, they are truncated by the post-Olmos unconformity in southern Zavala County.

Sandstones of unit E were deposited primarily in two belts along depositional strike (fig. 21). One belt is in Dimmit County, where sandstone percent is only 22 percent (about 60 ft; 18 m), and the other is in Maverick County, where sandstone percent is 45 percent (about 90 ft; 27 m). Notably absent are any thick sandstones downdip in Webb County and any dip-elongate sandstone trends throughout the western depocenter, in contrast with unit D.

Lithofacies

Two principal lithofacies of unit E are recognized in the Tesoro No. 2 Gates Ranch core (fig. 22): (1) highly burrowed, shelly, sandy siltstone and (2) upward-fining, erosionally based, crossbedded sandstone. These lithofacies represent deposits found in a transgressive barrier-island setting.

(1) *Highly burrowed, shelly, sandy siltstone*

Typically as much as 15 ft (4.5 m) thick, this lithofacies is dominated by horizontal *Thalassinoides* burrows and gastropod and pelecypod shells (fig. 22A). Oyster shells are found commonly in horizontal orientation, although some

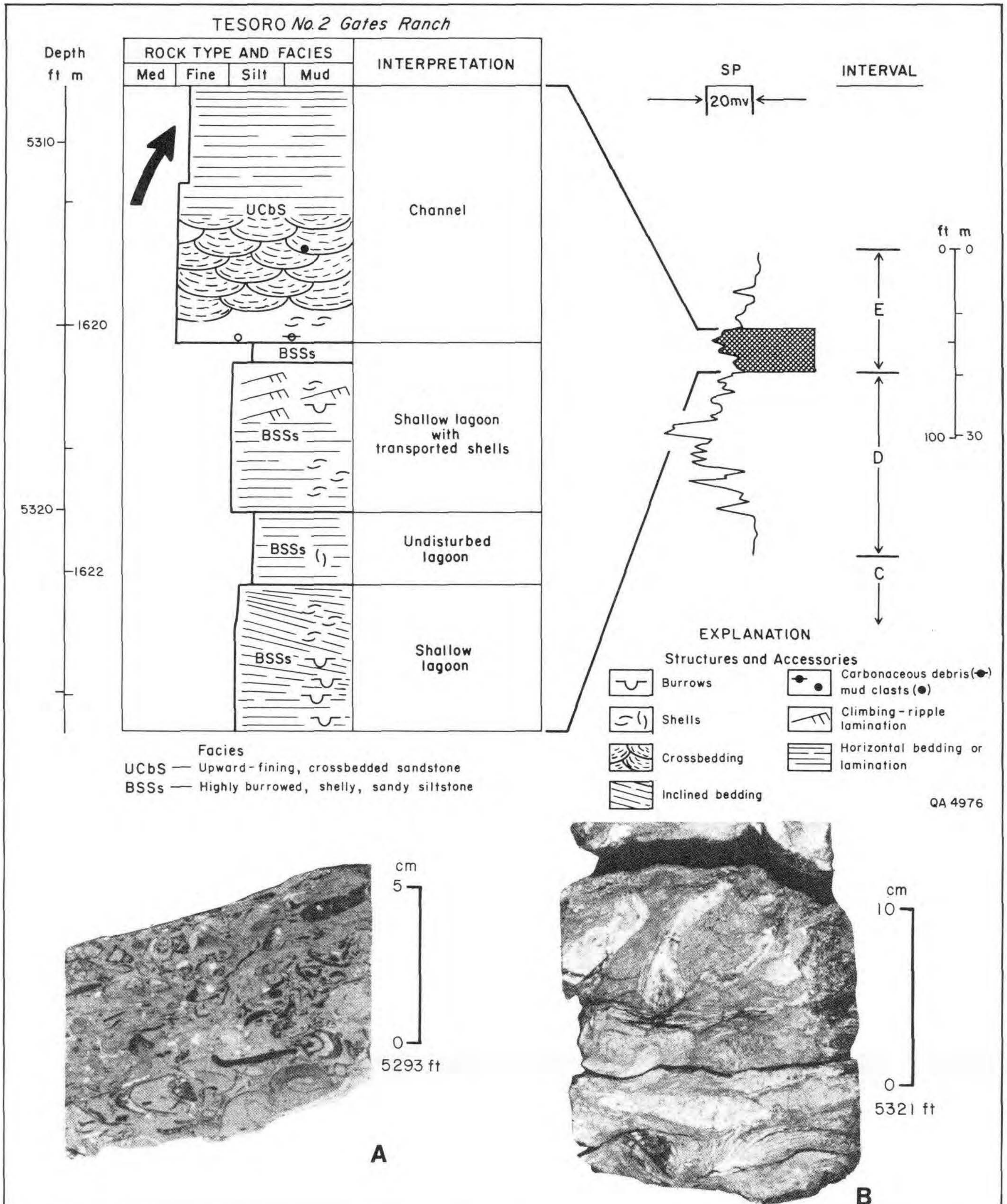

FIGURE 22. Shallow-lagoon sediments truncated by a tidal-channel sandstone in unit E, Tesoro No. 2 Gates Ranch core. Location of well shown in figure 21. A. Gastropod and pelecypod shells in shallow-lagoon deposits from an interval 15 ft (5 m) above that shown in the core description. B. Oyster shells preserved in growth position in undisturbed lagoon siltstone.

were preserved in vertical growth positions (fig. 22B). This lithofacies was deposited in a shallow lagoon.

(2) *Upward-fining, erosionally based, crossbedded sandstone*

These small-scale (10-ft-thick; 3-m-thick) sandstone deposits are characterized at the base by fine-grained sandstone with shell-lag and clay rip-up clasts. Trough crossbedding is evident mainly in basal parts of the section. The sandstones were deposited in tidal channels.

Depositional Environments

Interdeltaic barrier-lagoonal sedimentation continued during deposition of unit E and persisted until the end of Olmos sedimentation in the western depocenter. That sand was no longer being supplied in large quantities is evidenced by the absence of streamplain deposits and by the scarcity of sandstone seaward along the Lower Cretaceous shelf edge, in contrast with progradational units B and C of the Catarina delta system.

BIG FOOT DELTA SYSTEM

Deltaic Unit F

Regional Extent

Unit F is the oldest and least geographically widespread sandstone unit in the eastern depocenter (fig. 23). Although it extends farther north (pinching out in southern Medina and extreme northern Atascosa Counties) than the stratigraphically higher units G and H, it is mainly limited to Atascosa and eastern Frio Counties. Unit F pinches out downdip 25 mi (40 km) north of the Cretaceous shelf edge.

Sandstones of unit F are poorly developed, reaching a maximum thickness of only 50 ft (15m) in northwestern Atascosa County. The net-sandstone pattern of F is lobate and encompasses a northeast-southwest-trending depositional axis in northwestern Atascosa County.

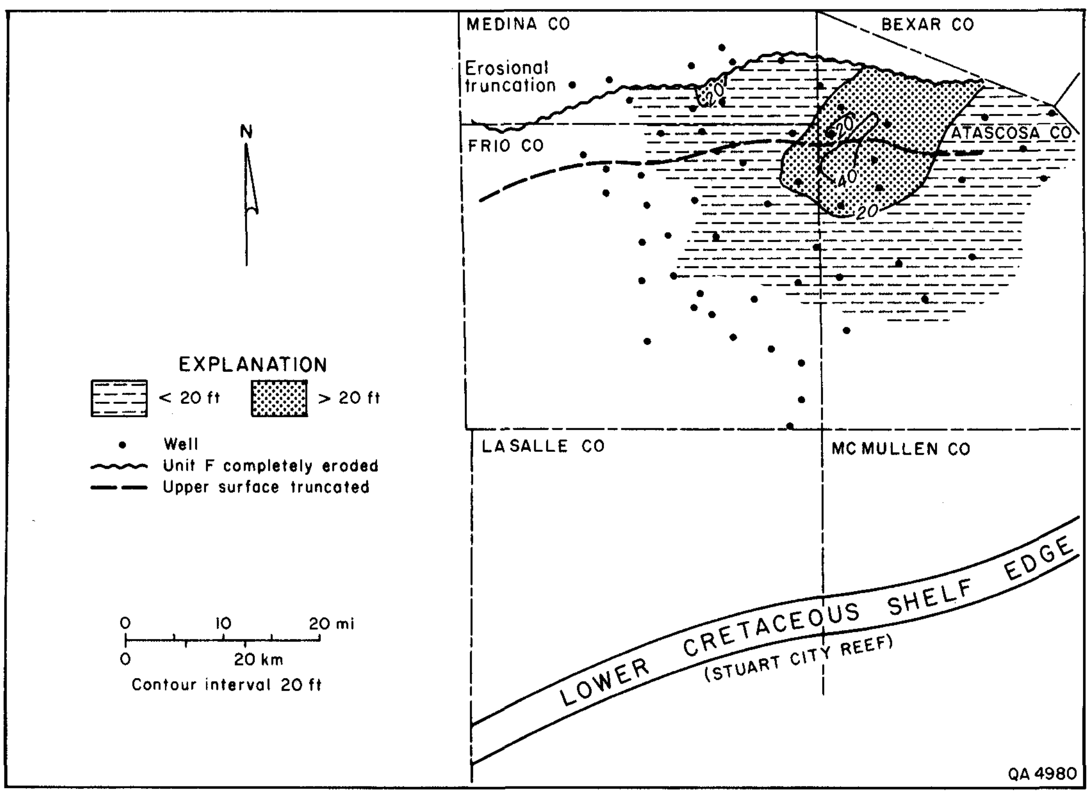

FIGURE 23. Net-sandstone map, unit F.

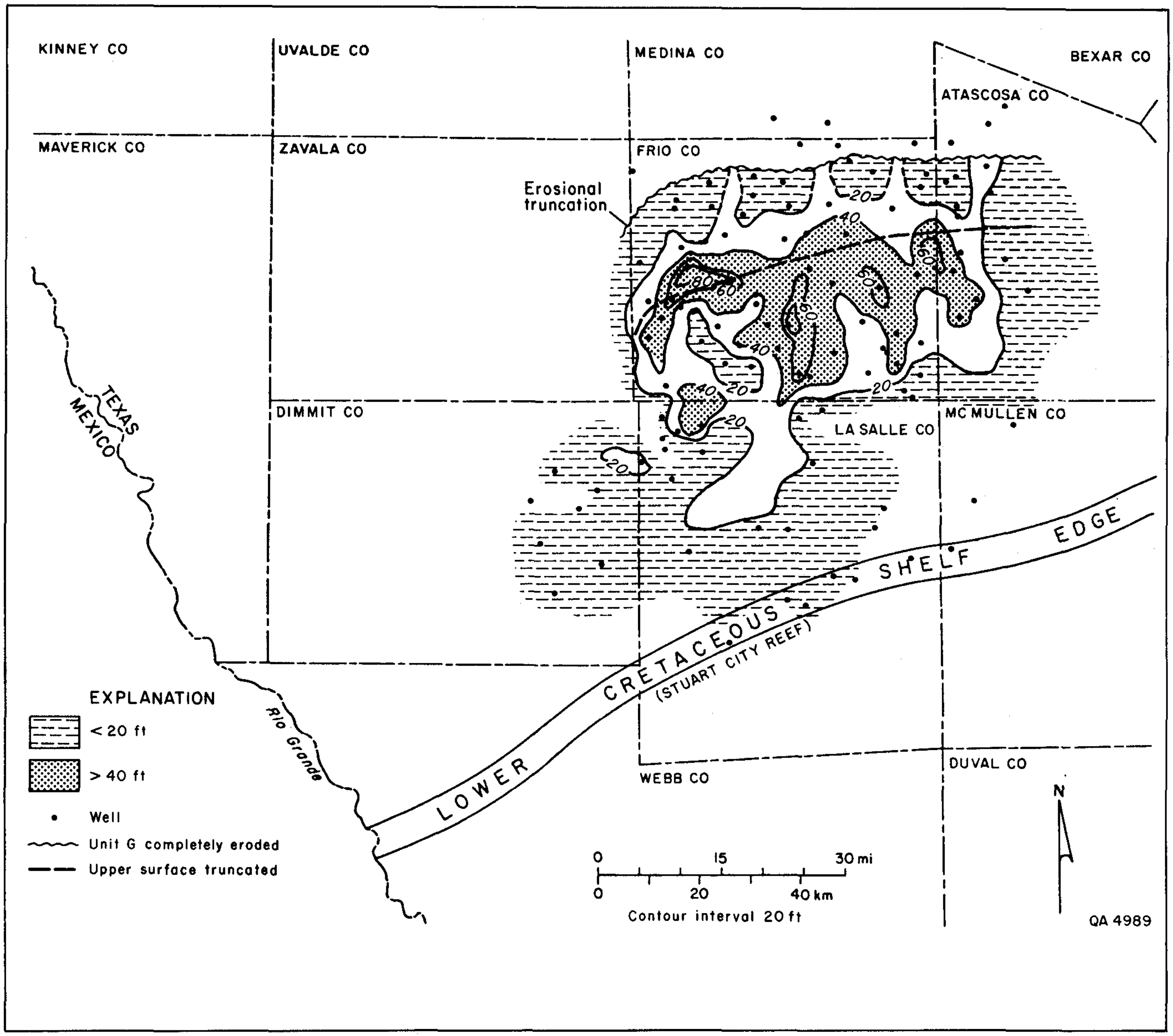

FIGURE 24. Net-sandstone map, unit G.

Depositional Environments

During deposition of unit F, the western depocenter received most of the terrigenous sediment entering the Maverick Basin. Deltaic deposits of unit C, which are contemporaneous with those of unit F, were high-constructive and elongate. In contrast, areally restricted lobate sands of unit F suggest a constructive but wave-modified delta. Deltaic progradation in the eastern depocenter was minor, for delta-front sands of unit F pinch out 25 mi (40 km) north of the shelf edge. Some modification of sand distribution patterns may have taken place during erosion of the updip Olmos Formation.

Deltaic Unit G

Regional Extent

Unit G is much more extensive than unit F, which it overlies; downdip, unit G extends to the shelf edge in La Salle County (fig. 24). To the west, deposits of unit G interfinger with barrier deposits of unit D of the western depocenter. Because unit G is stratigraphically higher than unit F, it is completely truncated farther south (in northern Frio County) than is unit F.

Net-sandstone patterns of unit G are strongly affected by pre-Escondido erosion. Fluvial entrants into the basin are indicated by three dip-elongate

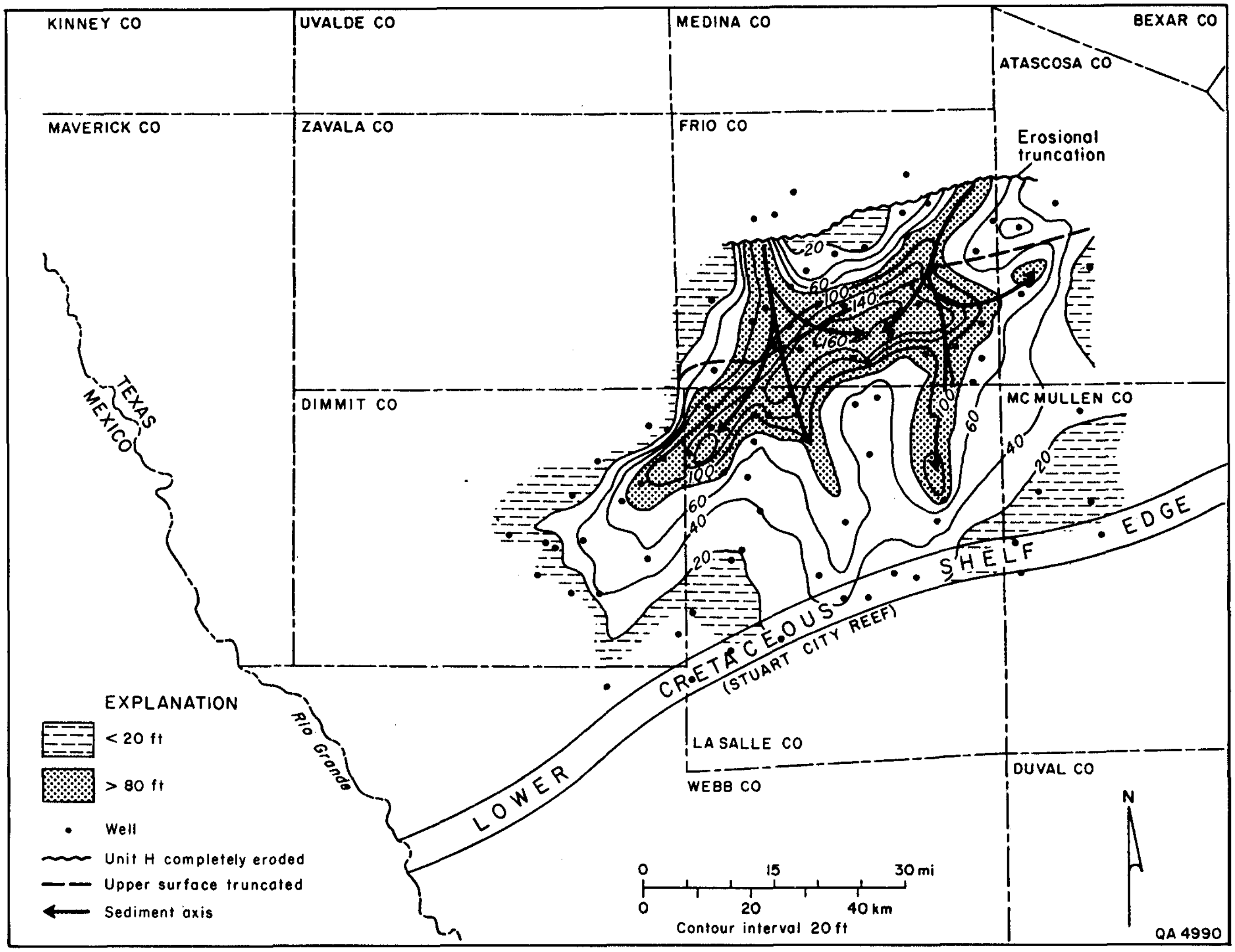

FIGURE 25. Net-sandstone map, unit H.

belts 20 to 40 ft (6 to 12 m) thick that merge downdip with a sandstone complex 40 to 100 ft (12 to 30 m) thick (fig. 24). The thickest sandstone trends (60 to 100 ft; 18 to 30 m) are arranged in a series of diverging dip-elongate axes separated by areas relatively deficient in sandstone. Minor amounts of sandstone (0 to 25 ft; 0 to 8 m) exist downdip in La Salle and Dimmit Counties.

Electric Log Response

Spontaneous potential log response to unit G is dominated by upward-coarsening patterns. Lesser aggradational, upward-fining log responses exist updip in northern Frio County near the updip limit of unit G.

Depositional Environments

Unit G was deposited in a high-constructive, wave-modified, delta complex. Updip fluvial channels were partly eroded; consequently, mostly upward-coarsening delta-front and channel-mouth bar deposits are shown in SP facies maps. Beginning with deposition of the unit G high-constructive delta, primary sediment influx into the Maverick Basin shifted to the eastern depocenter. As shown by the lateral relations of units D and G in southeastern Dimmit County (pl. 1A), progradation of the Big Foot delta system in the eastern subbasin was accompanied by contemporaneous barrier/strandplain deposition (the Rocky Creek system) in the adjacent interdeltaic bight.

Deltaic Unit H

Regional Extent

The most widespread unit in the eastern depocenter, unit H extends beyond the shelf edge in McMullen and La Salle Counties (fig. 25). To the southwest in southeastern Dimmit County, delta-front sandstones of unit H interfinger with barrier/strandplain deposits of unit E of the western depocenter. Fluvial-feeder sandstones of unit H are truncated by the pre-Escondido unconformity in central Atascosa and Frio Counties.

Sandstones of unit H display a bifurcating depositional pattern. Two dip-elongate belts (more than 80 ft [24 m] thick) that lie updip in northeastern and western Frio County intersect a strike-elongate system of sandstones 90 to 150 ft (27 to 46 m) thick in southern Frio County. Toward the shelf edge in south-central La Salle County, two prominent dip-elongate sandstone thicks of 55 to 100 ft (16.5 to 30 m) of net sand represent the southernmost deposits of unit H.

Electric Log Response

As in unit G, the SP log responses of unit H are predominantly upward coarsening owing to nearly complete truncation of updip fluvial sediments north of central Frio and Atascosa Counties. Upward-fining responses appear only in isolated localities in eastern and southwestern Frio County near the updip limit of unit H. Serrate upward-coarsening responses correspond to areas of low sandstone content in north-central La Salle County.

Depositional Environments

Unit H, the youngest in the Big Foot delta system, was deposited as a wave-modified but fluvially dominated delta during the final Olmos progradational pulse into the Maverick Basin. Sediment was carried as far south as the shelf edge, where upward-coarsening prodelta and channel-mouth bar sequences were deposited. Longshore currents deflected delta-front sediments of unit H southwestward into Dimmit County, supplying sediment to the more southerly barrier/strandplain system of unit E (fig. 21).

OLMOS DEPOSITIONAL HISTORY

Early Olmos deposition was characterized by progradation of three deltaic lobes, A, B, and C, of the Catarina delta system centered in Maverick, Dimmit, and Webb Counties. In contrast, the eastern half of the Maverick Basin received minor amounts of sediment, represented by a single deltaic lobe, unit F, during the first half of Olmos deposition (fig. 26). Regressive conditions in the western depocenter reached a maximum with deposition of the C delta, which prograded as far south as the Lower Cretaceous shelf edge. To the east, however, delta-front sands of the contemporaneously deposited unit F reached only as far as 25 mi (40 km) north of the shelf edge. Delta types in the Catarina delta system reflected an interplay between wave and fluvial processes. Delta-front sands of unit A were reworked along depositional strike by waves and longshore currents. Lobate and elongate delta-front sands of deltas B and C, however, reflect the relatively greater importance of fluvial processes.

Late Olmos deposition is marked by a net shift in sediment influx toward the eastern depocenter, as evidenced by the two widespread and well-developed deltaic units G and H of the Big Foot delta system in Frio and La Salle Counties. At the same time, aggradation coupled with coastal onlap in units D and E of the Rocky Creek barrier/strandplain system led to the deposition of a retrogradational sequence in the western depocenter (fig. 27). This coastal/interdeltaic system appears to have been fed from two principal sources: (1) longshore drift from delta-front sediments in the eastern depocenter, which are continuous along strike and interfinger with sediments of the western depocenter, and (2) minor amounts of streamplain sediments updip from the western depocenter. Preservation of transgressive mudstones above unit C suggests that reworking of underlying deltaic units contributed little sediment to the shore-zone system. Because of poor information about units in Mexico it is difficult to evaluate sediment contribution from the west. A western sediment source would require sediment transport to the east or opposite to the regional longshore drift; for this reason, a western source would be minor.

The Big Foot delta system was deposited under increasingly regressive conditions in the eastern depocenter, as reflected by *a* succession from strongly lobate to digitate-lobate to digitate net-sand patterns (fig. 28). Final deposition of the Olmos Formation culminated in the development of high-constructive deltaic unit H, which prograded beyond the Lower Cretaceous shelf edge. Differential compaction and faulting of delta-front sands of unit H along the shelf edge resulted in one of the most active plays (as of 1985) in the Olmos.

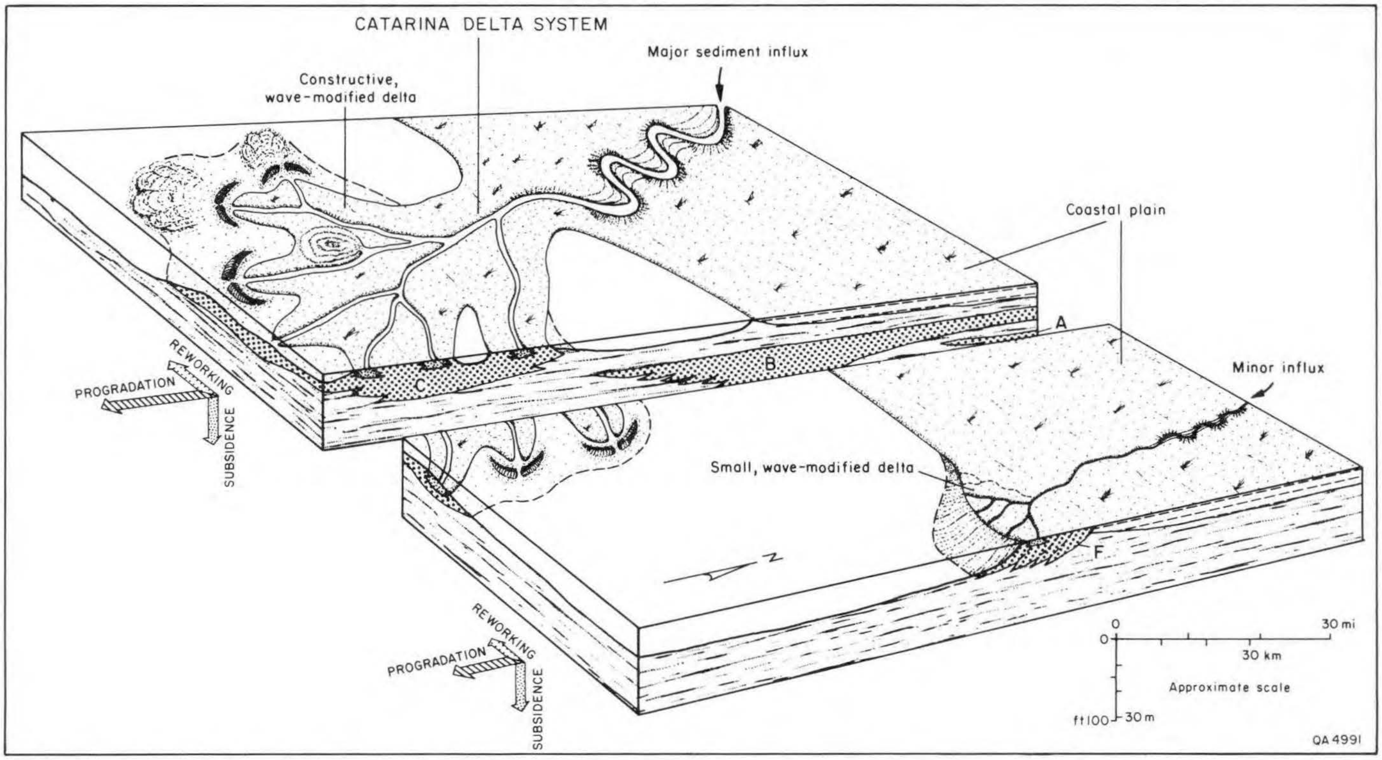

FIGURE 26. Early to middle Olmos depositional setting. High-constructive, wave-modified deltaic sedimentation (unit C) built a major deltaic headland on older deltaic foundations in the western depocenter and was contemporaneous with minor deltaic sedimentation (unit F) in the eastern depocenter.

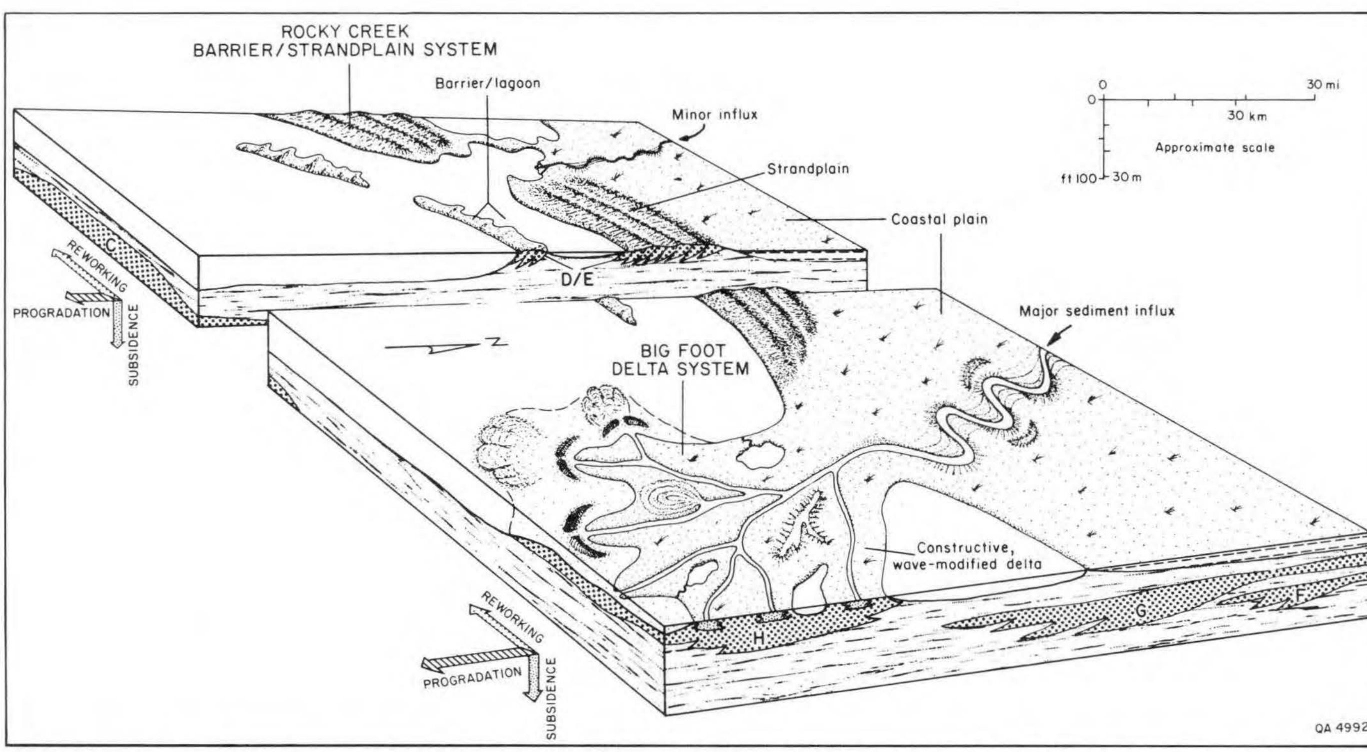

FIGURE 27. Late Olmos depositional setting. The axis of sediment influx shifted to the east during late Olmos sedimentation (units G and H). Longshore drift fed elastics to fringing shore-zone systems (units D and E) in the western depocenter.

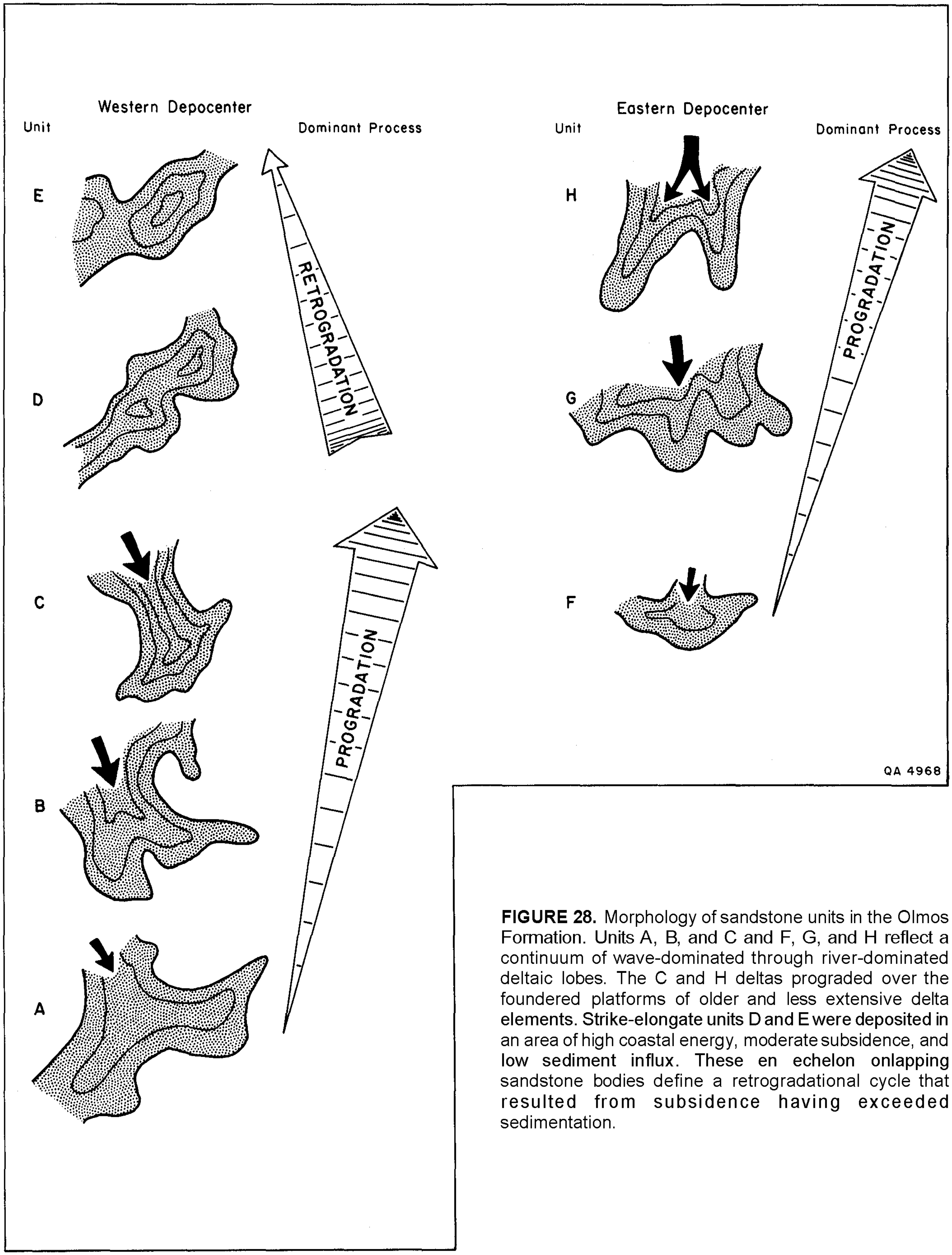

FIGURE 28. Morphology of sandstone units in the Olmos Formation. Units A, B, and C and F, G, and H reflect a continuum of wave-dominated through river-dominated deltaic lobes. The C and H deltas prograded over the foundered platforms of older and less extensive delta elements. Strike-elongate units D and E were deposited in an area of high coastal energy, moderate subsidence, and low sediment influx. These en echelon onlapping sandstone bodies define a retrogradational cycle that resulted from subsidence having exceeded sedimentation.

OLMOS OIL AND GAS PLAYS

The Olmos Formation has long been an active oil and gas exploration target. Earliest Olmos production was established in the 1920's, and by the late 1930's three fields had been discovered in the formation (fig. 29). The next 10 years witnessed the discovery of an additional seven fields. Discovery rates peaked in the 1950's with the detection of 44 fields, 23 of which were oil fields and the remaining 21, gas fields. Since then the oil field discovery rate has declined slowly but steadily. Conversely, as attention shifted to deeper targets in the Olmos, gas field discovery rates peaked again in the 1970's. The Olmos continues to be a prime exploration target, particularly for independent operators.

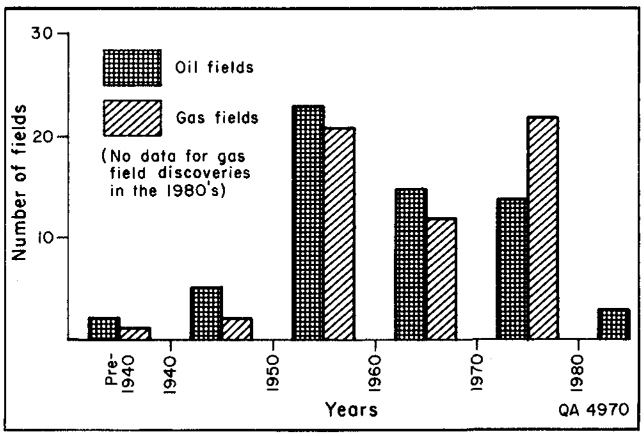

FIGURE 29. Discovery history of Olmos oil and gas fields.

Most Olmos oil fields are small; 61 percent of all Olmos oil pools have produced less than 250,000 barrels of oil (fig. 30). Oil field size, based on cumulative production, is bimodal: the formation contains one group of numerous smaller oil fields and a second group of intermediate to large fields having cumulative productions of between 0.5 million and more than 10 million barrels of oil, respectively. These produce mainly from shallow and thick deltaic sandstones in the eastern depocenter in Frio and Atascosa Counties. Cumulative hydrocarbon production, including oil, condensate, and associated, nonassociated, and casinghead gas, amounts to 157 million barrels of oil equivalent (boe, using a conversion factor of 6 Mcf to 1 barrel of oil). Cumulative oil and condensate amounts to 93 million barrels as of 1984.

Olmos oil and gas fields are grouped into seven exploration and production plays (fig. 31), which are defined on the basis of the depositional origin of the reservoir and structural or trap style. The updip, shallower oil-prone plays are mature. Downdip deltaic and barrier/strandplain sandstones in the western depocenter were designated tight gas reservoirs. To the east of this area, faulting along the Cretaceous shelf edge has led to entrapment of hydrocarbons in distal deltaic sandstones of the Big Foot delta system.

Cumulative Olmos oil production figures were taken directly from the annual report of the Railroad Commission of Texas (1984). Unfortunately, this report lists only annual gas production figures (including condensate, nonassociated gas, and casinghead gas), so estimates of total cumulative gas yield had to be based on many sources of information. We therefore emphasize that whereas oil production data are clearly defined, gas production data and barrel-of-oil equivalents are only estimates.

Updip Stratigraphic Traps

The most prolific play in the Olmos encompasses a group of fields in Frio County that tap stratigraphically trapped oil from G and H delta sandstones of the Big Foot delta system (fig. 31). Fifty-two million boe have been produced from this mature play (table 1 and fig. 32). Most of the oil and

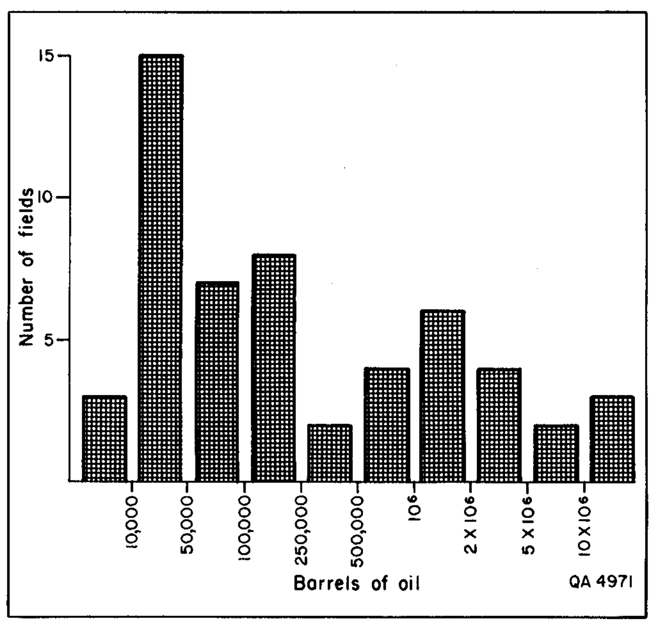

FIGURE 30. Olmos oil field size based on cumulative production to 1983.

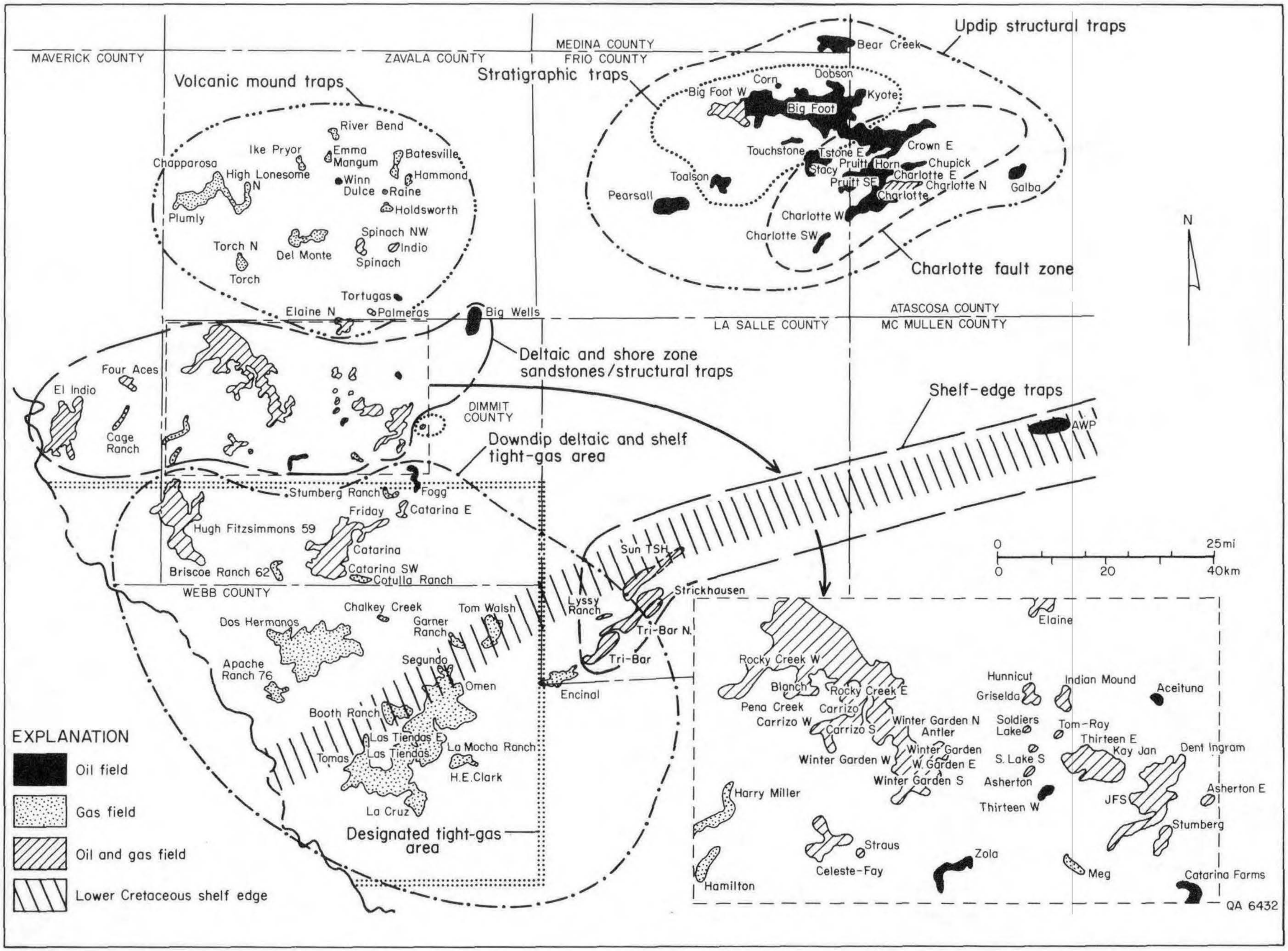

FIGURE 31. Oil and gas fields and major exploration and production plays, Olmos Formation.

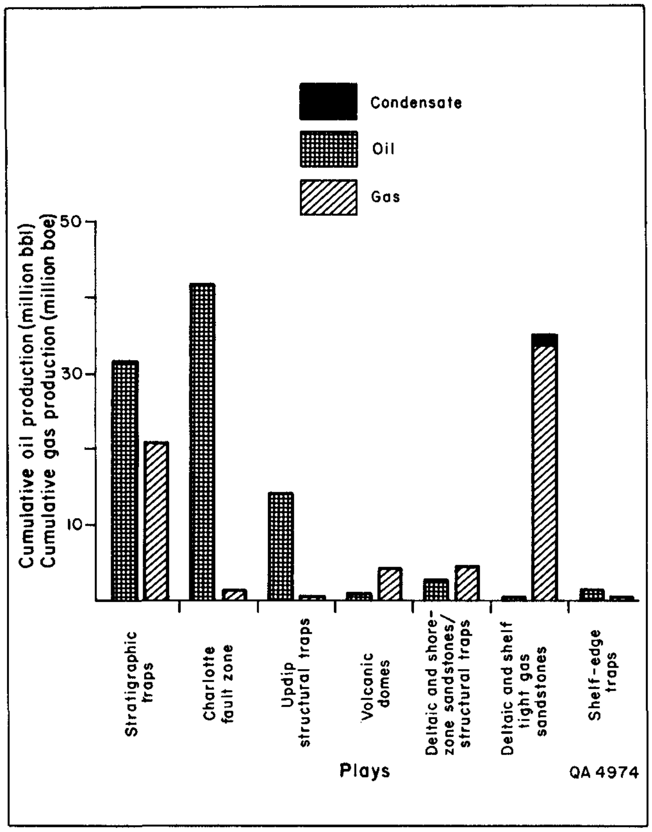

FIGURE 32. Cumulative oil and gas production (in boe) from the seven Olmos plays.

nonassociated gas comes from two fields, Big Foot and Big Foot West, which are dominantly oil and gas reservoirs, respectively (table 2). The Big Foot field is a classic unconformity-related trap, in which post-Olmos erosion truncated successively older sandstone units updip. The sand shales out to the east and west (Dunham, 1954), and Escondido mudstones seal the reservoir. Kyote, Dobson (Navarro), and Touchstone traps also result from regional truncation; the remaining fields are related mainly to sand pinch-out.

This shallow oil and gas play has moderate permeabilities and porosities, high water saturations, intermediate-gravity crude oils, and low residual oil saturations (table 2). Wells are typically fractured to stimulate production, and most fields have undergone waterflooding or pressure maintenance by gas or water injection to supplement inefficient solution-gas-drive mechanisms.

Charlotte Fault Zone

This oil-prone play in central Atascosa and southeastern Frio Counties (fig. 31) is the second most prolific in the Olmos. Cumulative production amounts to 42.7 million boe; however, in contrast with the Olmos stratigraphic trap play, it has produced comparatively little gas. Cumulative oil

TABLE 1. *Olmos plays ranked by cumulative total hydrocarbon production.*

Play	Play maturity	Oil and condensate (bbl)	Casinghead and nonassociated gas (boe)	Total production (boe)
Updip stratigraphic traps	M	31,307,000	20,620,833	51,927,833
Charlotte Fault Zone	M	41,590,000	1,109,067	42,699,067
Downdip deltaic and shelf tight-gas sandstones	MY	200,000 1,248,000 (c)	33,410,967	34,858,967
Updip structural traps	M	13,980,000	233,000	14,213,000
Deltaic and shore-zone sandstone structural traps	MM	2,673,000 293,000 (c)	4,108,300	7,074,300
Volcanic mounds	M	531,221	4,084,407	4,615,628
Shelf-edge traps*	Y	1,327,000 83,000 (c)	300,500	1,710,500
Totals		93,232,221	63,867,074	157,099,295

* Production data from AWP field only.
(c) = condensate; M = mature; MM = moderately mature; MY = moderately youthful; Y = youthful

TABLE 2. *Geologic, engineering, and production characteristics of the stratigraphic trap play and explanation of abbreviations.*

Counties: Dimmit, Frio **Play type:** Oil and Gas

Field and reservoirs	Disc. date	Trap	Drive	Depth (ft)	Por. (%)	Perm. (md)	H_2O sat.(%)	Net pay(ft)	API grav.	Init. GOR	Init. press. (psi)	Prod. tech.	Well spacing (acres)	Cum. prod. (bbl ×1000)	ROS (%)
Asherton, E (Olmos)	72	UPP	-	4,601	20	15	50	13	37	760	-	-	20	60	-
Big Foot (Olmos B, D3)	49	RT	SG	4,500	27	4	60	24	45	300	1,455	WF PMG	20/10	29,555	20
Dobson (Navarro)	53	RT	-	3,238	28	2	50	5	39	360	-	PMW	20	48	-
Kyote	51	RT	SG	3,600	26	11	50	10	40	950	1,039	WF	20	1,301	25
Toalson (Olmos A)	63	PPS	SG	4,222	28	422	31	7	26	-	1,745	-	40	102	-
Touchstone (Olmos A)	57	RT	SG	3,600	25	236	35	4	38	-	1,540	PMW	40	214	17
Touchstone E (Olmos A)	57	I	SG	3,600	26	235	35	4	38	-	1,525	WF	-	137	21
Average				3,852	25.7	132	44	10	37	593	1,460		Total	31,307	21

Other oil and gas field in this play: Big Foot West

Cumulative oil production	31,307,000 bbl
Cumulative condensate	813 bbl
Cumulative nonassociated gas production	106,899,000 Mcf
Estimated cumulative casinghead gas production	16,826,000 Mcf
Estimated boe from gas production	20,620,833 boe
TOTAL HYDROCARBON PRODUCTION	51,927,833 boe

Column headings: Disc. date = discovery date, Por. = average porosity, Perm. = permeability, H_2O sat. = water saturation, API grav. = oil gravity, Init. GOR = initial gas-oil ratio, Init. press. = initial reservoir pressure, Prod. tech. = production technology, Cum. prod. = cumulative production as of January 1, 1984, ROS = residual oil saturation.

Trap: FA = faulted anticline or dome, FBA = fault-bounded anticline or dome, FM = faulted monocline, I = isolani (isolated porous lens), LT = local truncation, NPP = porosity pinch-out across a nose (dome, terrace), PPS = partly productive structure, RT = regional truncation, SA = simple anticline or dome, SSF = simple sealing fault, UPP = updip porosity pinch-out.

Drive mechanism: GC = gas-cap expansion, SG = solution-gas drive (depletion, fluid expansion, etc.), WD = water drive.

Production technology: FRAC = fracture, PMG = pressure maintenance by gas injection, PMW = pressure maintenance by water injection, U = unitized, WF = waterflood.

production amounts to 41.6 million barrels (table 1) from fault-sealed monoclines and from anticlines in the Charlotte fault system (fig. 1). This play produces from thick delta-front sandstones of the Big Foot delta system. The reservoirs here are slightly deeper than those in the stratigraphic-trap oil and gas play, and they display lower average permeabilities and higher initial pressures but equivalent porosities, pay thicknesses, water saturations, oil gravity, and gas-to-oil ratios (table 3). Reservoir energy during primary production is supplied by solution-gas drives; waterfloods were used in all the large reservoirs to improve recovery.

Updip Structural Traps

Five Olmos oil fields, producing from delta-front, delta-fringe, and delta-plain sandstones of the F and G delta complexes in Atascosa, Frio, and Medina Counties (fig. 31), have produced 14.2 million boe from structural traps in this updip oil play. Two of the fields are fault bounded (table 4). The Navarro and Olmos A reservoirs in the Pearsall field produce from the Pearsall anticline; sand pinch-out in the Olmos A pool results in a combined structural/-stratigraphic trap. As in the Charlotte Fault Zone play, gas here contributes little to cumulative hydrocarbon production; oil production totals 14 million barrels.

Reservoir energy in this shallow play is supplied by water drives; pressure maintenance through water injection and waterfloods has been used to improve oil recovery (table 4). This play is petrophysically similar to the other plays in the Big Foot delta system, the only substantial differences being lower initial pressures and water saturations.

Volcanic Mounds

Late Cretaceous volcanism 90 to 70 mya resulted in a northeast-trending curvilinear belt of volcanic centers or mounds in South and Central Texas. Most of the approximately 200 tuff mounds in the 250-mi-long trend (Ewing and Caran, 1982) are contained in two volcanic provinces known as the Uvalde (between Del Rio and San Antonio) and Travis (east of Austin) fields. Both volcanic provinces have been extensively explored and are in a mature stage of development. The Olmos volcanic mound trap play in Zavala County (fig. 31) produces gas and minor amounts of oil from faulted anticlines over volcanic centers in the Uvalde volcanic field. Additional oil and gas are produced from (1) the underlying San Miguel Formation, which also forms domes by compactional draping over the volcanic mounds; (2) porous carbonate beachrock (Anacacho Formation) deposited in high-energy marine shoals flanking the bathymetrically positive tuff mounds; and (3) porous zones in the tuff (Ewing and Caran, 1982).

During the past several decades this Olmos play has been actively explored. It has produced 4.6 million boe, but only 0.5 million barrels of oil (table 1 and fig. 32). Olmos fluvial and barrier/strandplain sandstones thin over the mounds and have undergone severe faulting (Indest and McPherson, 1983) that created heterogeneous, multiple-compartment reservoirs. Ultimate recoveries are likely to be poor; even in the large Elaine (Olmos) field, a unitized multiple-reservoir field that has been waterflooded and subjected to pressure maintenance by gas injection, less than 10 percent of the 2.4 million barrels of original oil in place will be recovered. As a result of poor oil and gas recovery, at least six of the Olmos gas fields in this play have been abandoned.

Little petrophysical, production, or engineering information is available on the fields in this play. Characteristics of the Elaine (Olmos) reservoir are shown in table 5. This field is, however, atypical in that it is dominantly an oil field, whereas the others in the same play have produced mostly gas.

Deltaic and Shore-zone Sandstone Structural Traps

This gas-prone play produces from multiple stacked Olmos reservoirs gently folded into low-relief anticlinal traps in southern Dimmit and Maverick Counties (fig. 31). Sandstones are of barrier/strandplain and wave-modified, high-constructive delta platform and delta-front origin. Consequently, whereas hydrocarbon entrapment was dominantly structural, the traps are partly modified by sand pinch-out, resulting in numerous partly productive structures.

The play is relatively shallow and has moderate permeabilities and porosities (table 6). Water saturations and oil gravities are high. The drive mechanism in oil reservoirs of this play is solution gas that has been supplemented in several fields by water-injection pressure maintenance or by waterfloods. Cumulative production amounts to 7 million boe, two-thirds of which is from nonassociated and casinghead gas production totaling almost 25 Bcf.

Downdip Deltaic and Shelf Tight Gas Sandstones

Deltaic, barrier/strandplain, and shelf sandstones are productive in this gas-rich play. Almost

TABLE 3. *Geologic, engineering, and production characteristics of the Charlotte Fault Zone play.*

Counties: Atascosa, Frio **Play type:** Oil

Field and reservoirs	Disc. date	Trap	Drive	Depth (ft)	Por. (%)	Perm. (md)	H_2O sat.(%)	Net pay(ft)	API grav.	Init. GOR	Init. press. (psi)	Prod. tech.	Well spacing (acres)	Cum. prod. (bbl ×1000)	ROS (%)
Charlotte (Navarro)	63	SSF	SG,GC	5,200	22	18	46	20	35	-	2,348	PMW	-	18,684	25
Charlotte N	53	SSF	SG	4,980	25	60	40	14	38	350	2,200	U,WF	20	3,631	18
Charlotte SW (Olmos, Up.)	64	FBA	WD	5,540	23	77	51	11	32	1043	2,250	WF	-	715	42(?)
Charlotte W, E	49/54	SSF	-	-	25	64	-	-	-	-	-	-	-	679	-
Chupick (Olmos A)	63	SSF	SG	5,243	27	38	45	8	39	700	2,263	-	20	623	12
Crown E (Navarro)	54	FM	SG	4,300	28	24	45	10	41	490	1,870	WF	20	9,389	12
Horn (5300, Olmos, Up.)	54/66	SSF	SG	5,200	20	8	57	15	37	-	2,227	WF	-	195	-
Horn N (Olmos, Up.)	60	SSF	SG	5,165	-	-	-	-	38	-	-	-	-	125	-
Pruitt	51	SSF	SG	-	-	-	-	8	-	-	-	WF	-	3,422	-
Pruitt S, SE	51/55	SSF	SG	4,900	22	12	50	11	38	-	2,178	WF	20	3,236	25
Stacy (Olmos A)	55	SSF	SG	-	-	-	-	-	36	-	-	-	-	891	-
Average				5,078	24	37	47	12	37	655	2,190				18
													Total	41,590	

Cumulative oil production	41,590,000 bbl
Estimated cumulative casinghead gas production	6,654,400 Mcf
Estimated boe from gas production	1,109,067 boe
TOTAL HYDROCARBON PRODUCTION	42,699,066 boe

Column headings: Disc. date = discovery date, Por. = average porosity, Perm. = permeability, H_2O sat. = water saturation, API grav. = oil gravity, Init. GOR = initial gas-oil ratio, Init. press. = initial reservoir pressure, Prod. tech. = production technology, Cum. prod. = *cumulative production* as of January 1, 1984, ROS = residual oil saturation.

Trap: FA = faulted anticline or dome, FBA = fault-bounded anticline or dome, FM = faulted monocline, I = isolani (isolated porous lens), LT = local truncation, NPP = porosity pinch-out across a nose (dome, terrace), PPS = partly productive structure, RT = regional truncation, SA = simple anticline or dome, SSF = simple sealing fault, UPP = updip porosity pinch-out.

Drive mechanism: GC = gas-cap expansion, SG = solution-gas drive (depletion, fluid expansion, etc.), WD = water drive.

Production technology: FRAC = fracture, PMG = pressure maintenance by gas injection, PMW = pressure maintenance by water injection, U = unitized, WF = waterflood.

TABLE 4. *Geologic, engineering, and production characteristics of the updip structural trap play.*

Counties: Atascosa, Frio, Medina **Play type:** Oil

Field and reservoirs	Disc. date	Trap	Drive	Depth (ft)	Por. (%)	Perm. (md)	H_2O sat.(%)	Net pay(ft)	API grav.	Init. GOR	Init. press. (psi)	Prod. tech.	Well spacing (acres)	Cum. prod. (bbl ×1000)	ROS (%)
Bear Creek/ Sleepy Creek (Olmos D-3)	47	SSF	-	2,100	25	10	46	-	39	290	907	-	20	2,420	19
Galba (Navarro)	55	SSF	SG,WD	4,900	24	33	40	12	41	-	1,850	U,WF	20	1,072	-
Pearsall (Navarro)	24	SA	WD	3,900	34	-	31	30	27	200	-	PMW	20	8,129	-
Pearsall (Olmos A)	62	PPS	WD	4,124	26	129	39	7	26	87	1,620	PMW	40	2,359	13
Average				3,756	27	57	39	16	33	192	1,459				16
													Total	13,980	

Cumulative oil production	13,980,000 bbl
Estimated cumulative casinghead gas production	1,398,000 Mcf
Estimated boe from gas production	233,000 boe
TOTAL HYDROCARBON PRODUCTION	14,213,000 boe

Column headings: Disc. date = discovery date, Por. = average porosity, Perm. = permeability, H_2O sat. = water saturation, API grav. = oil gravity, Init. GOR = initial gas-oil ratio, Init. press. = initial reservoir pressure, Prod. tech. = production technology, Cum. prod. = cumulative production as of January 1, 1984, ROS = residual oil saturation.

Trap: FA = faulted anticline or dome, FBA = fault-bounded anticline or dome, FM = faulted monocline, I = isolani (isolated porous lens), LT = local truncation, NPP = porosity pinch-out across a nose (dome, terrace), PPS = partly productive structure, RT = regional truncation, SA = simple anticline or dome, SSF = simple sealing fault, UPP = updip porosity pinch-out.

Drive mechanism: GC = gas-cap expansion, SG = solution-gas drive (depletion, fluid expansion, etc.), WD = water drive.

Production technology: FRAC = fracture, PMG = pressure maintenance by gas injection, PMW = pressure maintenance by water injection, U = unitized, WF = waterflood.

TABLE 5. *Geologic, engineering, and production characteristics of a volcanic mound field as exemplified by the Elaine (Olmos) pool.*

Disc. date	1953
Trap	Faulted anticline
Drive	Solution gas
Depth (ft)	3,624
Por. (%)	26
Perm. (md)	126
Net pay (ft)	16
API grav. (°)	31
Init. press. (psi)	1,590
Prod. technology	U, PMG, WF*
Well spacing (acres)	30
Cum. prod. (bbl × 1000)	339
Est. OOIP (bbl × 1000)	2,400
Ult. rec. (%)	8

**U = unitized, PMG = pressure maintenance gas, WF = waterflood*

35 million boe was produced from structural and stratigraphic traps in Webb and southern Dimmit Counties. Updip traps in the play are dominantly stratigraphic and result from landward pinch-out of barrier/strandplain sands of the Rocky Creek barrier/strandplain system. Downdip fields are related to down-to-the-coast normal faults along the Lower Cretaceous shelf edge (Snedden and Kersey, 1982). Most of the play falls within an area designated as tight gas productive (fig. 31).

Oil production is minor, accounting for only 200,000 barrels (table 7). However, the play has produced more than 1.25 million barrels of condensate and 199 Bcf of nonassociated gas. Production characteristics vary widely across the play. Updip gas fields produced 51.7 Mcf of gas per well on average in 1980, whereas the downdip fields yielded 32.5 Mcf of gas per well (Snedden and Kersey, 1982). These downdip fields produce from delta-front splay and other shelf sandstones that are thinner, finer grained, and less mature than their more productive updip equivalents.

The oil-producing reservoirs in the play are tight (porosities and permeabilities are less than 20 percent and 10 md, respectively), display very high water saturations, and produce very high gravity crude oil (table 7). Detailed petrologic study of these sandstones (Güven and Jacka, 1981) indicates that they have undergone advanced diagenesis in which porosity has been partly occluded by quartz, ferroan calcite, and phyllosilicate authigenesis (dominated by illite and to a lesser extent chlorite, kaolinite, and smectite).

Shelf-Edge Traps

Deep Olmos production has been discovered recently along a trend extending from southern Webb County (described in the previous play) through La Salle and McMullen Counties to possibly as far east as western Live Oak County. Few data are available from these newly discovered fields, with the exception of the AWP field in McMullen County (fig. 31). Although this play currently (1985) is undergoing intense exploration activity, the potential for deep Olmos production was recognized in the early 1970's. However, early development was unsuccessful, largely because fracturing technology at that time was inadequate to stimulate the low-compressive-strength, tight sandstones of the Olmos (Gregorcyk and others, 1984). Although the first wells completed in the play produced at low rates (8 to 14 bbl/day), they continued to yield oil through the early 1980's, and thus interest in deep Olmos production was renewed.

The AWP field produces from distal delta-front sandstones slightly tilted to the southeast as a result of differential compaction over the Stuart City Reef. The sandstones updip of the shelf edge are locally truncated by erosion that is spatially unrelated to the updip unconformity and that may be the product of submarine canyon formation. The field is crosscut by two faults that parallel and are related to faulting during final compaction over the Lower Cretaceous shelf edge. Porosity is moderate (20 percent) for this depth of Olmos production (9,800 ft), but permeabilities are low, averaging approximately 1 md. There are local "sweet spots" of better porosity and permeability that result from early gas migration into the stratigraphic trap with the subsequent inhibition of cementation (Gregorcyk and others, 1984).

As a consequence of improved fracturing technology, this play offers the best potential for continued Olmos discovery and production. To date, cumulative production from the AWP field is 1.7 million boe, mostly of high-gravity (44°) crude oil and condensate (table 1). Refractured pilot wells in which heavy concentrations and large volumes of sand were carried in gelled diesel frac-fluids increased production by an order of magnitude in this field (20 bbl/day to 200 bbl/day after restimulation; Gregorcyk and others, 1984).

TABLE 6. *Geologic, engineering, and production characteristics of the deltaic and shore-zone sandstone structural trap play.*

Counties: Dimmit, Maverick **Play type:** Gas and Oil

Field and reservoirs	Disc. date	Trap	Drive	Depth (ft)	Por. (%)	Perm. (md)	H_2O sat.(%)	Net pay(ft)	API grav.	Init. GOR	Init. press. (psi)	Prod. tech.	Well spacing (acres)	Cum. prod. (bbl ×1000)	ROS (%)
Aceituna (Olmos)	57	-	-	4,205	-	-	-	-	37	-	-	-	-	120	-
Asherton (Olmos)	55	FBA	-	-	-	-	-	5	-	-	-	-	-	gas	-
Blanch (Olmos)	59	NPP	SG	2,329	22	-	44	5	39	100	950	WF	-	68	21
Carrizo S (Olmos 2370)	77	FA	-	2,387	-	-	-	12	32	1,600	-	-	-	45	-
Indian Mound	67	PPS	SG	3,525	25	150	48	15	35	-	1,580	WF,PMW	20	430	55(?)
Rocky Creek (Olmos 3-D, 3-E)	56	PPS	-	2,224	26	50	40	15	39	580	960	FRAC	20	126	-
Stumberg (Olmos)	79	FA	-	4,195	19	3	-	-	50	-	-	-	-	276	-
Thirteen E (3470 Olmos)	59	PPS	SG,GC	3,476	26	108	31	12	48	1,940	1,690	WF	40	1,514	25
Tom-Ray (Olmos 1)	69	FBA	SG	3,482	-	-	-	6	34	-	-	-	-	59	-
Winter Garden	49	PPS	SG	2,821	24	50	54	10	42	-	1,175	FRAC,PMW	20	35	-
Average				3,183	24	72	43	10	40	1,055	1,271		Total	2,673	23

Other gas and oil fields in this play: Big Wells (Olmos), Blanch, Celeste-Fay, Dent Ingram, El Indio (Olmos and E,N), Farias, Griselda (Olmos 3518), Hamilton Ranch, Harry Miller, Hunnicut, John High, Kay-Jan, Pena Creek, Pendencia, Rocky Creek (Olmos and East), Soldiers Lake (and South), Straus, Zola.

Cumulative oil production	2,673,000 bbl
Oil production from small fields (not included above)	293,000 bbl
Cumulative condensate production	45,000 bbl
Cumulative nonassociated gas production	14,862,000 bbl
Estimated cumulative casinghead gas production	9,787,800 Mcf
Estimated boe from gas production	4,108,300 boe
TOTAL HYDROCARBON PRODUCTION	7,074,300 boe

Column headings: Disc. date = discovery date, Por. = average porosity, Perm. = permeability, H_2O sat. = water saturation, API grav. = oil gravity, Init. GOR = initial gas-oil ratio, Init. press. = initial reservoir pressure, Prod. tech. = production technology, Cum. prod. = cumulative production as of January 1, 1984, ROS = residual oil saturation.

Trap: FA = faulted anticline or dome, FBA = fault-bounded anticline or dome, FM = faulted monocline, I = isolani (isolated porous lens), LT = local truncation, NPP = porosity pinch-out across a nose (dome, terrace), PPS = partly productive structure, RT = regional truncation, SA = simple anticline or dome, SSF = simple sealing fault, UPP = updip porosity pinch-out.

Drive mechanism: GC = gas-cap expansion, SG = solution-gas drive (depletion, fluid expansion, etc.), WD = water drive.

Production technology: FRAC = fracture, PMG = pressure maintenance by gas injection, PMW = pressure maintenance by water injection, U = unitized, WF = waterflood.

TABLE 7. *Geologic, engineering, and production characteristics of the Olmos downdip deltaic and shelf tight-gas sandstone play.*

Counties: Dimmit, La Salle, Webb **Play type:** Gas and Condensate (minor oil)

Field and reservoirs	Disc. date	Trap	Drive	Depth (ft)	Por. (%)	Perm. (md)	H_2O sat.(%)	Net pay(ft)	API grav.	Init. GOR	Init. press. (psi)	Prod. tech.	Well spacing (acres)	Cum. prod. (bbl ×1000)	ROS (%)
Catarina Farms	80	LT/PPS	-	4,458	15	16	-	10	48	8,950	1,866	-	-	93	-
Catarina SW (Olmos 2)	75	-	-	5,017	-	-	-	-	51	2,248	-	-	-	39	-
Catarina E (Olmos A)	76	PPS	-	4,729	19	3	62	12	47	470	1,881	-	-	33	-
Average				4,735	17	10	62	11	49	3,890	1,873				
													Total	165	

Other gas and oil fields in this play: Apache Ranch, Booth Ranch, Briscoe Ranch, Dos Hermanos (and DH, East, West), Encinal, Garner Ranch, H. E. Clark, Hugh Fitzsimmons, La Cruz, La Mocha Ranch, Las Tiendas (and E), Segundo, Stumberg Ranch, Tom Walsh, Tomas, Tri Bar.

Cumulative oil production	165,000 bbl
Oil production from small fields (not included above)	35,000 bbl
Cumulative condensate	1,248,000 bbl
Cumulative nonassociated gas production	198,855,000 Mcf
Estimated cumulative casinghead gas production	1,610,000 Mcf
Estimated boe from total gas production	33,410,967 boe
TOTAL HYDROCARBON PRODUCTION	34,858,967 boe

Column headings: Disc. date = discovery date, Por. = average porosity, Perm. = permeability, H_2O sat. = water saturation, API grav. = oil gravity, Init. GOR = initial gas-oil ratio, Init. press. = initial reservoir pressure, Prod. tech. = production technology, Cum. prod. = cumulative production as of January 1, 1984, ROS = residual oil saturation.

Trap: FA = faulted anticline or dome, FBA = fault-bounded anticline or dome, FM = faulted monocline, I = isolani (isolated porous lens), LT = local truncation, NPP = porosity pinch-out across a nose (dome, terrace), PPS = partly productive structure, RT = regional truncation, SA = simple anticline or dome, SSF = simple sealing fault, UPP = updip porosity pinch-out.

Drive mechanism: GC = gas-cap expansion, SG = solution-gas drive (depletion, fluid expansion, etc.), WD = water drive.

Production technology: FRAC = fracture, PMG = pressure maintenance by gas injection, PMW = pressure maintenance by water injection, U = unitized, WF = waterflood.

CONCLUSIONS

The Olmos Formation was deposited on a broad, shallow shelf that was strongly influenced by marine processes. Five progradational cycles, consisting of units A and B and contemporaneous sandstone couplets C-F, D-G, and E-H, compose the framework sandstones of the Olmos. These units and couplets are separated by thin shelf mudstones that probably represent episodic marine inundations over foundered deltaic and shore-zone platforms. Early Olmos sedimentation followed the axis of the Rio Grande Embayment, being concentrated in the western depocenter of the Maverick Basin and coincident with the principal axis of sedimentation in the underlying San Miguel Formation. Vigorous progradation resulted in offlap of deltaic units A, B, and C of the Catarina delta system. During deposition of unit C, sediment began to enter the eastern half of the Maverick Basin. Initially influx was minor, but during the latter half of Olmos sedimentation this depocenter became dominant. Thick, wave-modified, high-constructive delta sandstones of the Big Foot delta system were deposited in the eastern depocenter. Alongshore to the west, coastal processes dominated and, together with subsidence, resulted in a retrogressive (onlapping) sequence of shore-zone deposits that compose the Rocky Creek barrier/strandplain system.

In the total universe of Texas hydrocarbon resources, the Olmos Formation is a minor star. Cumulative hydrocarbon production from the entire formation amounts to only 157 million boe, which is less than the cumulative oil production from selected individual large reservoirs in the Frio Formation. Nonetheless, the Olmos Formation will continue to be an attractive target for independent operators because of its shallow depth and proved history of oil and gas production. Recent developments in deep Olmos trends, both in the gas-prone, and to a lesser extent, condensate-prone western depocenter, as well as the oil-prone eastern depocenter, suggest that the best years of Olmos production may lie ahead.

Future Exploration Targets

Future exploration strategies in the Olmos will differ depending on whether the target lies within the shallower mature updip plays or the deeper youthful plays of the shelf edge. In the updip plays, there are two alternatives for explorationists: either to extend known plays or to embark on a program of reexploration of known fields. For example, the distribution of the volcanic-mound trap play is confined at present to Zavala County, yet detailed proprietary seismic lines have delineated numerous smaller domes throughout the updip Olmos depositional area. The updip stratigraphic trap play also offers several potential wildcat targets. Regional mapping of thicker sandstone units lying in direct contact with the post-Olmos unconformity and presumably sealed by Escondido mudstones has pinpointed seven promising exploration fairways in the gas-prone western depocenter and 10 much larger targets in the oil-prone eastern depocenter (fig. 33). These objectives are not confined to any single sandstone unit but rather are present in all of the intervals in the Olmos Formation. The production potential of these stratigraphic-trap targets is emphasized by the 30 million barrels of oil obtained from the Big Foot field, a classic unconformity-related stratigraphic trap and the most prolific field in the Olmos Formation.

An alternative strategy for increasing updip Olmos production is oil field reexploration. In heterogeneous reservoirs, oil can be prevented from migrating to the well bore by discontinuities such as facies pinch-outs, mud plugs and drapes, permeability differences, and a variety of other heterogeneities. At abandonment, this nonresidual mobile oil remains stratigraphically trapped in the reservoir. By carefully detailing the internal architecture of the reservoir using interpretive geological mapping, explorationists can use strategically sited wells to tap this oil and to increase the recovery from the reservoir. More detailed explanations and examples of strategic infill drilling may be found in Fisher and Galloway (1983) and Tyler and others (1984).

Oil recovery from Cretaceous sandstone reservoirs in South Texas is characteristically low, averaging about 20 percent of the oil in place (Galloway and others, 1983). An optimistic estimate of the ultimate cumulative production of oil from the updip plays based on current trends is 100 million barrels. Thus, by extrapolation, the original oil in place was probably on the order of 500 million barrels. Approximately 142 million barrels of mobile oil will remain stratigraphically trapped in the updip oil reservoirs at abandonment. This oil, which amounts to a little less than 1.5 times the ultimate production, represents a significant target for smaller operators with the resources to reexplore older Olmos fields.

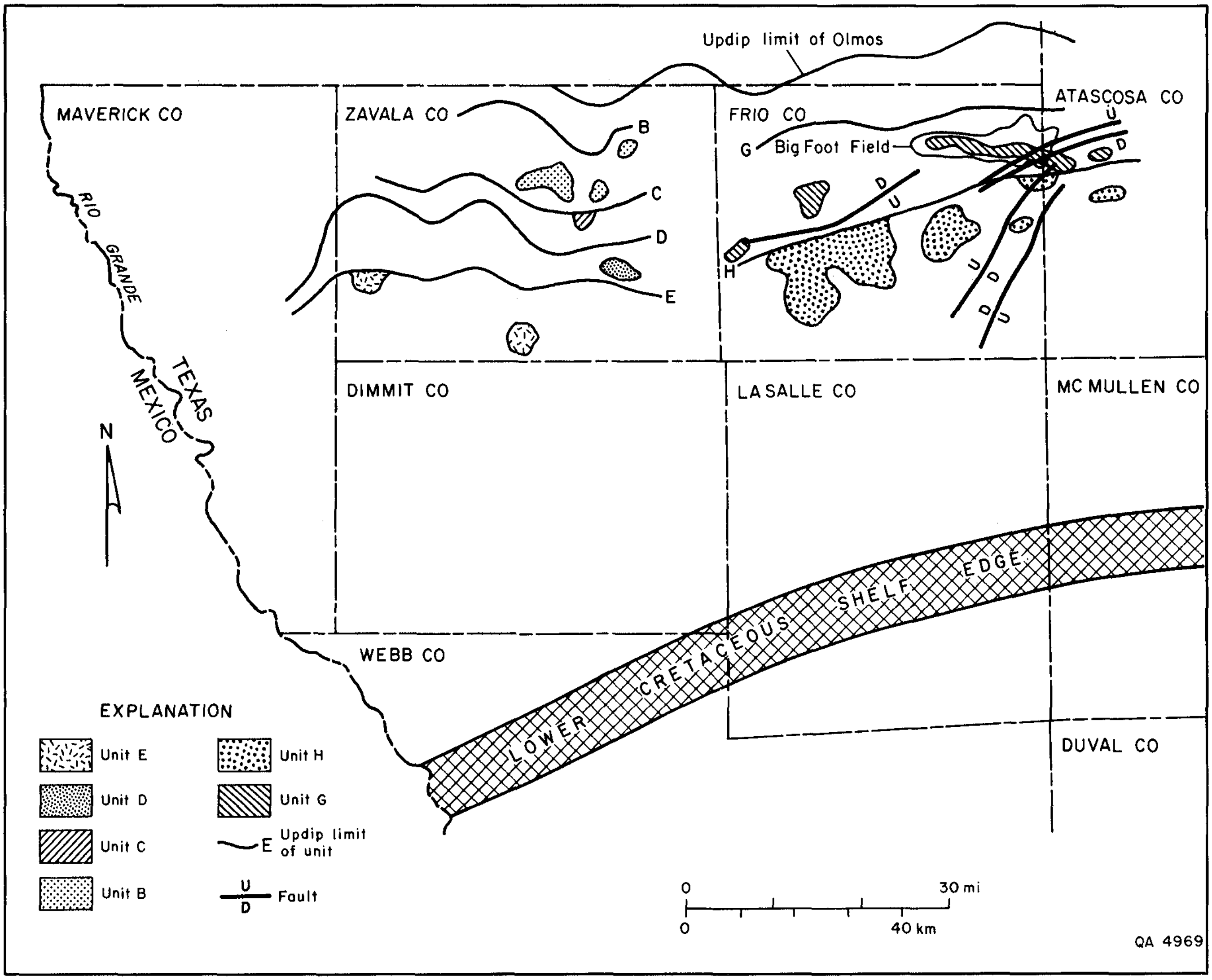

FIGURE 33. Map showing potential areas of unconformity-related stratigraphic traps. Solid lines represent the total removal of component units, and stippled patterns show areas of more than 15 ft (5 m) of sandstone in direct contact with the unconformity. The trap in the Big Foot field in Frio County is the result of erosion and the unconformable superposition of sealing Escondido mudstones over reservoir sandstones.

In the youthful shelf-edge plays in Webb County, and within and basinward of La Salle and McMullen Counties, exploration strategies will continue to focus primarily on wildcatting. Potential targets include fault-bounded structures similar to those in the distal parts of the downdip deltaic and shelf tight-gas sandstone play, as well as isolated sandstone units in intraslope subbasins, and perhaps submarine canyon, fan, and basin-plain deposits farther seaward. The prolific production from the two deep Olmos plays (36.5 million boe produced in a decade), coupled with vastly improved geophysical prospecting and reservoir fracturing techniques, suggests that these plays will be active for many years to come.

ACKNOWLEDGMENTS

Funding for this research was provided by the Texas Energy and Natural Resources Advisory Council under grant no. IAC(82-83)-0821 and in part by the Gas Research Institute under contract no. 5082-211-0708. The manuscript was reviewed by L. F. Brown, Jr., J. R. DuBar, W. E. Galloway, B. R. Weise, and C. M. Garrett, Jr. Word processing and typesetting were by Rosanne M. Wilson, Lisa Farnam, and Lola Huitt under the supervision of Lucille C. Harrell. Editing was by Amanda R. Masterson. All figures were drafted by Joel L. Lardon, except figure 3, which was drafted by Annie Kubert-Kearns, and figure 31, which was drafted by Richard M. Platt, under the supervision of Richard L. Dillon. Text illustration photography was by James A. Morgan. Margaret L. Evans and Jamie S. Haynes designed the publication.

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