STRATIGRAPHY AND DEPOSITIONAL SYSTEMS OF THE LOWER CRETACEOUS TRAVIS PEAK FORMATION EAST TEXAS BASIN

TOPICAL REPORT
(July 1987 - October 1988)

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RESEARCH SUMMARY

Title	Stratigraphy and Depositional Systems of the Lower Cretaceous Travis Peak Formation, East Texas Basin
Contractor	Bureau of Economic Geology, The University of Texas at Austin, GRI Contract No. 5082-211-0708, entitled "Geologic Analysis of Primary and Secondary Tight Gas Sand Objectives."
Co-Principal Investigators	R. J. Finley and S. P. Dutton
Report Period	July 1987 - October 1988
Objectives	(1) To provide a regional stratigraphic overview of the Travis Peak Formation that will serve as a foundation for future geologic and engineering studies; (2) to divide the Travis Peak into mappable depositional sequences that are based on geologically significant criteria (occurrence of regionally extensive shale beds and erosional hiatuses); (3) to quantify thickness, net-

sandstone and percent-sandstone values for each depositional sequence so that pertinent geologic information can be directly related to existing and future production trends; (4) to use core, log, and map data to interpret regionally occurring depositional facies that comprise the Travis Peak, and the processes responsible for their genesis and morphology; and (5) to reconstruct the paleogeography for specific time intervals of Travis Peak deposition and relate observed paleogeographic changes to the overall character of Travis Peak evolution during the Early Cretaceous.

Technical Perspective

Previous studies have established the regional structural and diagenetic history of the Travis Peak Formation. However, earlier stratigraphic investigations relied solely on well-log analyses of the Travis Peak Formation to address the regional distribution, general facies associations, and relation to salt-deformation patterns in the formation from East Texas to the Mississippi River. This report represents a synthesis of Travis Peak stratigraphy and depositional systems that is focused on the area of GRI-supported Tight Gas Research in East Texas and West Louisiana. Interpretations of depositional facies are based on well logs, core (acquired from cooperative and Staged Field Experiment wells and donations), and quantitative sedimentary maps. In light of these new data, refined interpretations of Travis Peak stratigraphy, depositional systems, and paleogeographic evolution are proposed.

Results

The Travis Peak Formation was divided into five lithostratigraphic units based on well-log correlations. Formation of a fluvial-deltaic-paralic-shelf depositional systems tract was interpreted from analyses of stratigraphic and sedimentologic data from each unit combined with well-log and core data. During early Travis Peak development, braided streams deposited channelbelt, floodplain, and overbank sediments in most of the study area. Downdip of the braided streams, deltas prograded to the south and southeast over a shallow, stable shelf. As braided streams migrated and enlarged, the site of deltaic deposition advanced southward and expanded to the northeast. Estuaries developed in relatively sediment-starved, embayed portions of the shoreline between centers of deltaic deposition. Seaward of the deltas, shelf sandstones accumulated through sediment-gravity processes triggered by high sediment loads and rapid deposition in the deltas. Shoreline transgression and development of coastal-plain and paralic environments characterize late Travis Peak evolution. Fluvial systems transported a mud-rich sediment load and assumed a sinuous-braided to meandering form. Channelbelts coursed across a coastal plain with expansive floodplains and lakes and fed a few small retrogradational deltas. Estuaries enlarged and became a dominant coastal feature as submergence of the coastal plain progressed. With continued transgression, marine limestone of the Sligo Formation onlapped the Travis Peak.

Technical Approach

Travis Peak stratigraphy was examined using over 300 logs from wells in 12 counties and 5 parishes in East Texas and West Louisiana. Regionally correlative resistivity markers divide the Travis Peak into lithostratigraphic units. Thickness, net-sand, and percent-sandstone data were mapped for the entire Travis Peak interval and for each lithostratigraphic unit. Cores recovered throughout the stratigraphic section from 10 wells (1,240 ft) distributed across the study area provided lithologic and sedimentologic data that were essential for well-log calibrations and interpretations of depositional processes and environments.

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ABSTRACT

Lower Cretaceous continental to marine deposits in the Travis Peak Formation rim the Gulf Basin from East Texas to Mississippi. This terrigenous-clastic sequence derived from sediments eroded from the Rocky Mountain and Ouachita forelands, forms a major basinward-thickening (1,400 to 3,200 ft-thick) wedge and records a significant progradational event in the East Texas Basin. Burial and subsequent uplift of the Sabine Arch place the top of the Travis Peak at present subsea depths of 5,899 to 9,600 ft, and natural-gas production from low-permeability (< 0.1 md) sandstones deposited in fluvial, deltaic, and paralic environments make the Travis Peak an important exploration target.

Five lithostratigraphic units were defined in the Travis Peak based on correlation of over 300 well logs. Analyses of thickness, net-sandstone, and sand-percent trends for each unit, combined with well-log and core data, illuminated the occurrence of a fluvial-deltaic-paralic-shelf depositional system that formed during an Early Cretaceous sea-level rise. At the time of early Travis Peak development, north-south oriented braided streams deposited channelbelt and associated redbed-forming floodplain and overbank sediments over most of northeast Texas. At braided-stream terminations, deltas prograded to the south and southeast over a shallow, stable shelf. As braided streams migrated and enlarged, the site of deltaic deposition advanced southward and expanded to the northeast. Estuaries occupied embayed portions of the shoreline between centers of deltaic deposition. Seaward of the deltas, shelf sandstones accumulated through sediment-gravity processes triggered by high sediment loads and rapid deposition in the deltas.

Late Travis Peak evolution is characterized by shoreline transgression and development of coastal-plain and paralic environments. Fluvial systems adjusted to the rising Cretaceous Sea and decreased gradient (and perhaps decreased sediment supply

and increased tectonic subsidence), by assuming a braided-meandering morphology. These north-south to northwest-southeast oriented systems deposited channelbelts and small, retrogradational deltas. Floodplains and lakes between channelbelts, and interdeltaic estuaries enlarged as submergence of the coastal plain progressed. With continued transgression, marine oolitic and micritic limestones of the Sligo Formation capped the Travis Peak.

INTRODUCTION

In response to economic incentives granted by the Federal Energy Regulatory Commission (FERC) to drill and complete gas wells in low-permeability (< 0.1 md) sandstone reservoirs, the Gas Research Institute has over the past several years sponsored geologic research aimed at choosing particular sandstone formations in which to conduct research that will enhance the development and exploitation of low-permeability reservoirs (Finley, 1984; Holditch and others, 1987; Baumgardner and others, 1988). Goals of the GRI-supported Tight Gas Sands Project are twofold: 1) to improve understanding of low-permeability reservoirs from a geologic and engineering standpoint; and 2) to advance the massive-hydraulic-fracture (MHF) technology that must be utilized to commercially produce these "tight" sandstones.

A major multidisciplinary research effort conducted over the past few years has focused on the Early Cretaceous Travis Peak Formation in the East Texas Basin. The Travis Peak was chosen for detailed study owing to its ultimate recoverable reserves (13.8 to 17.3 Tcf if 12 to 15% of basin produced; Finley, 1984), operator-activity level, potential impact on the gas market, and the predicted presence of "broadly-lenticular" sandstone reservoirs. Permeability in most of the Travis Peak sandstones is less than 0.1 md; porosity ranges from 3 to 17%, but is generally less than 8% (Dutton and Finley, 1988). Direct benefits of this research to gas producers will be improved recovery and lowered completion costs achieved through better field-development and well-completion programs (Holditch and others, 1987). Other benefits of this research lie in the possibilities of locating new exploration objectives, improving field-development strategies, and making previously uncommercial reserves profitable through better reservoir delineation, improved technology, or both.

This stratigraphic synthesis represents a portion of an integrated geologic (structural, stratigraphic, and diagenetic), engineering, and petrophysical study of the Travis Peak Formation. To support this broad research effort, several goals were outlined in this study. Specific goals are: (1) to provide a regional stratigraphic overview of the Travis Peak Formation that will serve as a foundation for future geologic and engineering studies; (2) to divide the Travis Peak into mappable depositional sequences that are based on geologically significant criteria (occurrence of regionally extensive shale beds and erosional hiatuses); (3) to quantify thickness, net sand, and percent sand values for each depositional sequence so that pertinent geologic information can be directly related to existing and future production trends; (4) to use core, log, and map data to interpret the processes responsible for the genesis and morphology of regionally occurring depositional facies that comprise the Travis Peak; and (5) to reconstruct the paleogeography for specific time intervals of Travis Peak deposition and to relate observed paleogeographic changes to the overall character of Travis Peak evolution during the Early Cretaceous.

Study Setting

The Ouachita thrust front and the Mexia-Talco Fault Zone define the northern and western boundaries of the passive-margin East Texas Basin (fig. 1; Jackson, 1982). Since the opening of the Gulf Coast Basin during the Triassic (Jackson, 1982; Buffler, 1984), carbonate deposition dominated this basin (Moore, 1983; McGillis, 1984; Stewart, 1984). Late Jurassic progradation of the terrigenous-clastic Cotton Valley Group (fig. 2) marks the first major progradational event in the East Texas Basin. A second progradational event is recorded by Travis Peak sediments that form a terrigenous-clastic wedge rimming the Gulf Coast Basin from Texas through southern Arkansas and northern Louisiana, and eastward into southern Mississippi. Outside of

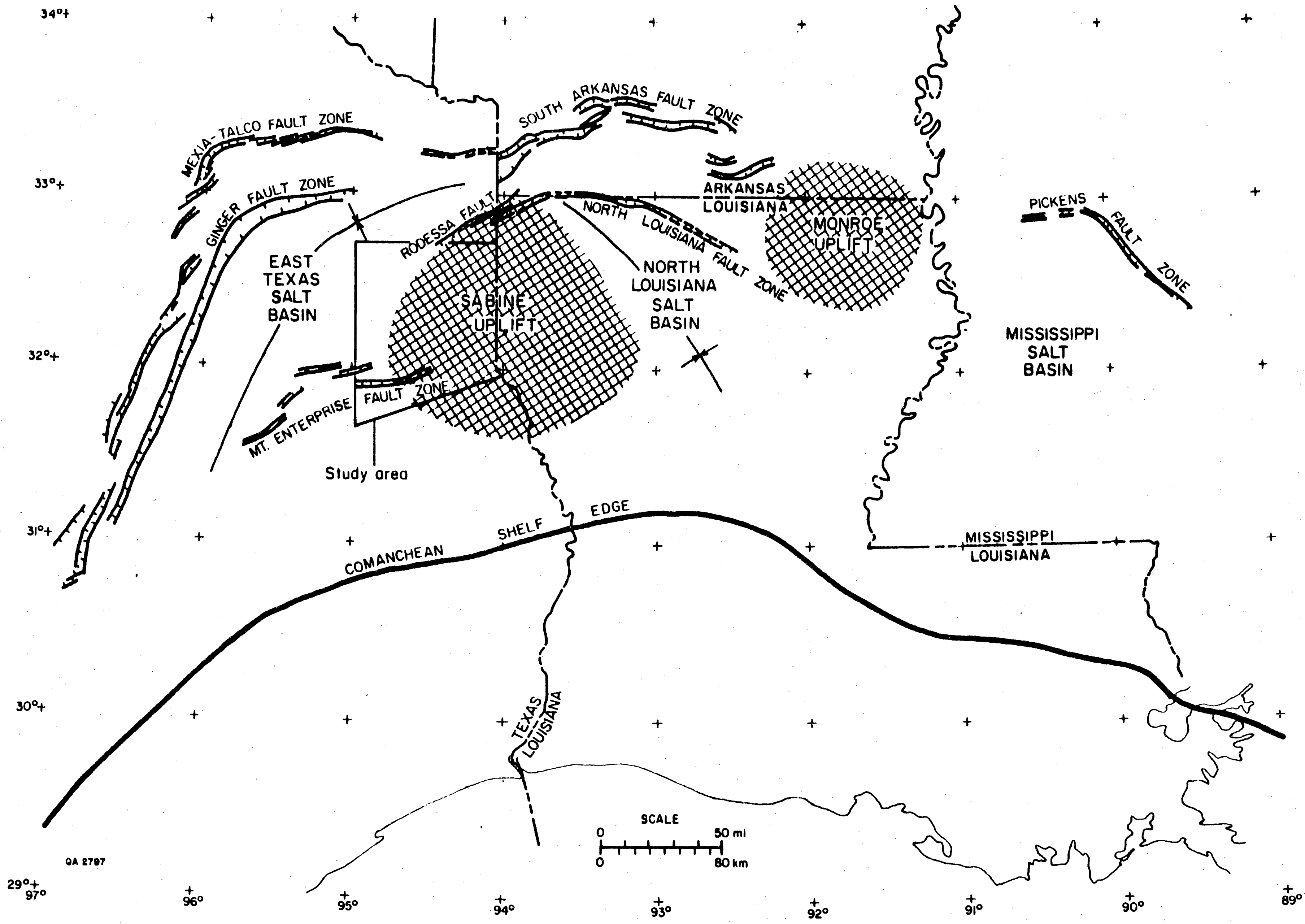

Figure 1: Regional tectonic map of the central Gulf coastal province and location of the East Texas Salt Basin. Modified from the Gulf Coast Association of Geological Societies (1972) tectonic map of the Gulf Coast region.

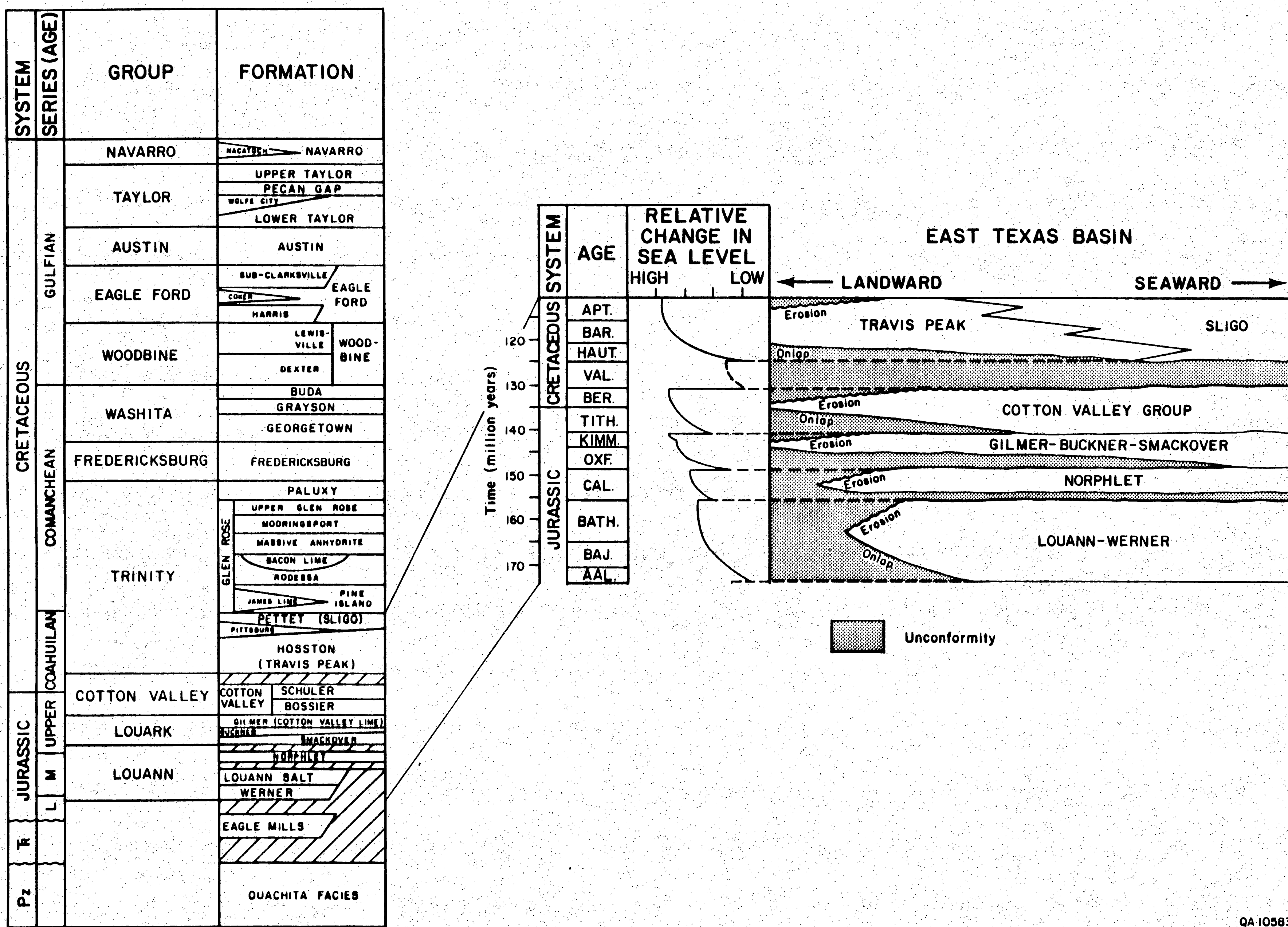

Figure 2: Stratigraphic column of the Paleozoic through Cretaceous section in the East Texas Basin. Modified from Wood and Guevara (1981) and Galloway and others (1983). Inset shows the Jurassic through Early Cretaceous sequence stratigraphy of East Texas and a relative sea-level curve. Note the presence of an unconformable contact between the Cotton Valley Group and the Travis Peak Formation. Modified from Todd and Mitchum (1977).

Texas, the Travis Peak and the overlying Sligo Formation are referred to as the Hosston Formation and the Pettet Formation respectively. These formations comprise the basal portion of the Trinity Group (fig. 2; Sellards and others, 1932; Wood and Guevara, 1981; Galloway and others, 1983).

The Travis Peak is described as a redbed-bearing sequence of fine- to coarse-grained sandstone, siltstone, mudstone, shale, dolomite, and cherty conglomerate, although shale, dolomite, and conglomerate were not observed in the study area (Hazzard, 1939; Imlay, 1940; Murray, 1961; Berryhill and others, 1967). It overlies the Late Jurassic to Early Cretaceous Cotton Valley Formation and is gradationally overlain by micritic and oolitic limestones of the Cretaceous Sligo Formation forming a time-transgressive boundary (Bebout and others, 1981). The lower Sligo in Louisiana is predominantly a marine siliciclastic unit that is a basal facies equivalent of the Travis Peak (Hosston). As in Texas, upper Sligo sediments in Louisiana are normal marine, dark gray, oolitic, fossiliferous limestone and dark shale (Berryhill and others, 1967).

The nature of the Travis Peak-Cotton Valley contact is uncertain (Nichols and others, 1968; Cooper and Shaffer, 1977; McFarlan, 1977; Todd and Mitchum, 1977; Seni, 1983; Saucier, 1985; McGowen and Harris, 1984). The Knowles Limestone, a thin transgressive-marine deposit, overlies the Cotton Valley Formation in the distal regions of the East Texas Basin, but pinches out updip. In the region where the Knowles Limestone is absent, the Travis Peak-Cotton Valley contact is generally considered to be unconformable (sandstone-sandstone contact; fig. 2). Todd and Mitchum (1977) defined the Travis Peak-Cotton Valley contact as a major sequence boundary (fig. 2), and radiometrically and biostratigraphically dated the Travis Peak as Hauterivian to Aptian (125 to 110 mya) in age. This age (125 to 110 mya) was revised by Haq and others (in press) and Vail and Sangree (1988) as Valaginian to Aptian in age. It corresponds to a period of relative sea-level rise following a low stand that created a Type 1 unconformity on top of the Cotton Valley Formation (fig. 2).

Depth to the top of the Travis Peak Formation ranges from 3,660 to 10,400 ft (fig. 3), and although the main portion of the Travis Peak in the study area (fig. 4) is centered over the Sabine Arch, stratigraphic cross sections and isopach, net-sandstone, and percent-sandstone maps (figs. 5-10) indicate that this basement-cored feature was not positive during Travis Peak deposition (Halbouty and Halbouty, 1982; Jackson and Laubach, 1988). An isopach map of the Travis Peak formation in East Texas and West Louisiana (fig. 8) illustrates its range in thickness (1,400 to 3,200 ft), and its southwest to northeast distribution pattern. The sequence gradually thickens to the south and southeast owing to deposition over a slowly subsiding, gently south- to southeast-dipping shelf. It reaches maximum thicknesses between 3,000 and 4,000 ft in Red River and Bienville Parishes (fig. 8; Cullom and others, 1962; Granata, 1963). Major thickness variations are apparent along a north-south trend through western Harrison County, Rusk, western Panola County, and perhaps into Shelby County and Sabine Parish. Decreased thickness of the Travis Peak along this trend coincides with the occurrence of salt pillows in the East Texas Basin (Seni, 1983). Seni (1983), McGowen and Harris (1984), and Jackson (1986) attribute this isopach pattern to be the result of deformation of the Louann Salt and formation of salt pillows induced by Cotton Valley and Travis Peak sedimentary loading.

Methods

To assess the stratigraphy of the Travis Peak Formation, over 300 well logs were used to correlate depositional packages and construct regional cross sections from East Texas into West Louisiana. The study area encompasses all or part of 12 counties in Texas and 5 parishes in Louisiana. Resistivity markers associated with

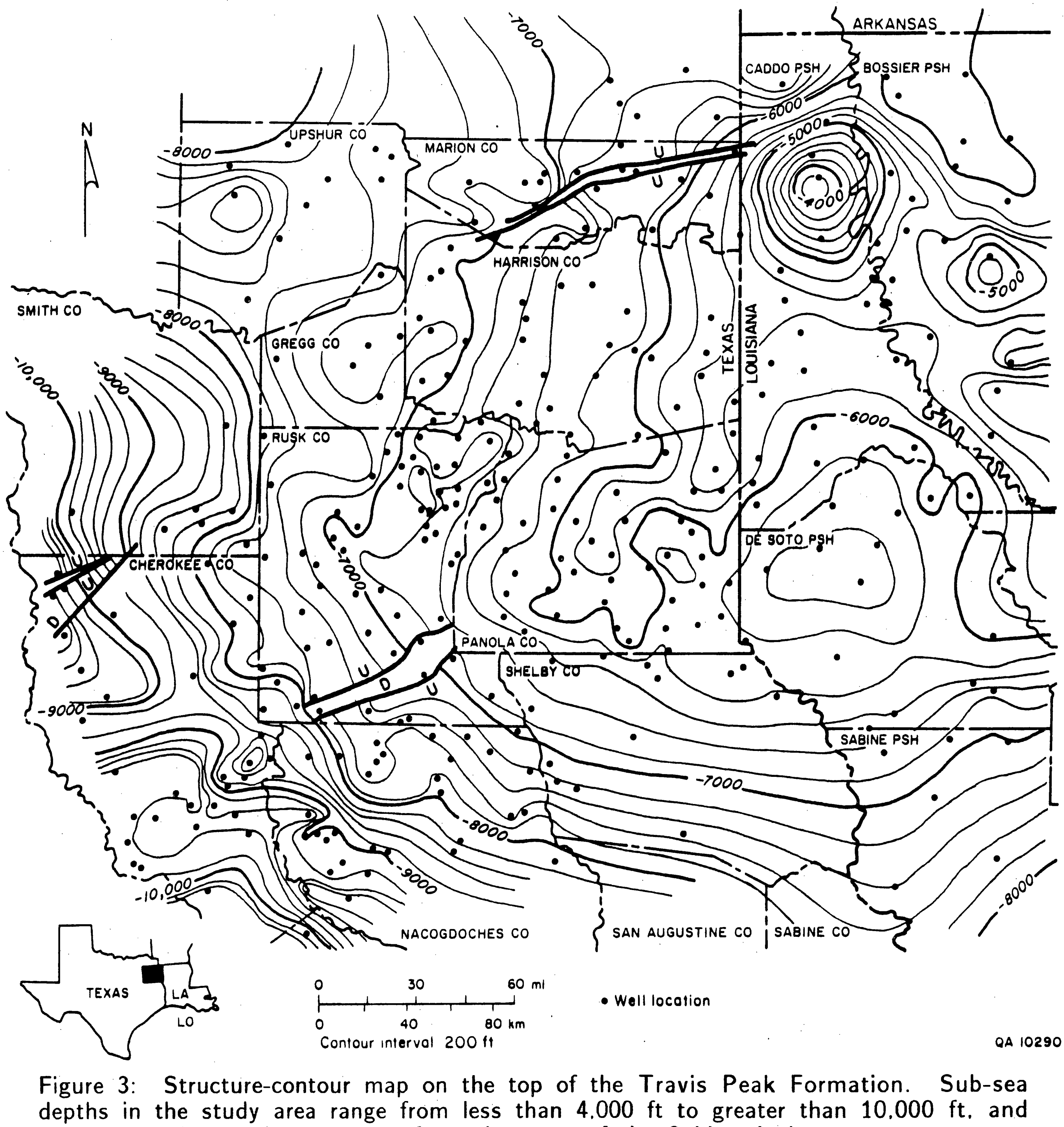

Figure 3: Structure-contour map on the top of the Travis Peak Formation. Sub-sea depths in the study area range from less than 4,000 ft to greater than 10,000 ft, and increase to the southwest, away from the crest of the Sabine Arch.

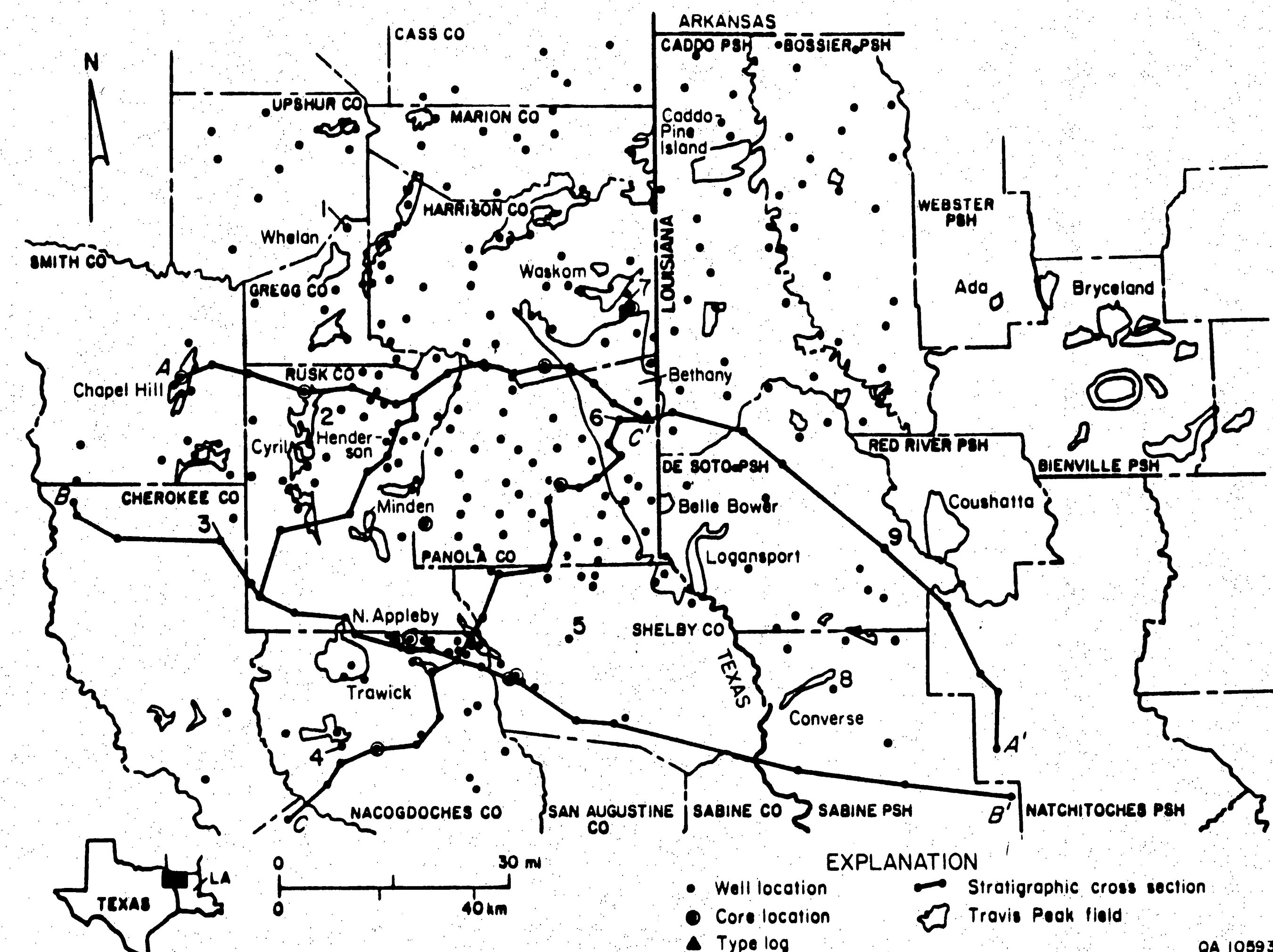

Figure 4: Location of East Texas counties and West Louisiana parishes included in the study of low-permeability, gas-bearing sandstones in the Travis Peak Formation. Major Travis Peak fields, well locations, and lines of cross sections are shown. Numbered wells correspond to well-logs shown in figures 29-33.

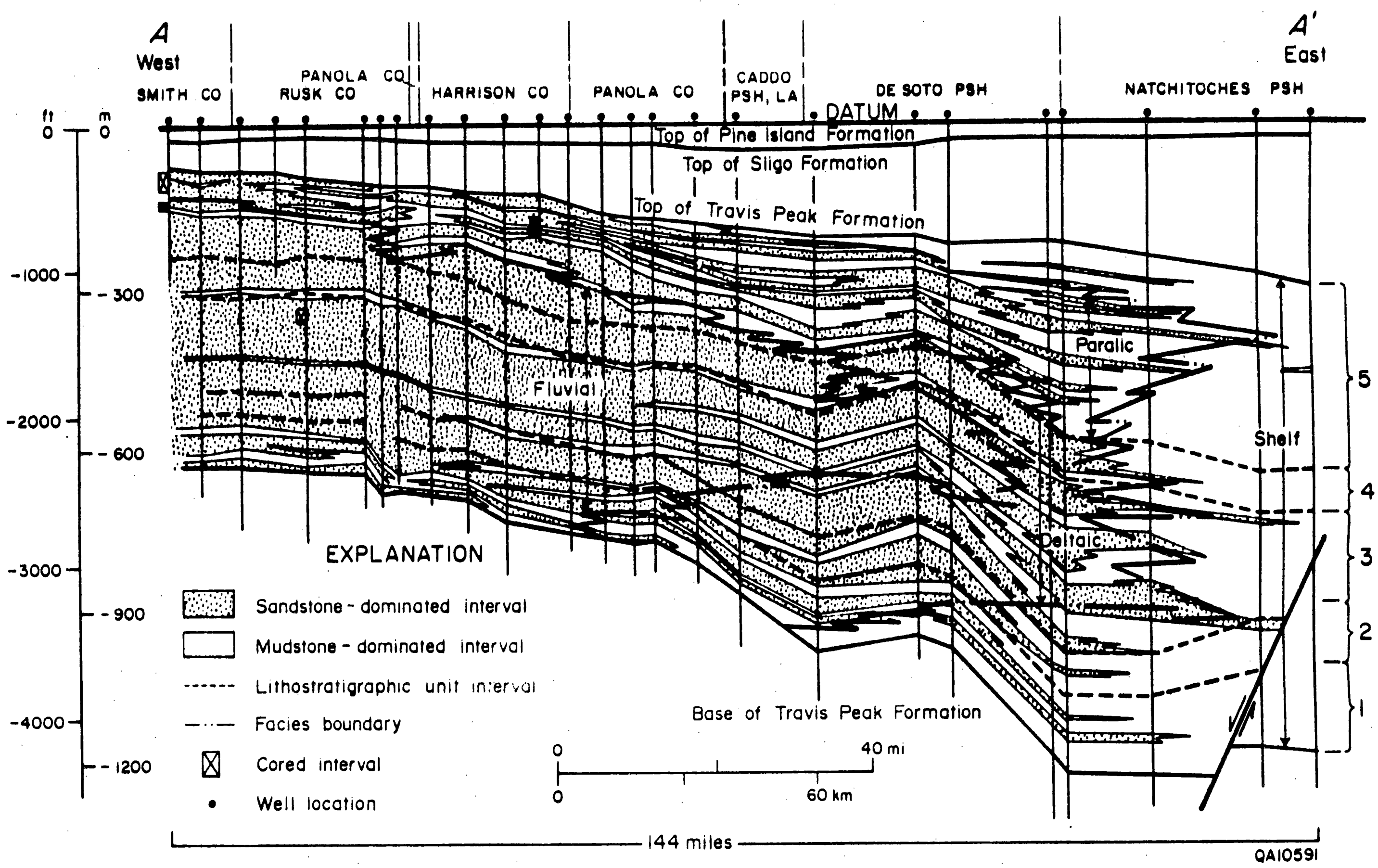

Figure 5: Stratigraphic cross section A-A' extends 144 mi from Smith County, Texas, eastward to Natchitoches Parish, Louisiana. Lithologic correlations (sandstone-mudstone) are illustrated, in addition to the lithostratigraphic units and interpreted depositional facies. Datum is the top of the Pine Island Shale.

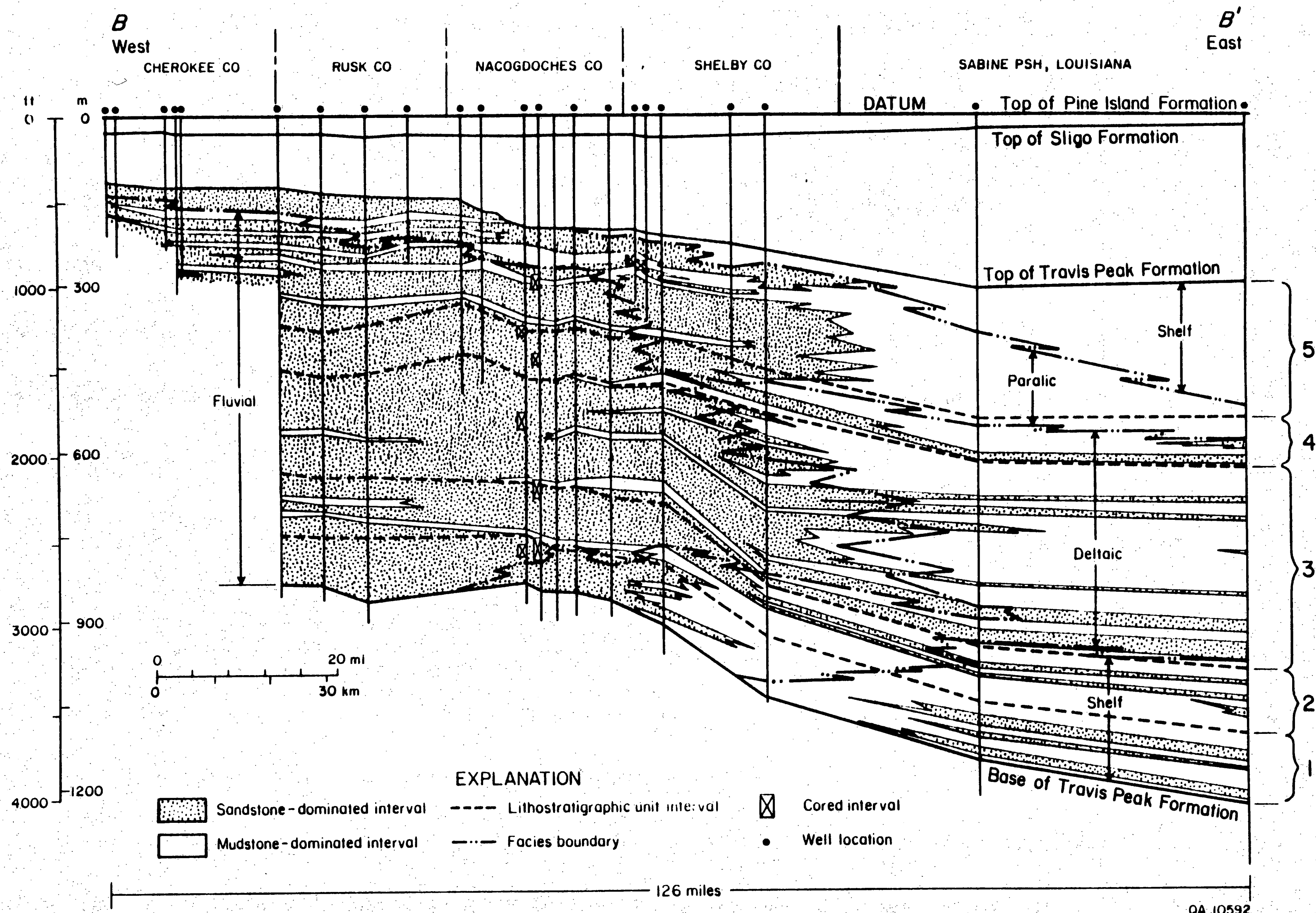

Figure 6: Stratigraphic cross section B-B' extends 126 mi from Cherokee County, Texas, eastward to Sabine Parish, Louisiana. Lithologic correlations (sandstone-mudstone) are illustrated, in addition to the lithostratigraphic units and interpreted depositional facies. Datum is the top of the Pine Island Shale.

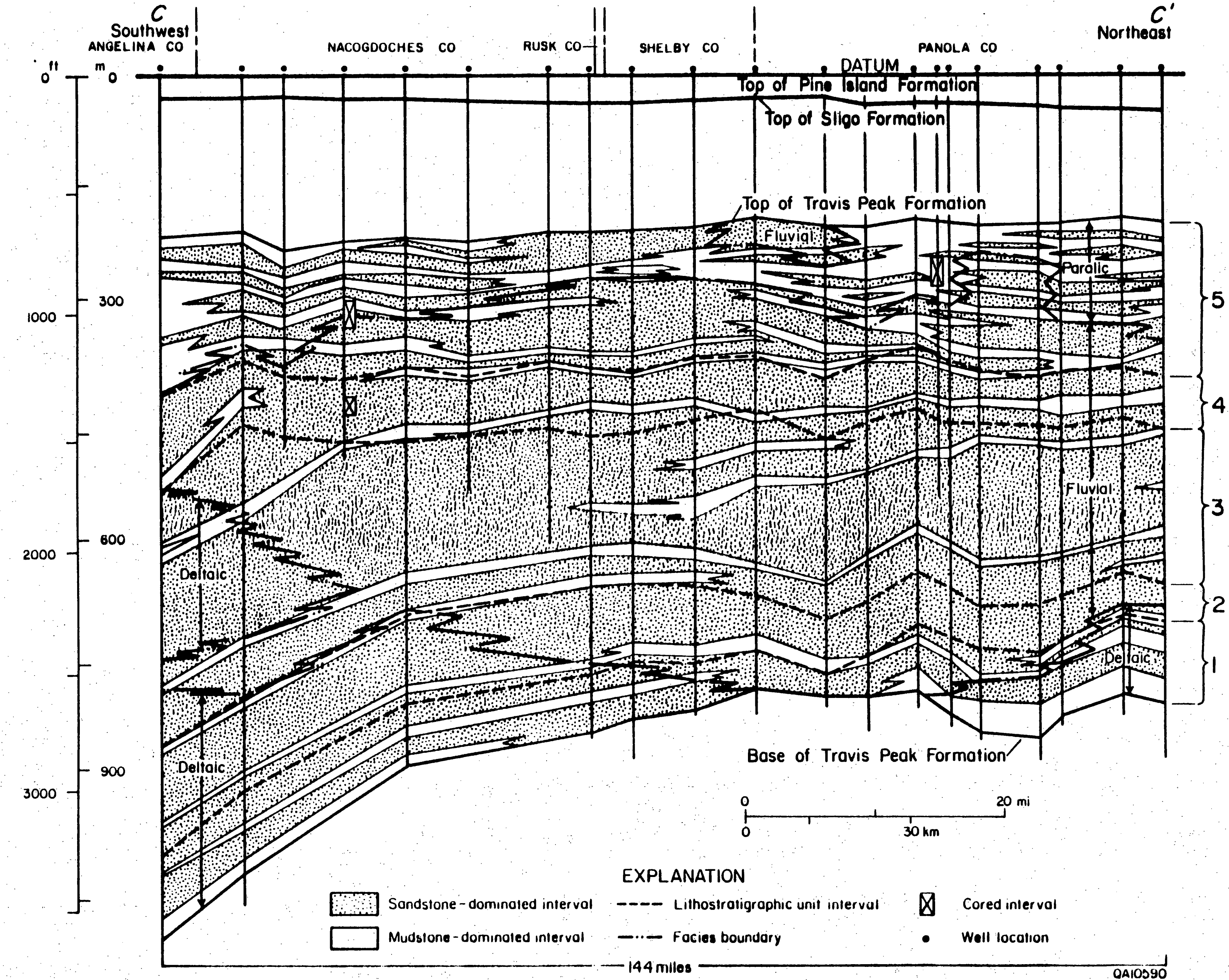

Figure 7: Stratigraphic cross section C-C' extends 79 mi from Angelina County, Texas, northeastward to Panola County, Texas. Lithologic correlations (sandstone-mudstone) are illustrated, in addition to the lithostratigraphic units and interpreted depositional facies. Datum is the top of the Pine Island Shale.

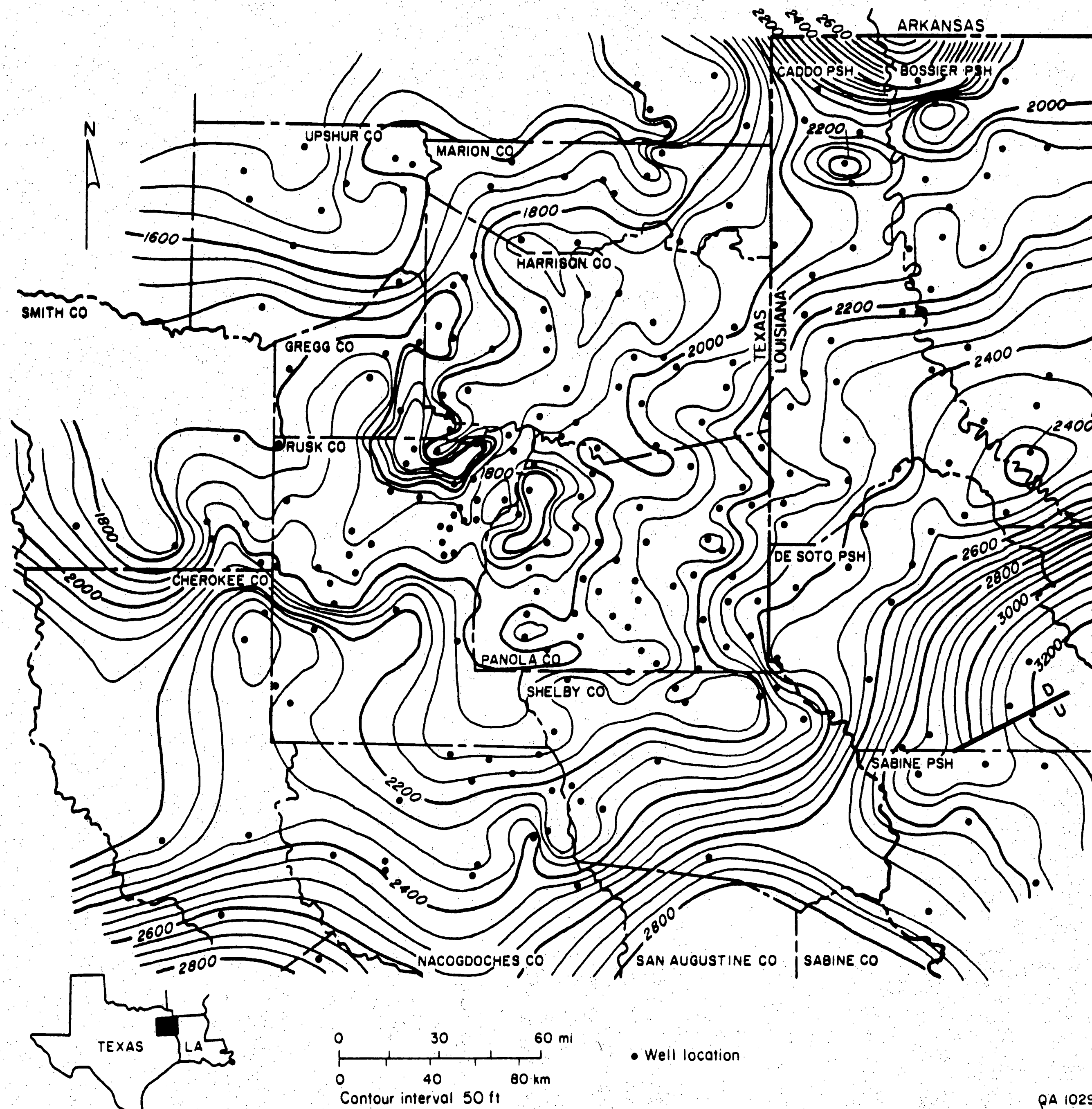

Figure 8: Isopach map of the Travis Peak Formation in the East Texas-west Louisiana study area. Thickness values range from 1,425 ft to 3,190 ft, and increase from the northwest to the southeast.

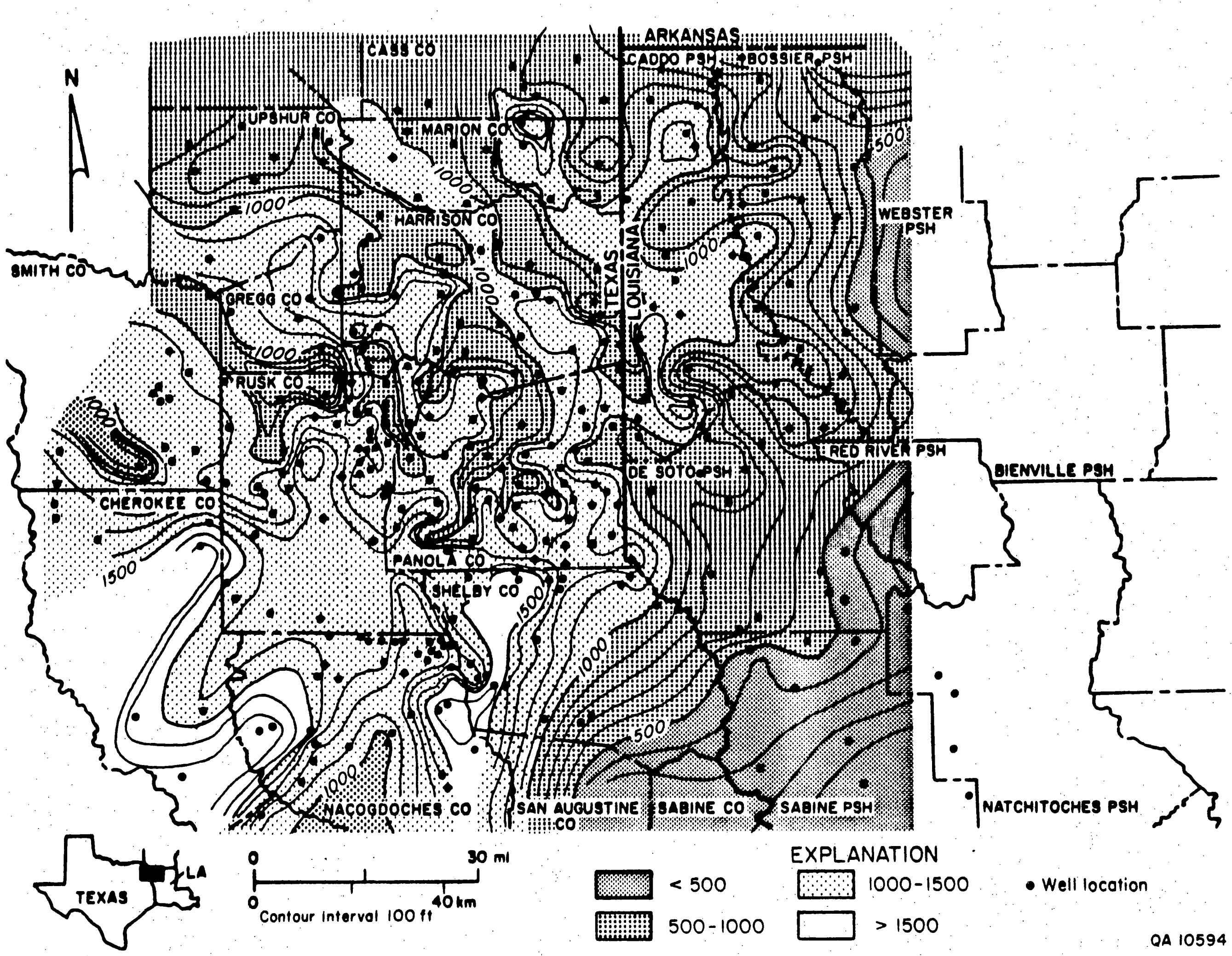

Figure 9: Regional net-sandstone map of the Travis Peak Formation in the East Texas-west Louisiana study area.

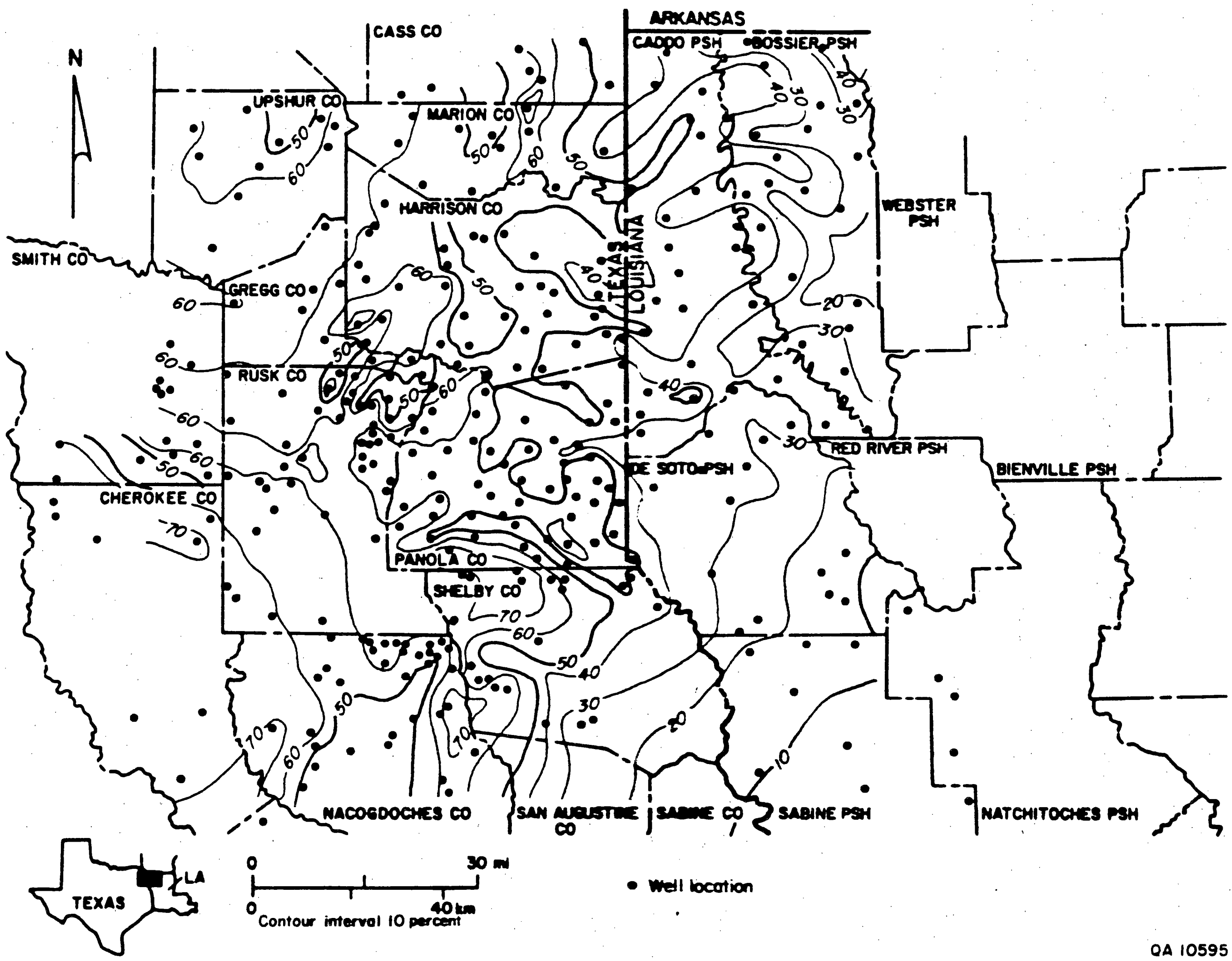

Figure 10: Regional percent-sandstone map of the Travis Peak Formation in the East Texas-west Louisiana study area.

subregionally persistent shale beds were chosen in the basinal region of western Louisiana where the Travis Peak is relatively shaley, and these markers were traced into the updip, more sand-rich parts of the basin (figs. 5-7 and 11). Where shales thin or pinchout, the resistivity markers could still be correlated. Sandstone-sandstone contacts at the position of these resistivity markers are considered to be an erosional or unconformable expression of the equivalent downdip shale beds.

Five lithostratigraphic units were defined (fig. 11). Each unit was mapped in the manner described by Krumbein and Sloss (1963) to illustrate thickness, net-sandstone, and sand-percent trends (figs. 12-26). Portions of the spontaneous potential (SP) well-log curve exceeding a 30% cutoff value (greater than 30% deflection from a shale baseline) denoted sandstone content. Percent-sandstone maps most clearly delineated the lithologic trends and provided valuable information for depositional systems interpretations. Based on this method, the middle, more sand-rich interval of the Travis Peak was separated from the lower and upper relatively mud-rich portions by regionally persistent resistivity markers. Moreover, this method allowed subdivision of the sand-rich middle section, which previously could not be easily subdivided.

Lithologic and depositional interpretations were extended throughout the study area by calibrating well-log response to particular rock types and depositional settings inferred from core data. Cores (1,240 ft from 10 wells; fig. 4) were acquired through donations to the Texas Bureau of Economic Geology, cooperative wells under joint study by GRI contractors and the operating company, and two Staged Field Experiment (SFE 1 & 2) wells (Holditch and others, 1987). The cores provide good geographic and depth coverage of the Travis Peak.

TENNECO
Harris-Drummond No. 1
Bethany Field, James Mathews Sur. A-42
PANOLA COUNTY, TEXAS

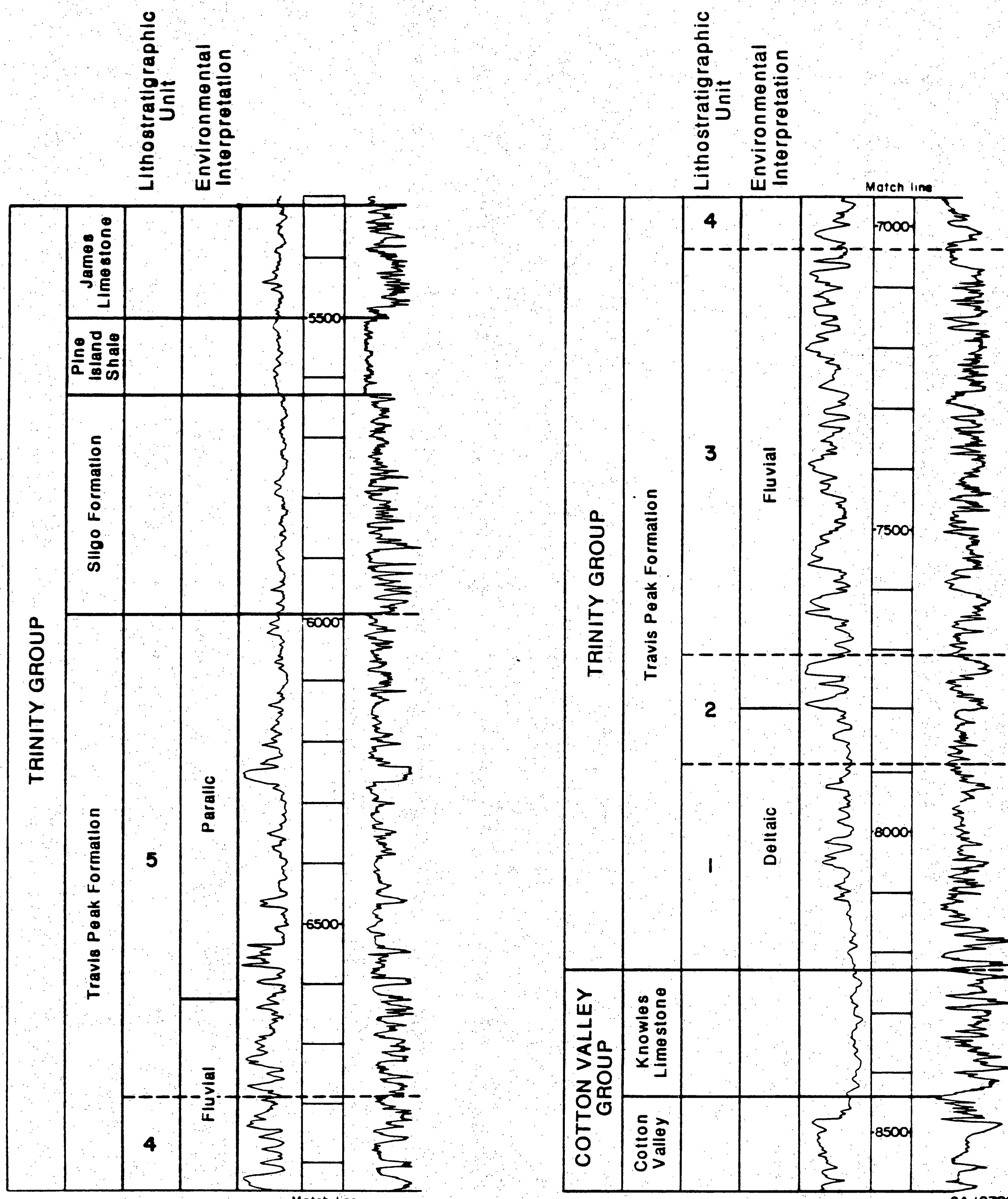

Figure 11: Type log of the Travis Peak Formation from eastern Panola County, Texas. Lithostratigraphic unit divisions and environmental interpretations are illustrated. Location shown in figure 4.

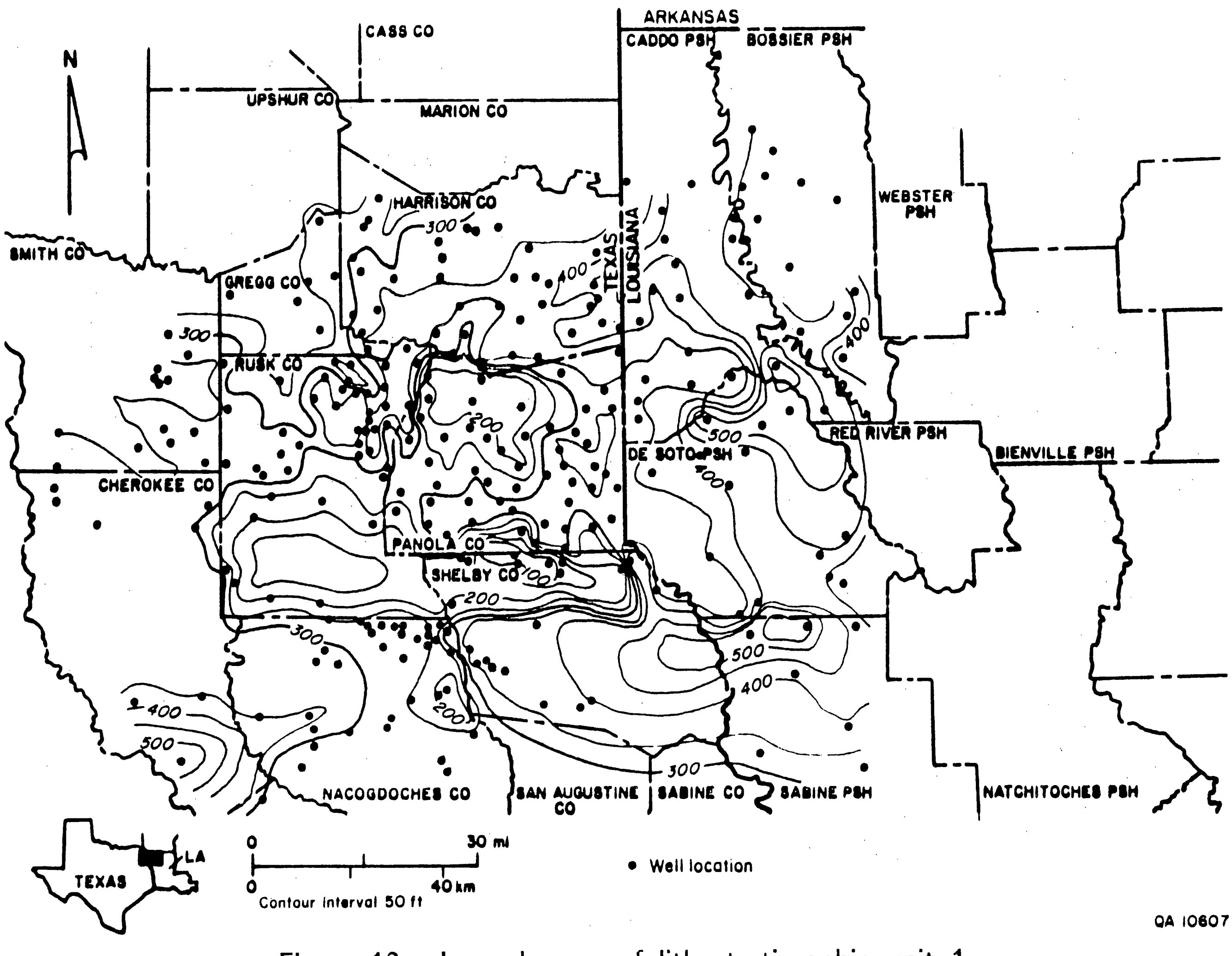

Figure 12: Isopach map of lithostratigraphic unit 1.

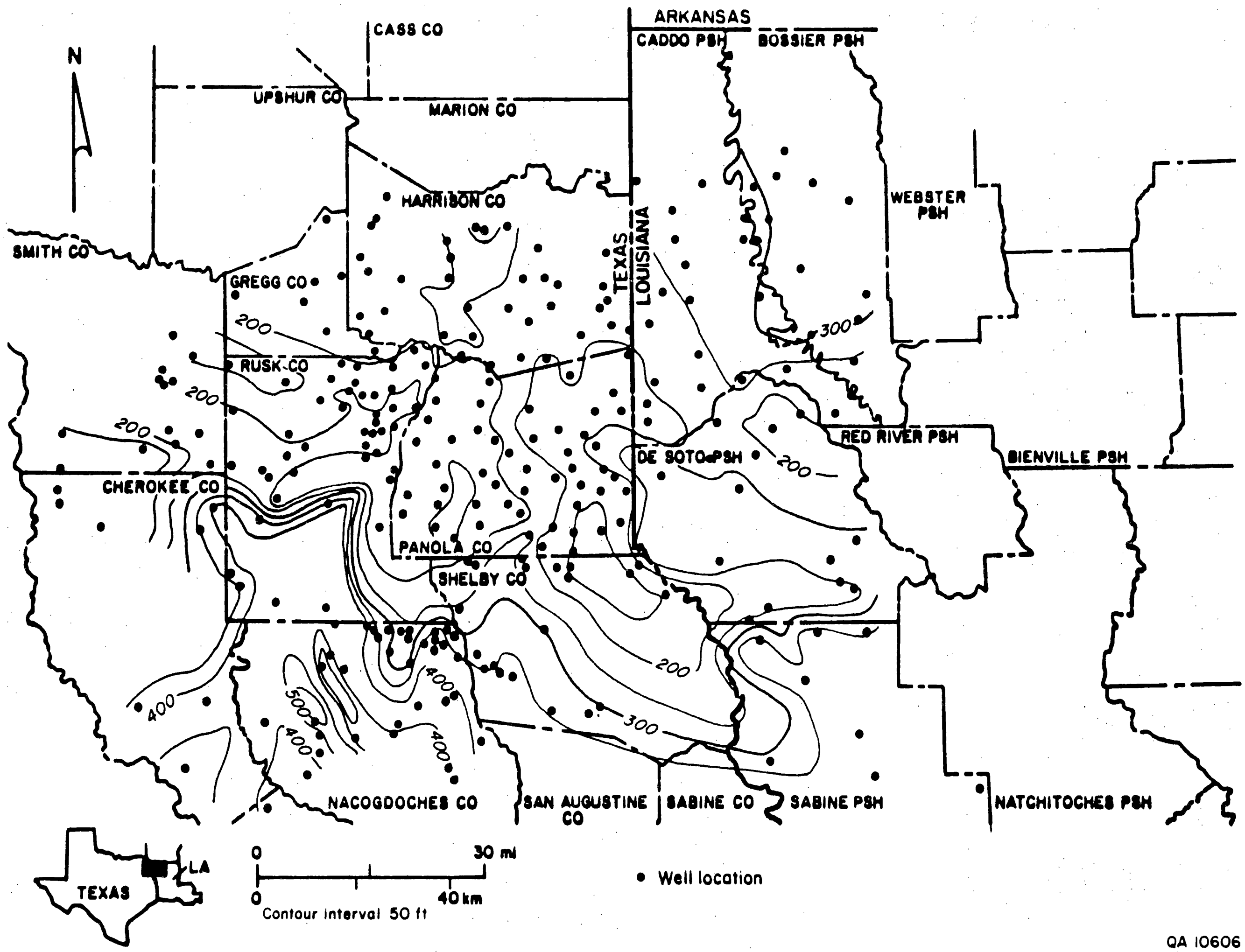

Figure 13: Isopach map of lithostratigraphic unit 2.

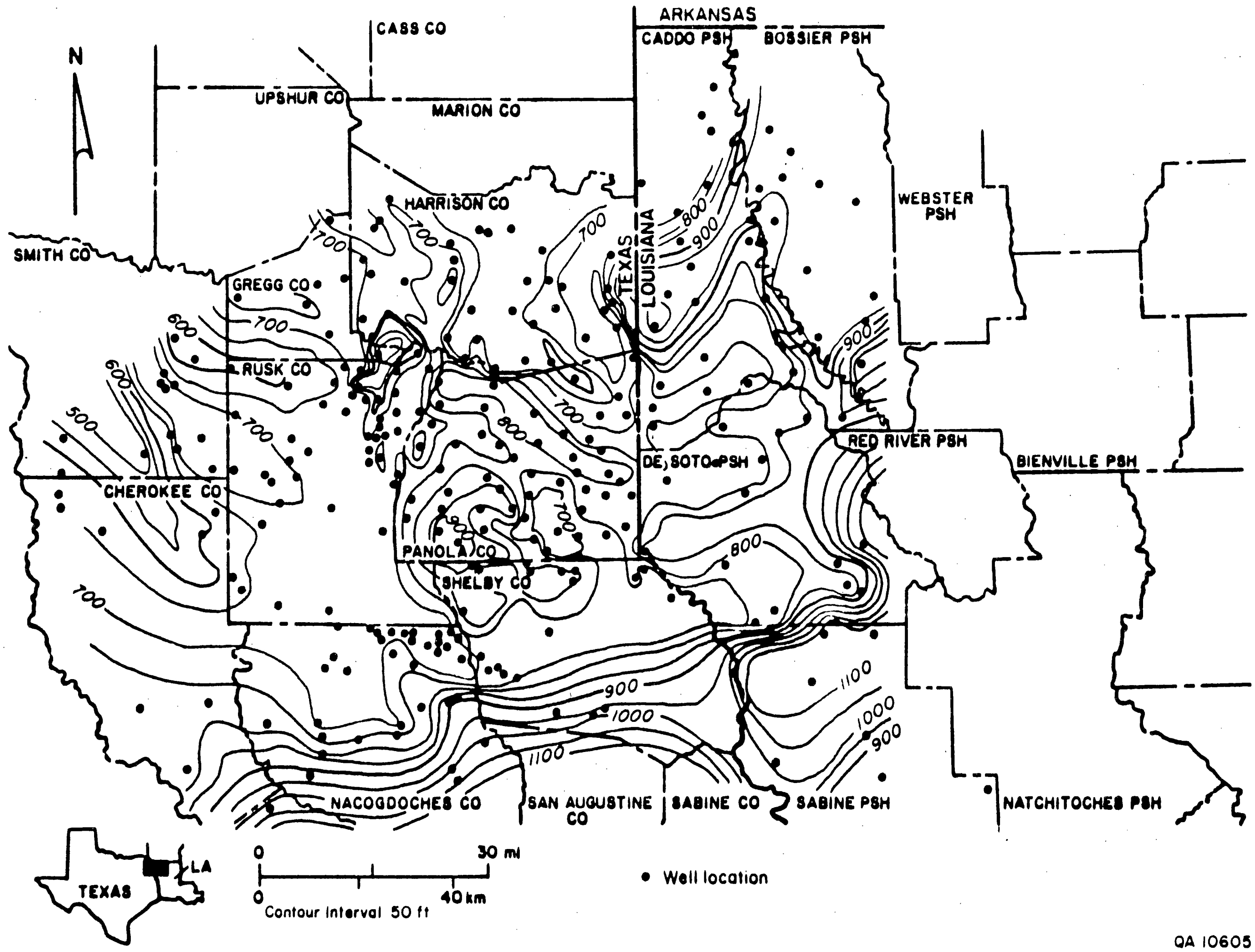

Figure 14: Isopach map of lithostratigraphic unit 3.

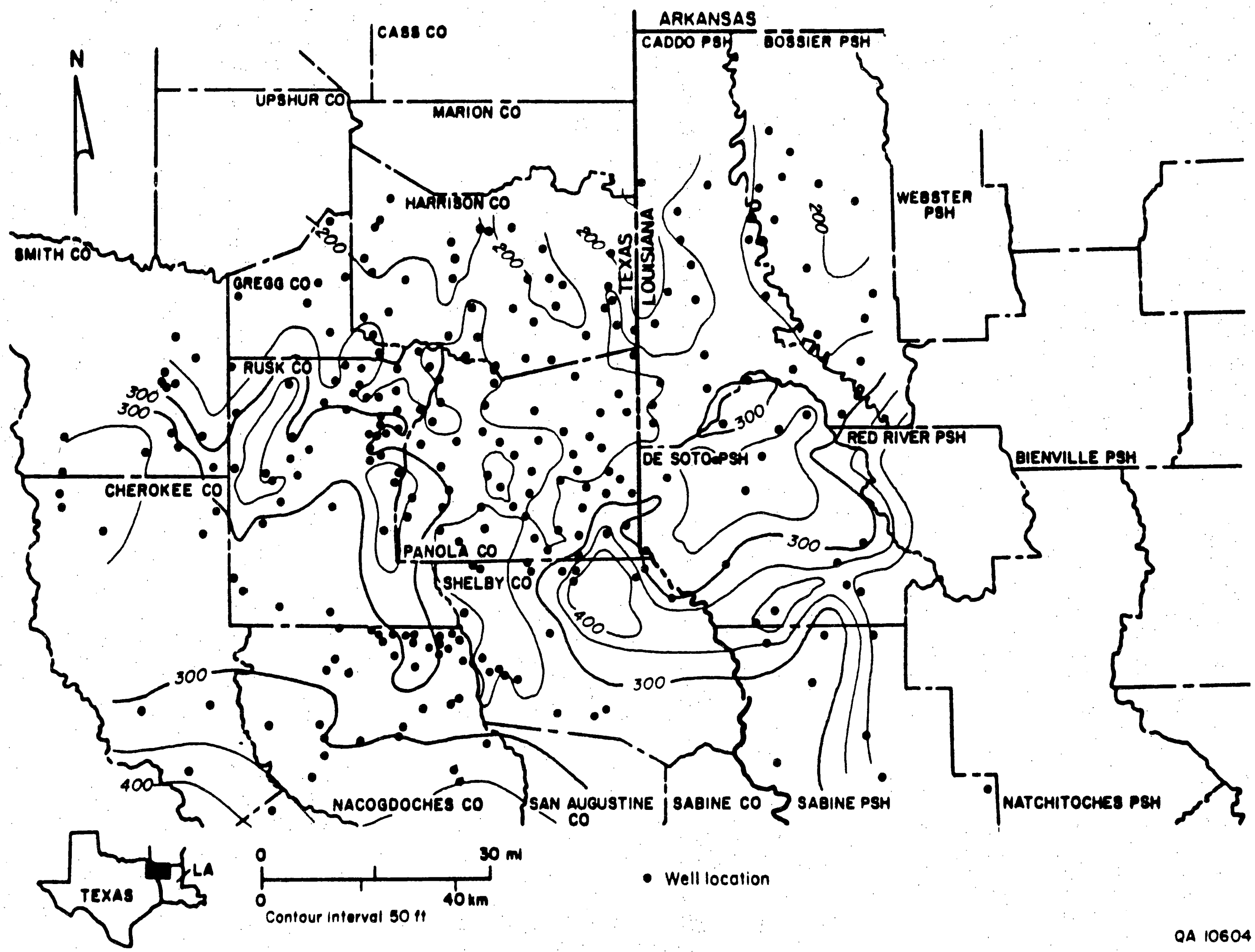

Figure 15: Isopach map of lithostratigraphic unit 4.

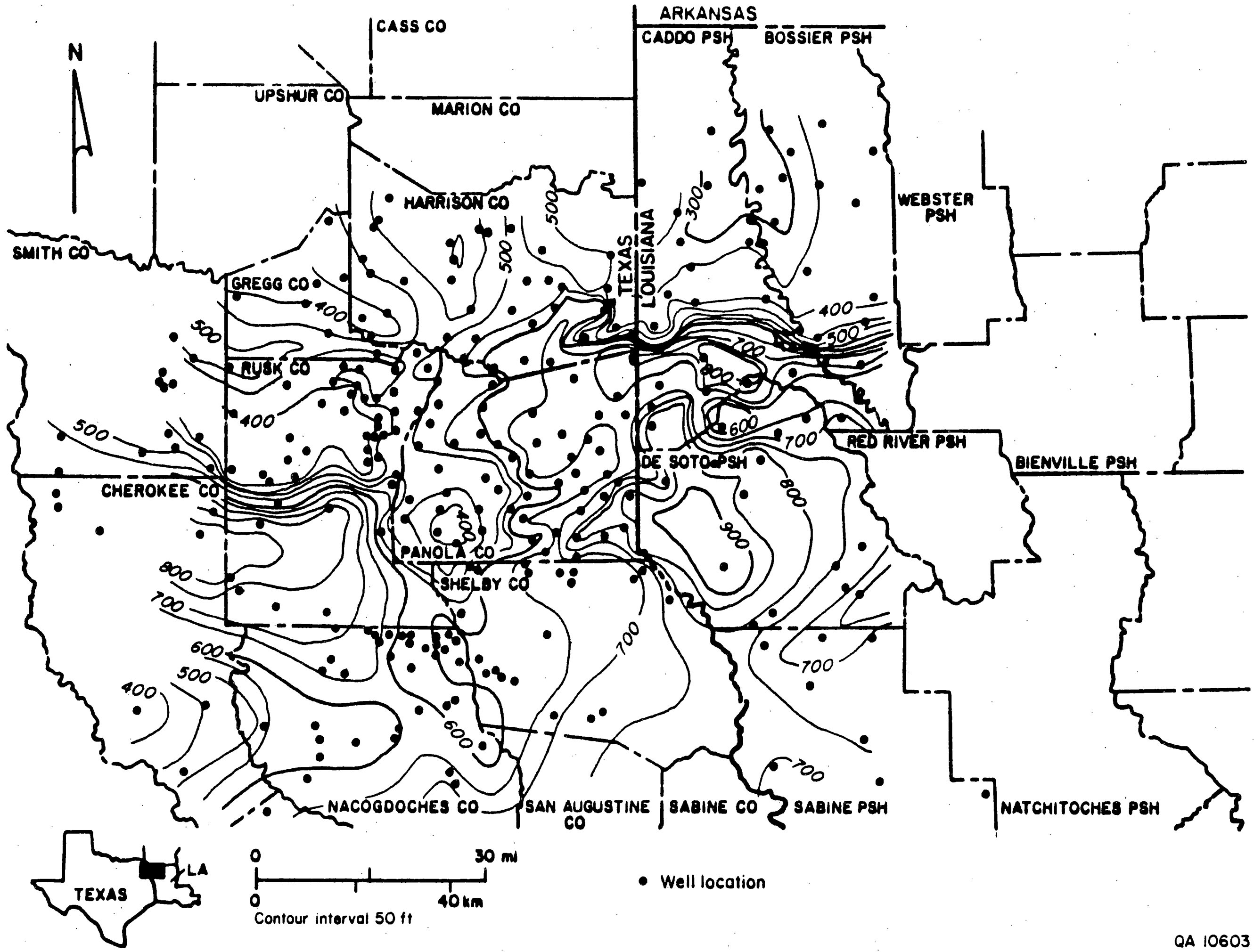

Figure 16: Isopach map of lithostratigraphic unit 5.

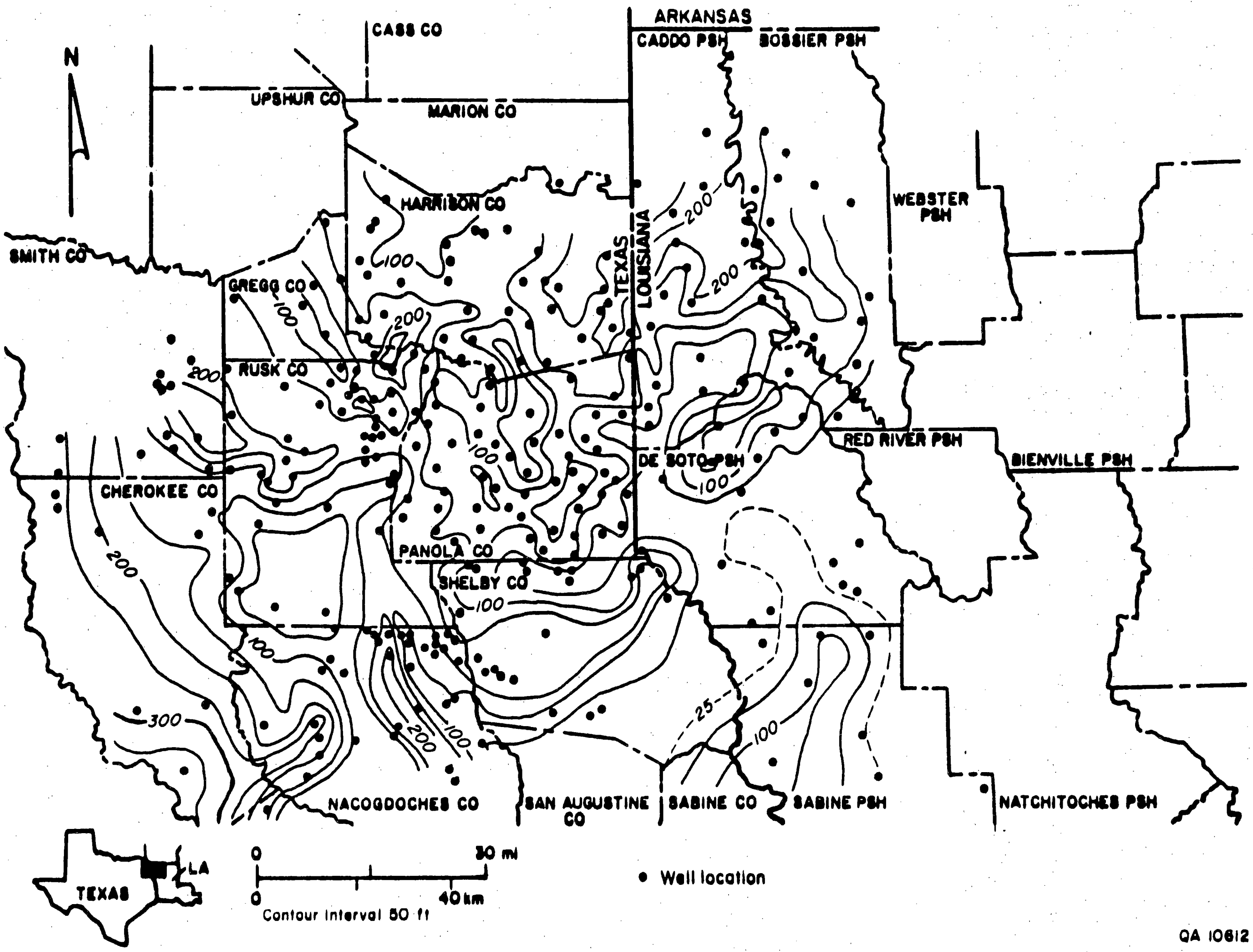

Figure 17: Net-sandstone map of lithostratigraphic unit 1.

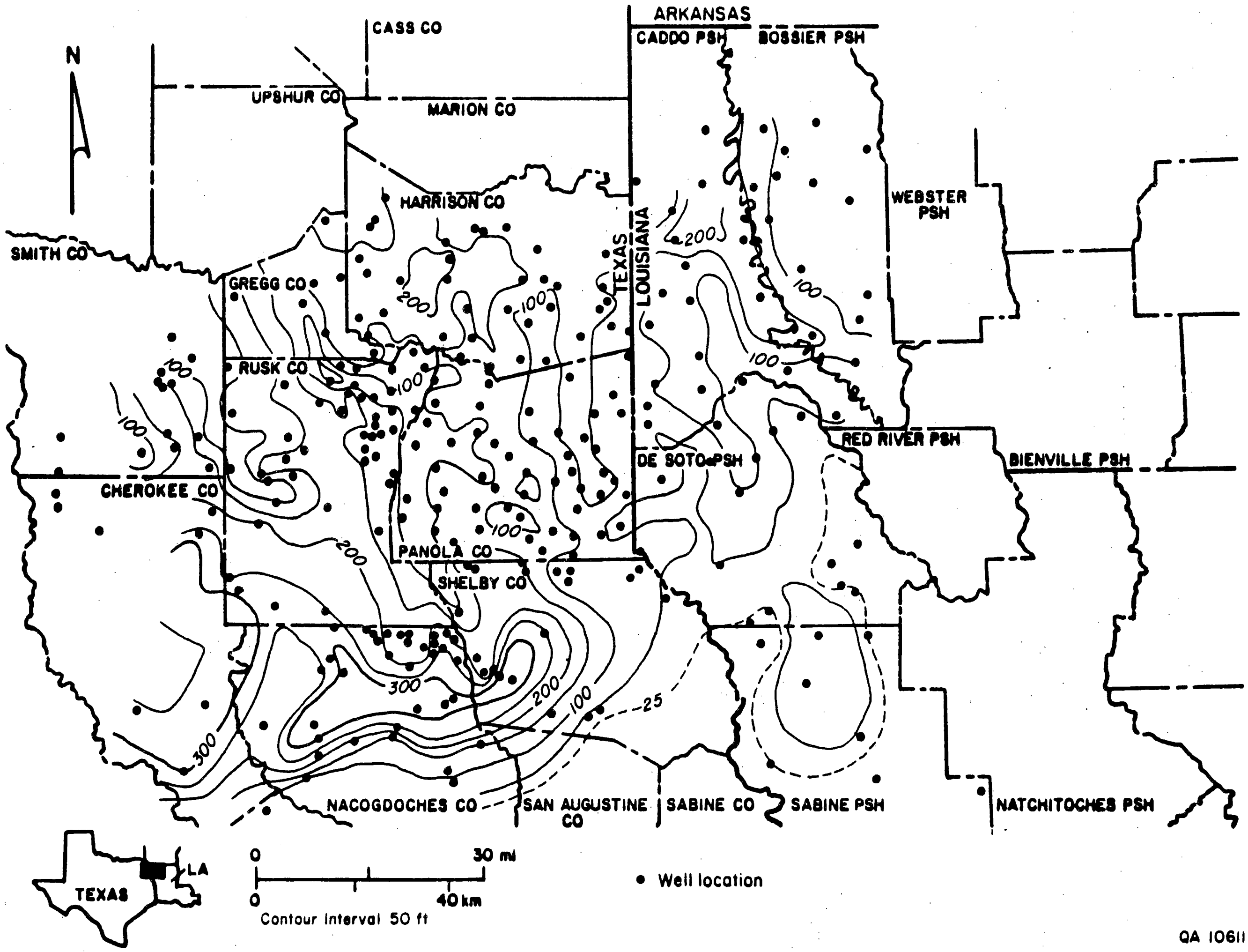

Figure 18: Net-sandstone map of lithostratigraphic unit 2.

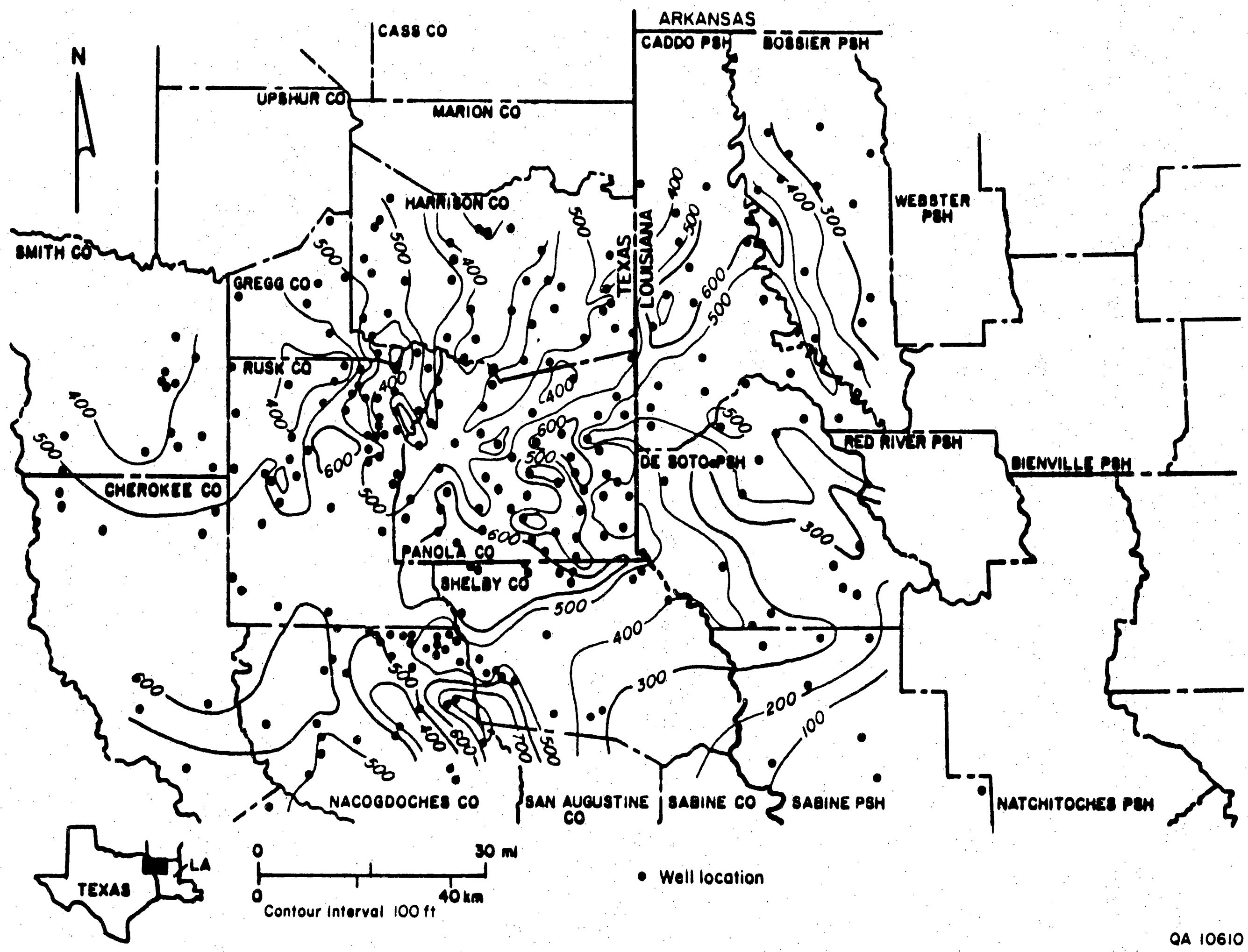

Figure 19: Net-sandstone map of lithostratigraphic unit 3.

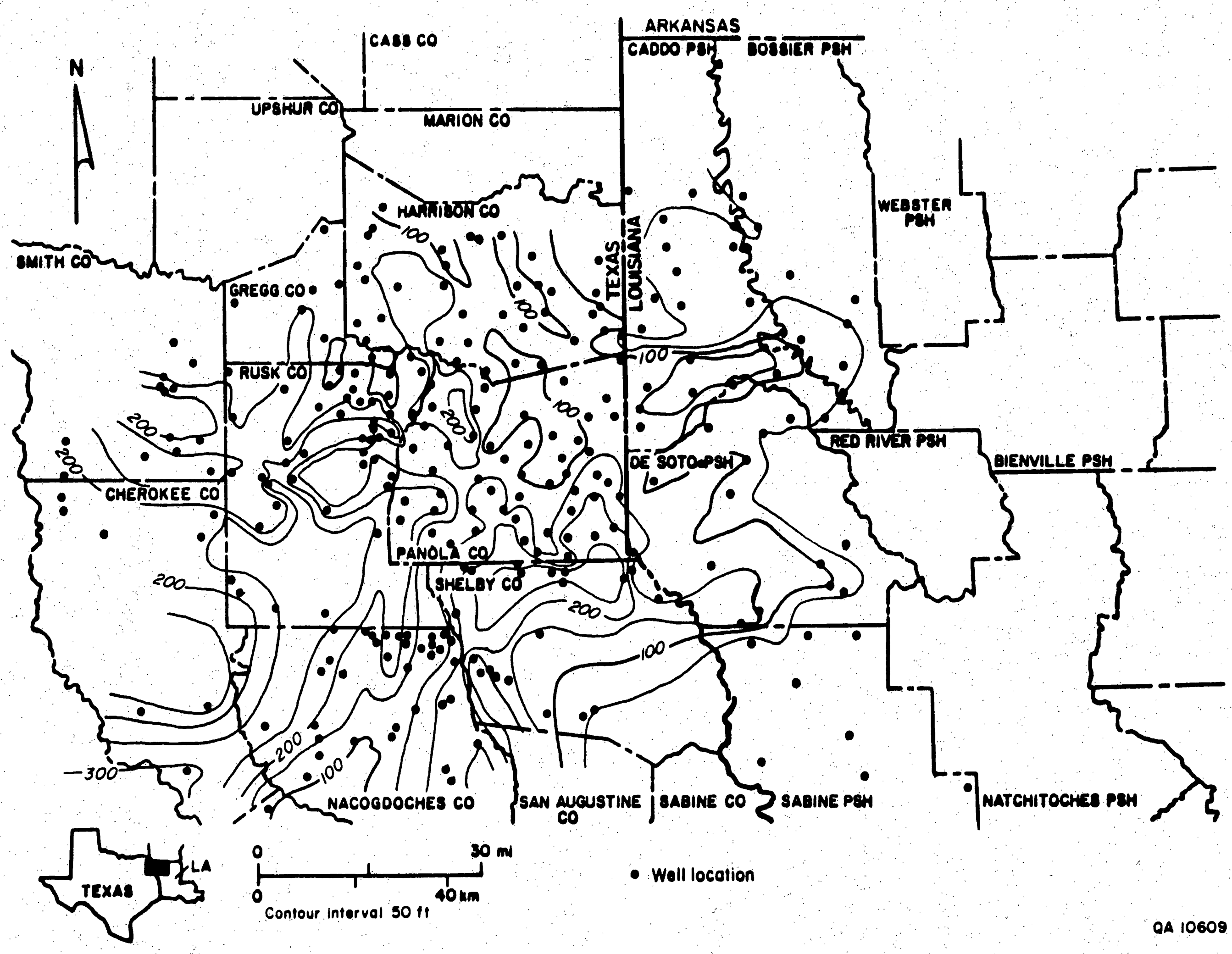

Figure 20: Net-sandstone map of lithostratigraphic unit 4.

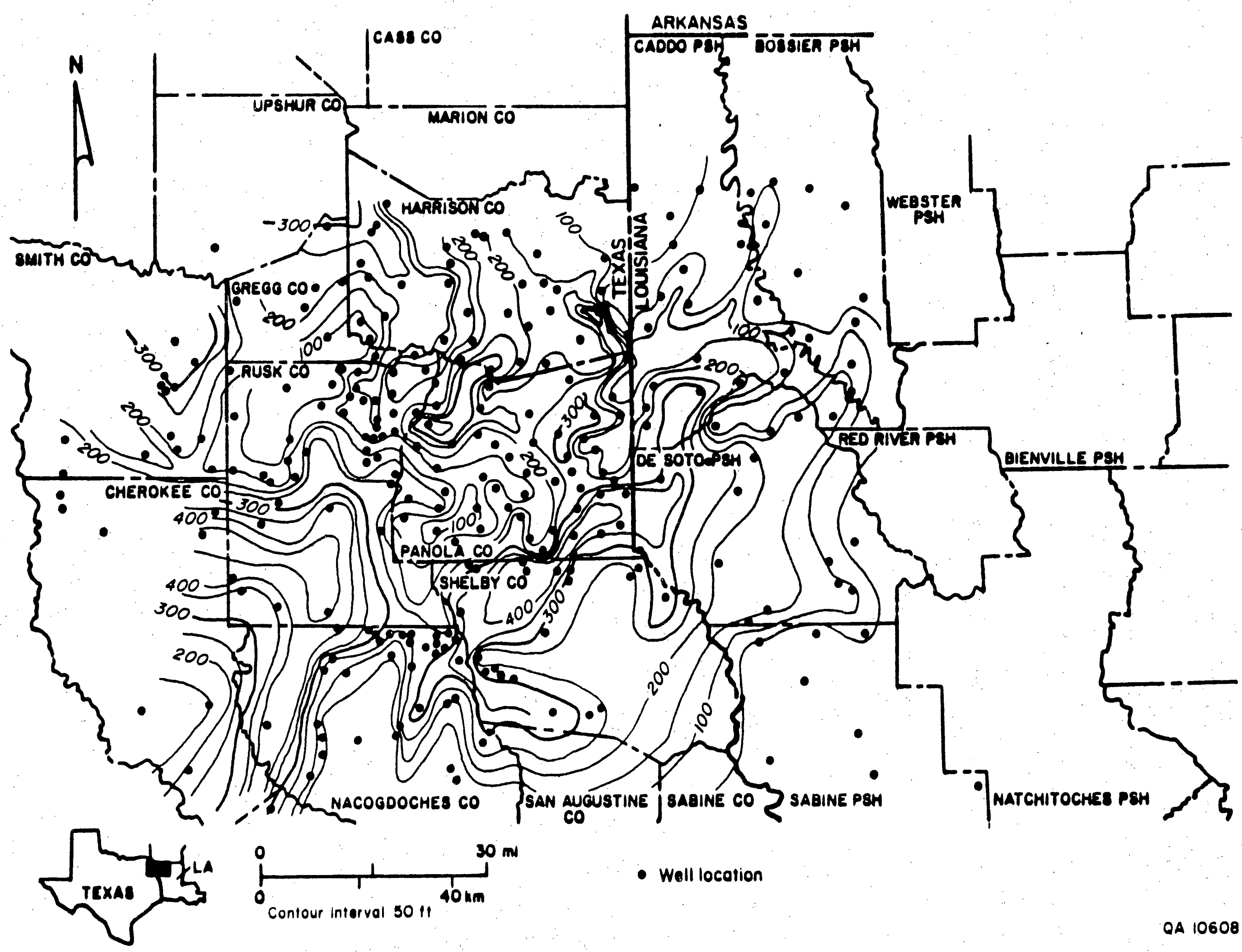

Figure 21: Net-sandstone map of lithostratigraphic unit 5.

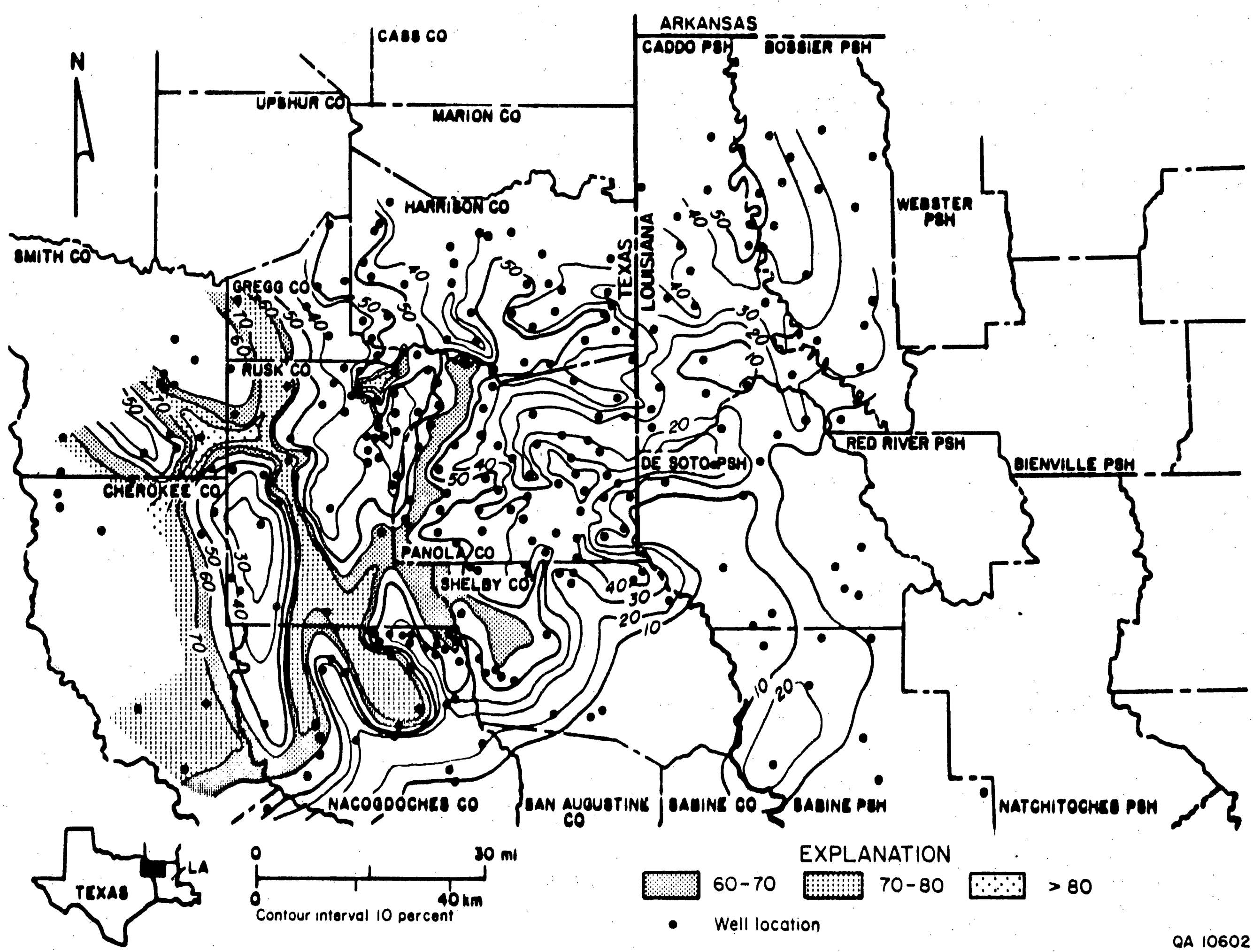

Figure 22: Percent-sandstone map of lithostratigraphic unit 1.

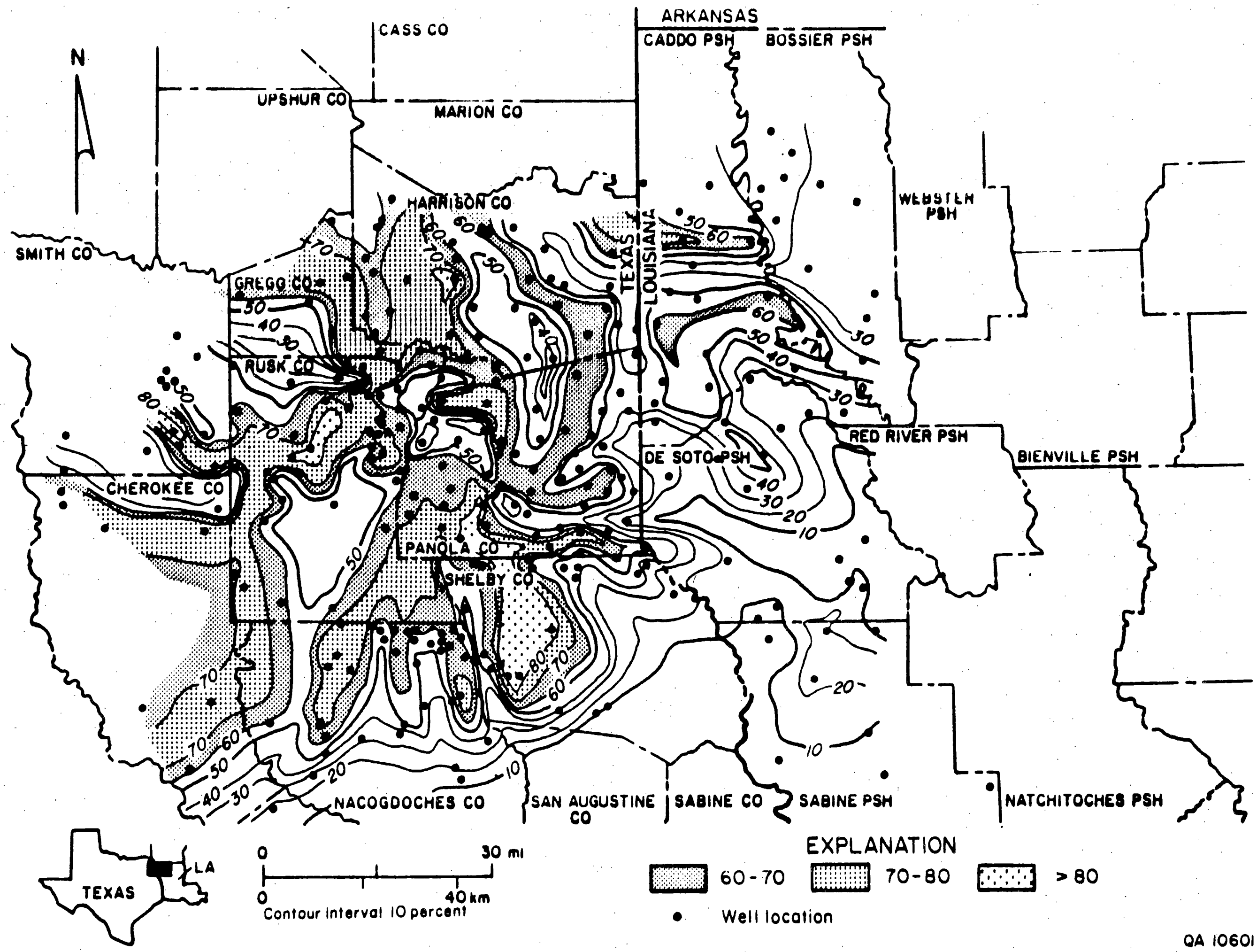

Figure 23: Percent-sandstone map of lithostratigraphic unit 2.

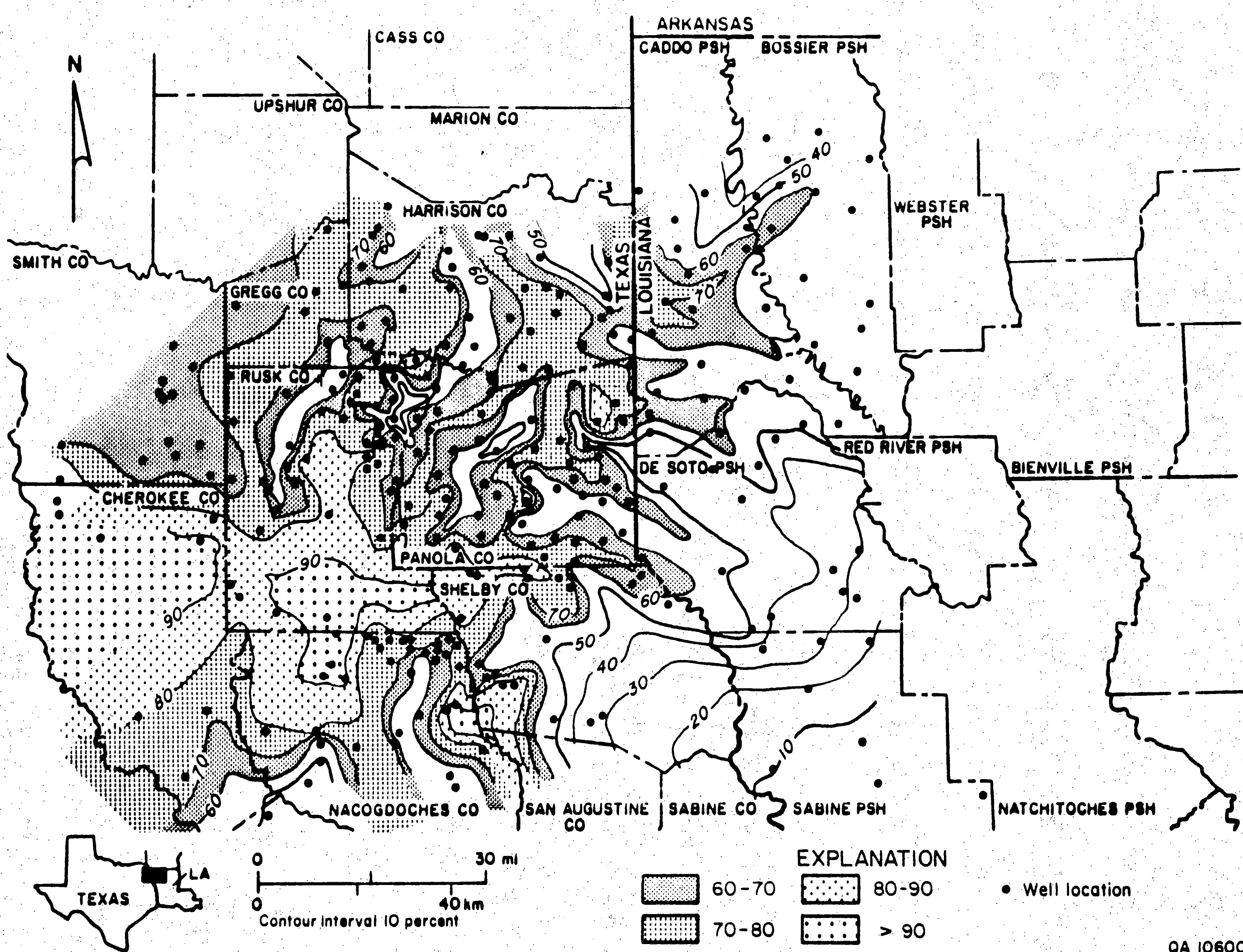

Figure 24: Percent-sandstone map of lithostratigraphic unit 3.

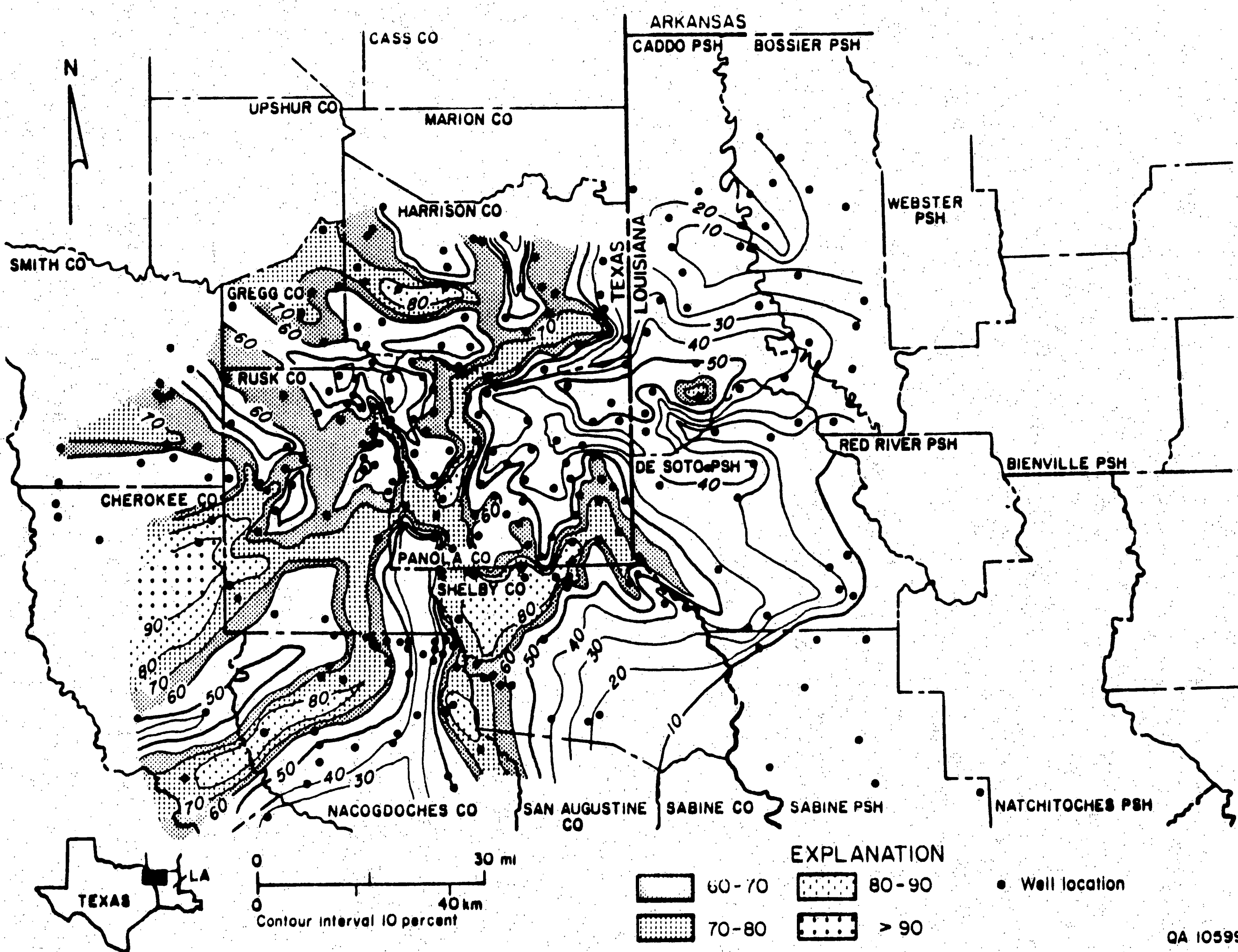

Figure 25: Percent-sandstone map of lithostratigraphic unit 4.

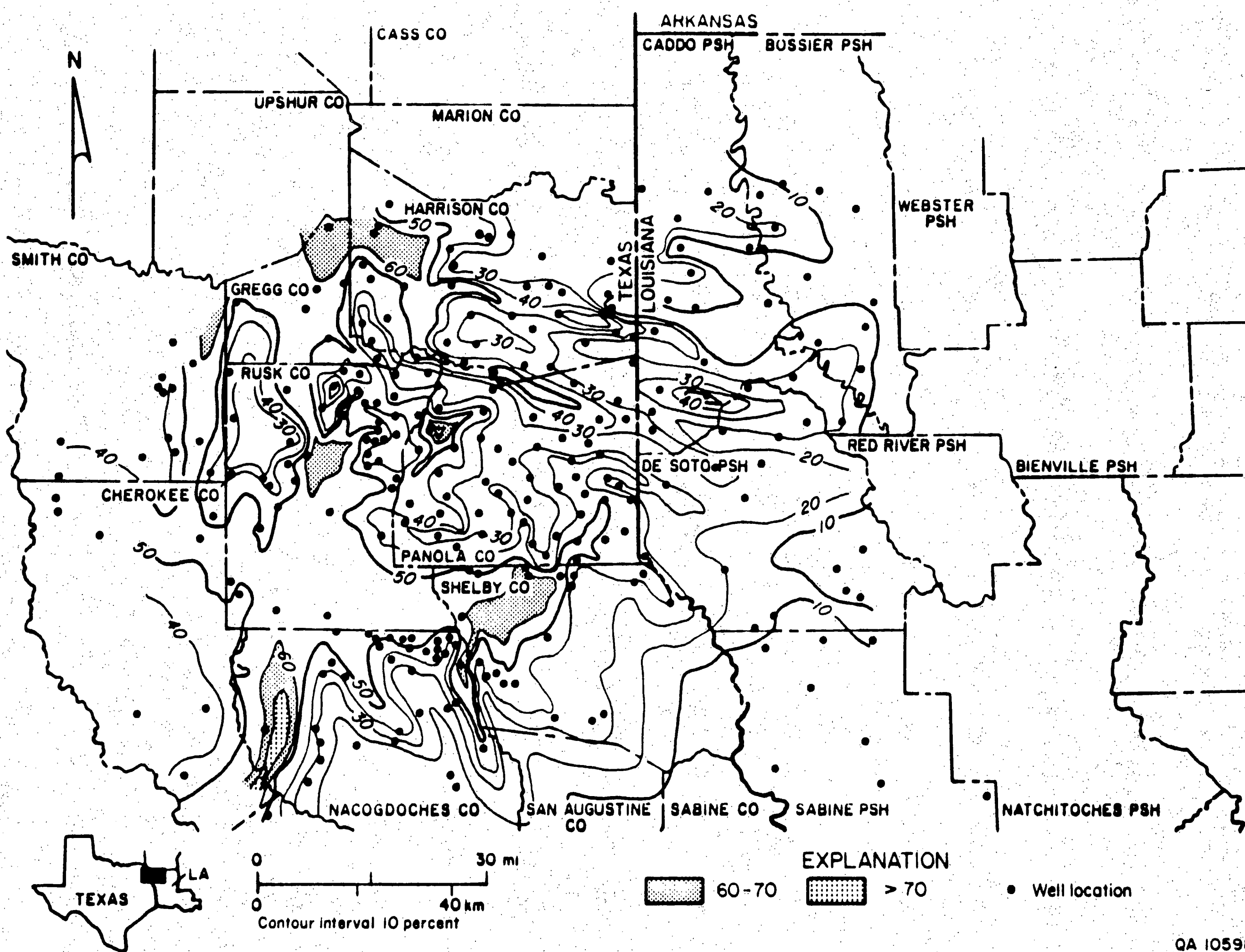

Figure 26: Percent-sandstone map of lithostratigraphic unit 5.

TRAVIS PEAK STRATIGRAPHY AND DEPOSITIONAL SYSTEMS

Stratigraphy

The Travis Peak is not divided into members, and as stated by McGowen and Harris (1984), Saucier and others (1985), and Dutton and Finley (1988), good marker horizons that could facilitate division of the Travis Peak and aid in interpretation of its component depositional environments do not exist in this formation. Based on the log character and relative distribution of sandstone intervals, previous studies (Seni, 1983; Saucier, 1985; Saucier and others, 1985) established a three-fold internal stratigraphic framework for the Travis Peak. They describe a middle sand-rich fluvial sequence that is gradationally underlain and overlain by marine-influenced, relatively mud-rich, fluvial-deltaic zones. The fluvial sequence is characterized by blocky SP-log traces that suggest stacking of sand bodies. In contrast, the lower and upper fluvial-deltaic sequences are generally characterized by more widely separated sand bodies with distinctly bell-shaped, inverse bell-shaped, or irregular-serrate SP log traces (Fracasso and others, 1988).

In this study, the Travis Peak was divided into five lithostratigraphic units or bodies of sedimentary rock delimited on the basis of their lithic characteristics and stratigraphic position (Bates and Jackson, 1987). Regionally correlative resistivity markers form the lithostratigraphic unit boundaries, and the arrangement and sedimentary characteristics of each unit are shown in figures 5-7 and 12-26. A type log from Panola County (figs. 4 and 11) shows the unit boundaries in addition to general facies interpretations.

Shales divide the distal portions of the Travis Peak into multiple sandstone beds that thicken and merge updip (toward the northwest; figs. 5-7). The greater mudstone content of the upper and lower Travis Peak is evident from the lithologic correlations and sediment maps (figs. 5-7 and 12-26). A significant lithologic contrast is noted in comparing maps of the combined percent-sandstone values for units 1-3 with those of units 4 and 5 (figs. 27 and 28). The upper portion of the Travis Peak (units 4 and 5) contains much more mudstone. Moreover, areas containing greater than 60% sandstone in the lower Travis Peak (units 1-3) form north-south oriented bands from Gregg and Harrison Counties through Cherokee, Nacogdoches, and Shelby Counties. Areas of equal sandstone content ($\geq$ 60%) in the upper Travis Peak are diminished in size and occur in pods or narrow bands of random orientation (east-west and north-south).

Depositional Systems

Bushaw (1968), McBride and others (1979), Bebout and others (1981), McGowen and Harris (1984), Saucier and others (1985), and Dutton (1987) utilized data from well logs, cuttings, seismic lines, isopach and net-sandstone maps, cross sections, and limited core analyses to characterize the depositional environments represented by Travis Peak deposits. A typical Travis Peak depositional systems tract defined by Hall (1976), McGowen and Harris (1984), and Saucier (1985) consists of (1) a braided-fluvial system that was possibly fed by numerous but small alluvial fans, (2) a delta system that prograded over a broad, stable shelf to form depocenters in the area of the Sabine Arch in East Texas and the Monroe Uplift in northeast Louisiana, (3) distal delta (delta front and prodelta with laterally equivalent strandplain and barrier island environments), and (4) marine-shelf systems (shelf, and slope).

Paleogeographic reconstructions of Travis Peak-Sligo deposition in the East Texas Basin (Bushaw, 1968) depict an early Cretaceous alluvial plain that extended from the northwest to the south-southeast into Cherokee, Rusk, and Panola Counties, and it graded basinward into neritic environments (shoreline and shelf). Despite rising sea

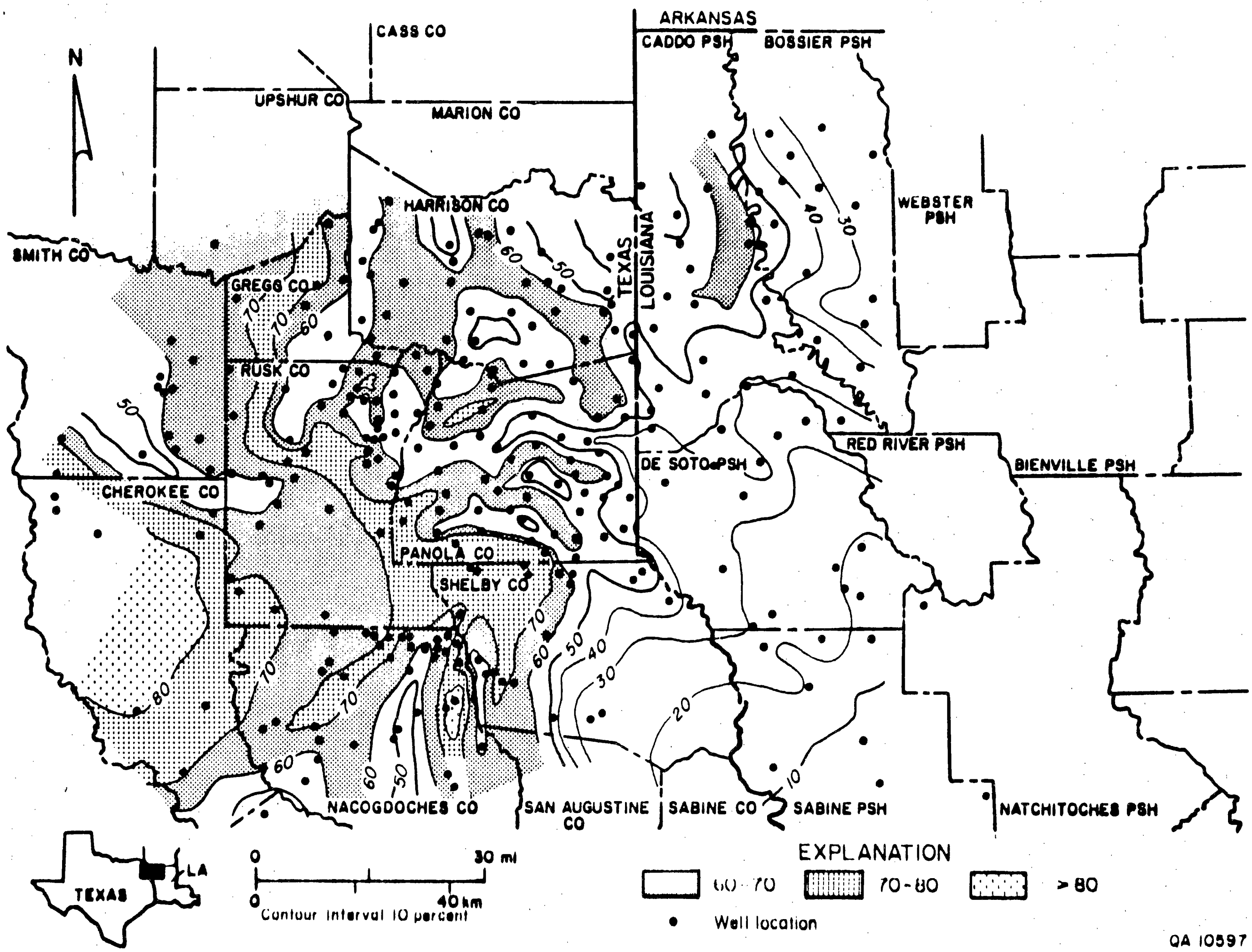

Figure 27: Percent-sandstone map of combined values for lithostratigraphic units 1 through 3.

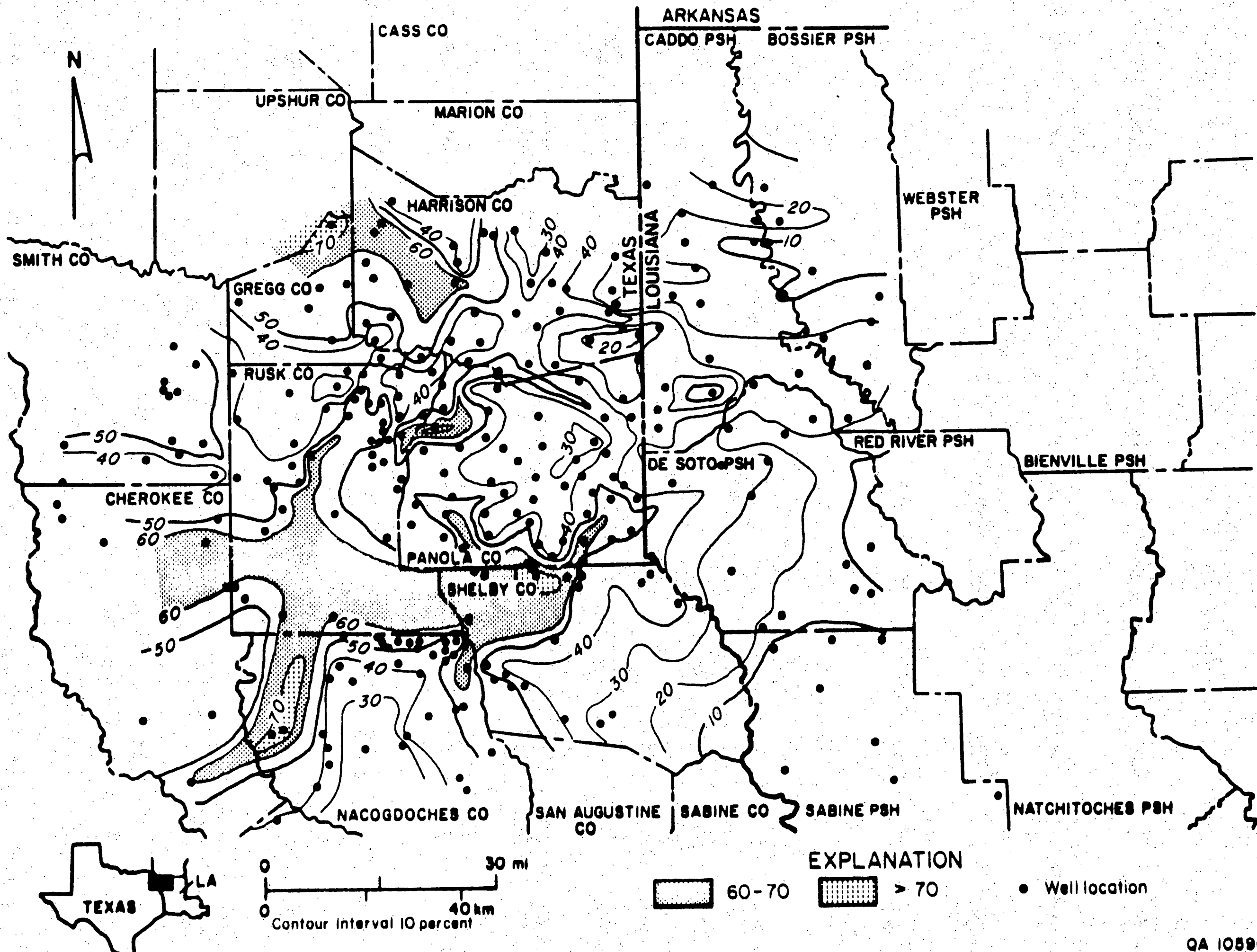

Figure 28: Percent-sandstone map of combined values for lithostratigraphic units 4 and 5.

level conditions during middle Travis Peak deposition (McFarlan, 1977; Todd and Mitchum, 1977), high sedimentation rates exceeded subsidence rates and formed a broad, southerly oriented delta plain centered over Cherokee, Rusk, and Panola Counties. This middle Travis Peak depocenter (Saucier and others, 1985), dominated deposition in the East Texas Basin. Continued sea-level rise resulted in transgression, and in deposition of poorly developed fluvial-deltaic, paralic (estuarine and bay), and neritic (strandplain, barrier island, and shelf) environments in the upper Travis Peak section.

Based on cross sections constructed for this study, Travis Peak sandstones seem to maintain uniform updip to downdip thickness trends (figs. 5-7). They thicken slightly and are stacked in a region just east of the Texas-Louisiana border. The farthest basinward transport of sandstone took place during early to middle Travis Peak deposition, and the stratigraphy of the upper interbedded sandstone-mudstone interval implies retrogradational (onlapping) depositional conditions. Using well-log, sediment-distribution, and core data, the Travis Peak Formation in this region of the East Texas Basin is interpreted to include (1) a braided- to meandering-fluvial system that forms the core of the Travis Peak section, (2) deltaic deposits that are interbedded with and encase the distal portion of the fluvial section, (3) paralic deposits that overlie and interfinger with the deltaic and fluvial deposits near the top of the Travis Peak, and (4) shelf deposits that are present at the downdip extent of the Travis Peak; they interfinger with and onlap deltaic and paralic deposits (figs. 5-7). The sedimentology of each facies that comprises this terrigenous-clastic depositional systems tract is discussed in a later section.

HYDROCARBON PRODUCTION PLAYS

Gas is produced from Travis Peak sandstones that were deposited in braided-fluvial, deltaic, paralic, and neritic environments. In considering fields with production in excess of 10 Bcf, Kosters and others (in prep.) delineated three Travis Peak play types in the East Texas Basin. Each play type is associated with particular structural features and characterized by a specific trap type. Fields located over the Sabine Arch produce primarily from combination structural-stratigraphic (porosity pinchouts) traps, and account for a majority of the total Travis Peak production in the East Texas Basin. Secondary production occurs from (1) closure traps over the crests of salt structures, and (2) traps formed by the association of intermediate-amplitude salt structures and lithologic and/or porosity pinchouts. Finley (1984) reported IPF values for 183 gas wells in East Texas as ranging from 67 to 31,000 Mcfd with an average of 5,249 Mcfd.

In Louisiana, within an approximately 3,000 ft-thick interval, the Travis Peak (Hosston) is known to produce from three zones (1) the upper 300 ft, (2) the middle 300 ft, and (3) the basal 200 ft. Some of the better fields in north Louisiana occur in the region of 5 to 20% sandstone content on percent-sandstone maps (Cullom and others, 1962). Locations of most large Travis Peak fields are shown on figure 4 and their occurrence can easily be compared to the net-sandstone and percent-sandstone maps of the entire Travis Peak or the lithostratigraphic units defined in this report (figs. 4,9 and 17-26).

SEDIMENTOLOGIC FACIES DESCRIPTIONS

Lithofacies have been defined in the Travis Peak Formation based on macroscopic descriptions of their lithologic and physical and biogenic sedimentary characteristics. Some of these lithofacies are interpreted to represent deposition in channel, floodplain, lacustrine, and overbank environments that were present as components of a well-developed braided-fluvial system. The remaining lithofacies document the preservation of various paralic environments (1) coastal plain (channel, floodplain), (2) marsh, (3) estuary or bay, (4) tidal flat, and (5) estuarine shoal.

Descriptive abbreviations for differing fluvial lithofacies defined by Miall (1977; 1978) from analyses of core and outcrop data, and developed in this study are useful in the description of the fluvial sediments (table 1). Because Miall (1977; 1978) did not use burrowing features as a facies discriminator, two additional minor facies, Sb and Fb, have been defined. Additionally, Miall's (1977; 1978) lithofacies classification was not intended to be used in descriptions of marginal-marine to marine lithofacies. Therefore, descriptive abbreviations for some paralic, deltaic, and shelf facies are not used.

Although the existence of deltaic and shelf environments have been postulated based on sediment-distribution maps (figs. 12-26), log character (figs. 29-33), and facies associations (figs. 5-7), no deltaic or shelf sediments in the Travis Peak section have been cored for use in this study. Deltas and the shelf over which they prograded were located east and south of the main study area. Therefore, discussions and interpretations of the deltaic and shelf facies are limited to their log response, areal distribution, and lithology (determined from logs).

Table 1: Lithofacies and sedimentary structure classification scheme for modern and ancient braided-stream deposits. Modified from Miall (1977).

Facies Code	Lithofacies	Sedimentary structures	Interpretation
Gms	massive, matrix supported gravel	none	debris flow deposits
Gm	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Gt	gravel, stratified	trough crossbeds	minor channel fills
Gp	gravel, stratified	planar crossbeds	linguoid bars or deltaic growths from older bar remnants
St	sand, medium to v. coarse, may be pebbly	solitary (theta) or grouped (pi) trough crossbeds	dunes (lower flow regime)
Sp	sand, medium to v. coarse, may be pebbly	solitary (alpha) or grouped (omikron) planar crossbeds	linguoid, transverse bars, sand waves (lower flow regime)
Sr	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
Sh	sand, very fine to very coarse, may be pebbly	horizontal lamination, parting or streaming lineation	planar bed flow (l. and u. flow regime)
Sl	sand, fine	low angle ($<10°$) crossbeds	scour fills, crevasse splays, antidunes
Se	erosional scours with intraclasts	crude crossbedding	scour fills
Ss	sand, fine to coarse, may be pebbly	broad, shallow scours including eta cross-stratification	scour fills
Sb	sand, silt	animal burrows	overbank deposits (crevasse splay; lacustrine delta)
Sse, She, Spe	sand	analogous to Ss, Sh, Sp	eolian deposits
Fl	sand, silt, mud	fine lamination, very small ripples	overbank or waning flood deposits
Fsc	silt, mud	laminated to massive	backswamp deposits
Fcf	mud	massive, with freshwater mollusks	backswamp pond deposits
Fm	mud, silt	massive, desiccation cracks	overbank or drape deposit
Fb	silt, clay	animal burrows	floodplain swamp, lacustrine
Fr	silt, mud	rootlets	seatearth
C	coal, carbonaceous mud	plants, mud films	swamp deposits
P	carbonate	pedogenic features	soil

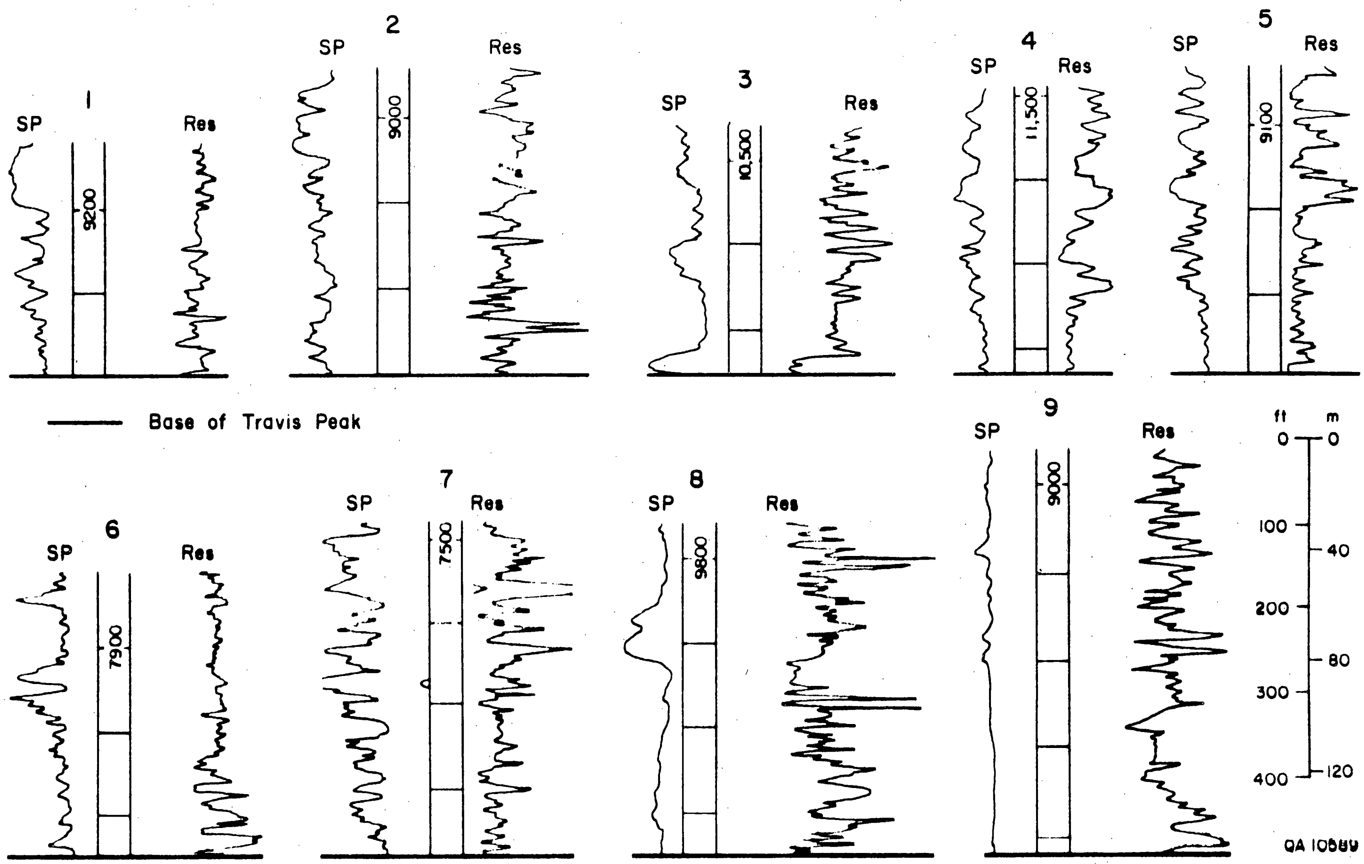

Figure 29: Representative spontaneous potential and resistivity curves for lithostratigraphic unit 1. Location of wells is given on figure 4.

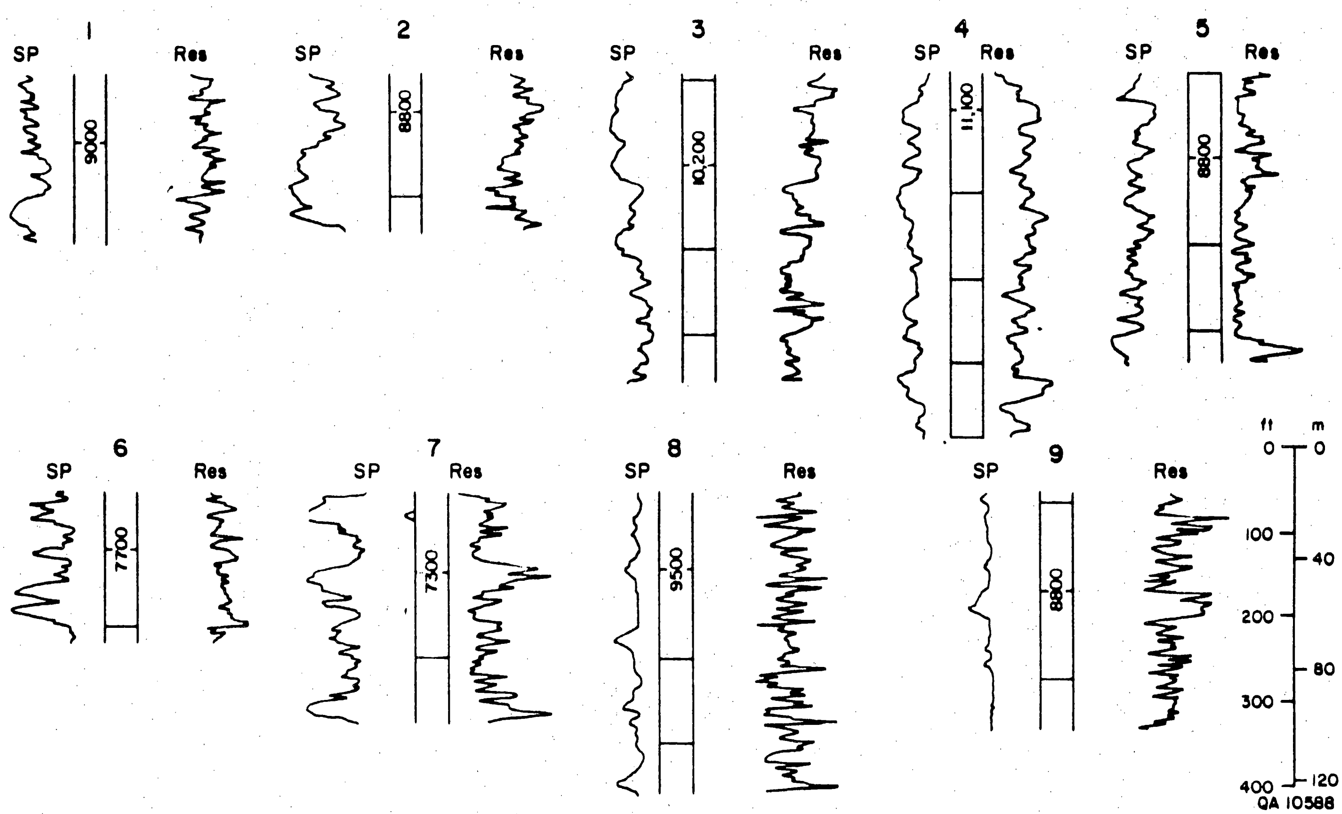

Figure 30: Representative spontaneous potential and resistivity curves for lithostratigraphic unit 2. Location of wells is given on figure 4.

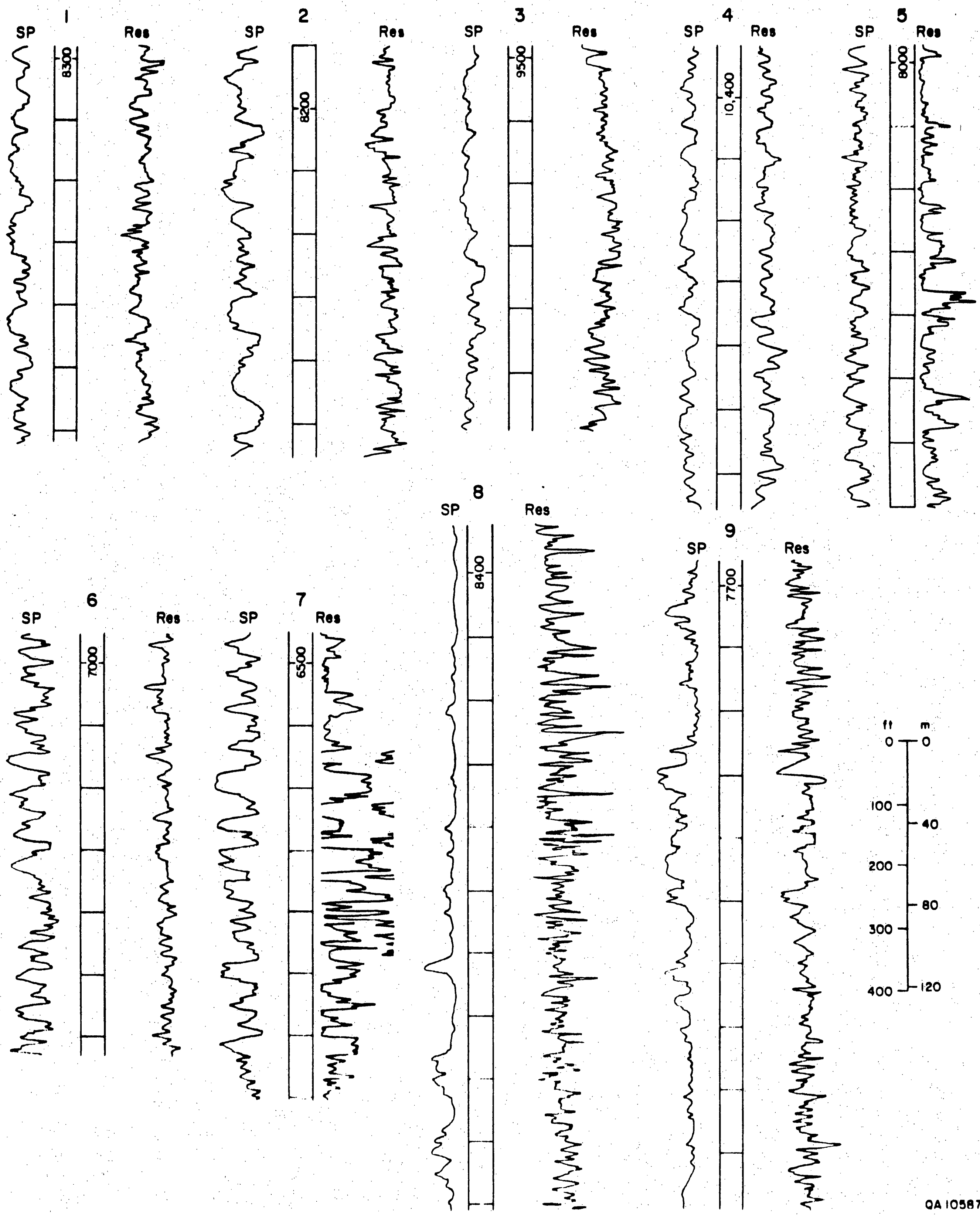

Figure 31: Representative spontaneous potential and resistivity curves for lithostratigraphic unit 3. Location of wells is given on figure 4.

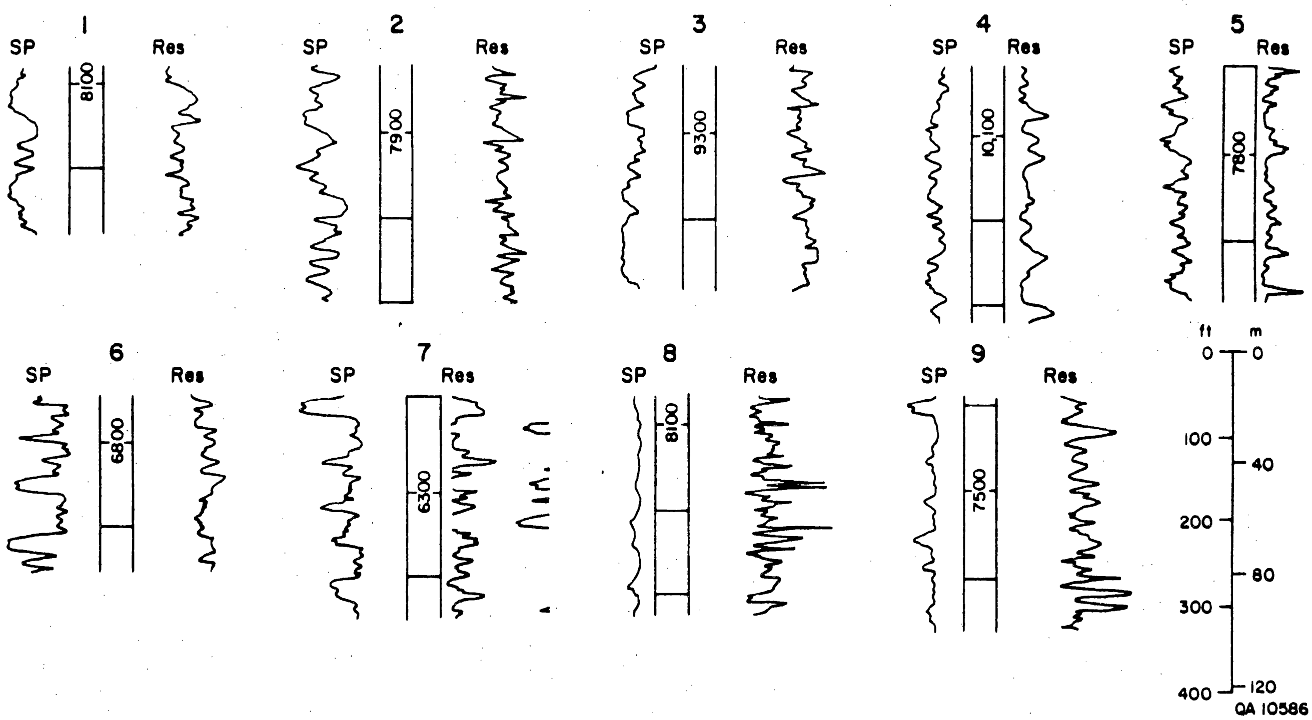

Figure 32: Representative spontaneous potential and resistivity curves for lithostratigraphic unit 4. Location of wells is given on figure 4.

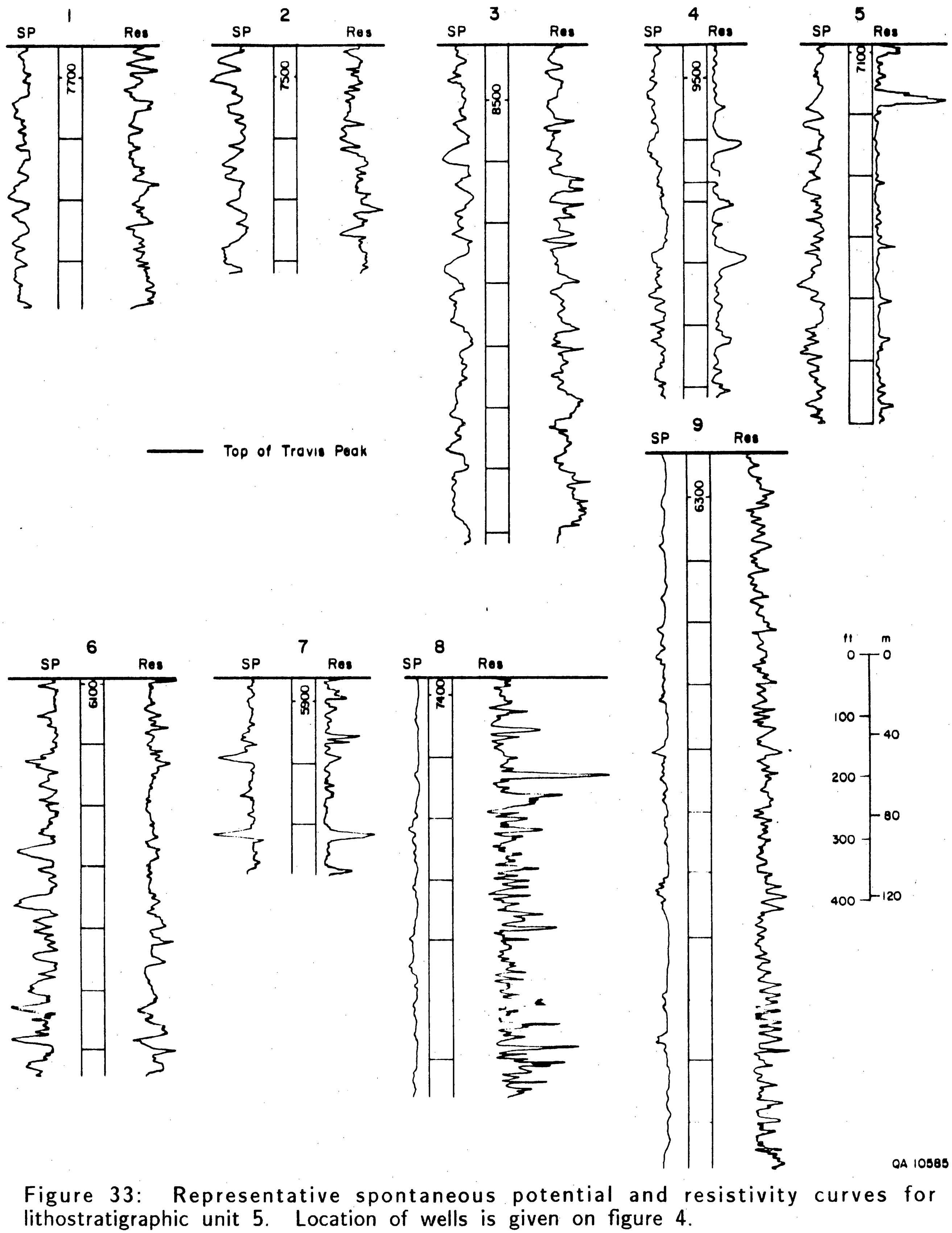

Figure 33: Representative spontaneous potential and resistivity curves for lithostratigraphic unit 5. Location of wells is given on figure 4.

Braided- to Meandering-Fluvial Facies

Braided, and to a lesser degree, meandering-fluvial deposits form the bulk of the Travis Peak section included in this study. In the proximal reaches of the study area, fluvial deposits form a sequence nearly 2,000 ft thick that unconformably overlies the Cotton Valley Formation. Downdip, fluvial deposits overlie and interfinger with the deltaic, paralic, and shelf facies (figs. 5-7). Based on their sedimentary character, five lithofacies are interpreted as representing discrete braided-fluvial depositional environments. Note that each main facies (**bold type**) may consist of several minor facies (Miall, 1978). Briefly, the main and minor lithofacies (environmental interpretations are given in parentheses) observed are (1) **Sp**, Sr, Se - cross-bedded and rippled medium-to fine-grained sandstone with thin clay-clast conglomerate layers (channel), (2) **Sr**, Sb, Fb - interbedded rippled very fine- to fine-grained sandstone and burrowed silty sandstone (abandoned channel), (3) **Fl**, Fb - laminated to burrowed sandy mudstones (lacustrine), (4) **Sb**, Fb, P - rooted and burrowed silty sandstones and sandy mudstones (floodplain, swamp), and (5) **Sr**, Sp, Sb - rippled to burrowed silty sandstones (overbank sandstones). The floodplain sequences contain sandstones and silty sandstones that are interpreted to be crevasse-splay or lacustrine-delta deposits. Due to limited data and uncertainties in discriminating between crevasse-splay and lacustrine-delta deposits in ancient fluvial sequences, these sediments are referred to as overbank sandstones.

Channel and Abandoned Channel (Sp, Sr, Se, Fb)

Channel sandstones are generally fine- to very fine-grained, although grain size can reach medium to coarse, and channel thickness ranges from 10 to 50 ft. Most have scoured bases, and commonly exhibit internal scour contacts (Se). All channel sandstones may include clay-clast conglomerates with clast size ranging up to pebbles (1.0 in). The primary bedding type in the basal portion of the channels is planar cross-bedding (Sp). Above the scoured base, planar cross-bed sets form beds 0.5 to 1.0 ft thick and are interbedded with gently inclined parallel-laminated beds (thickness 1.0 to 2.0 ft). The thickness of the parallel-laminated beds decreases upward, and in the middle to upper portions of the channel sandstones, they are replaced by beds (< 1.5 ft thick) of current-ripple laminations (Sr). Near the top of the channel sandstones, planar cross-bedding (sets 0.3 to 2.0 ft thick) grades upward into thinly interbedded (1.0 to 3.0 in) sets of planar cross-beds and current-rippled beds that commonly display Type A climbing ripple lamination (Allen, 1984). Mudstone is present in the sandstone interval as thin mud drapes on planar-cross beds, on ripples (flaser beds), and as rip-up clasts. Other features of channel sandstones include massive-appearing beds, soft-sediment deformation, detrital organics concentrated on bedding surfaces, pyrite, coal streaks, and root traces.

Channels are best-developed in the middle and lowermost portion of the Travis Peak (fig. 11). Vertical thickness of channel deposits is often increased by the stacking of separate channel bodies. On GR logs, channel sandstones appear blocky to irregular or serrate in form. Channel bases are generally sharp, but the log underestimates the actual channel thickness because clay-clast lags (clast size up to 1.0 in) on the channel bases are seen as "shales." Many "shaley" breaks noted by GR logs are actually channel lag deposits, and stacking of these channel deposits gives the sandstones a "dirty" appearance (fig. 29 wells 1, 2, 4, & 5 and fig. 30 wells 2, 3, 4, 5, & 7).

Abandoned-channel deposits abruptly to gradationally overlie the channel sandstones and are represented on the GR log by an overall upward-fining serrate pattern (fig. 31, wells 2, 6, & 7; fig. 32, well 4; fig. 33, wells 1-4). In core, these deposits consist of thin- to medium-bedded (0.04 to 1.0 ft), fine- to very fine-grained sandstone, silty sandstone, and mudstone (Sr, Fb). The prevailing conditions of low sediment input and weak depositional energies in the abandoned channels are reflected in the increased mud content of the sediments and evidence of greater activity by burrowing organisms. Trough and planar ripple cross-lamination is common, and ripple foresets are often accentuated by flaser beds and organic drapes. Pyrite associated with the detrital organics is abundant. Contorted, soft-sediment deformed beds up to 1.5 ft thick occur within the abandoned-channel deposits. Burrows and occasional rooting structures have obliterated primary structures in the uppermost portion of the abandoned-channel sequences.

Floodplain (P, Sb, Fb)

Densely rooted and burrowed red to greenish-gray and black sandy mudstones represent the floodplain environment. The thickness of cored floodplain sequences ranges from 2 to 15 ft. Intense biogenic reworking gives these deposits a mottled appearance, but some sedimentary structures such as laminations or ripples may be preserved. Diagenetic carbonate nodules and disseminated organic matter ("coffee grounds") are common in the floodplain sediments. Pyrite is absent, suggesting that floodplains were well drained.

Floodplain deposits exhibit serrate to uniform "shaley" patterns on the GR-log. The sandstone content of these deposits determined form core analyses is high, therefore, "shaley" log patterns are not indicative of true mudstones or shales. More thickly developed floodplain deposits appear serrate on the lithologic log, due to the inclusion of thin, mud-rich sandstones (fig. 33, well 5).

Lacustrine (FL, Fb)

Lacustrine sequences are thin (<6.0 ft), and not readily abundant in the cored intervals. They consist of intensely burrowed to laminated and rippled mudstones to silty sandstones. Burrowing is by far the dominant feature (Fb) but lacustrine sediments may also be rooted. Some organic material is preserved.

Lacustrine deposits overlie floodplain sediments and are usually overlain by a coarsening- or fining-upward muddy, lacustrine-delta sandstone. This association imparts an upward-fining, shaly character to the lacustrine deposits on the GR log (transition from floodplain to lacustrine), but because the lacustrine deposits are overlain by sandstones, a sharp upper contact is often noted.

Overbank (Sp, Sr, Sb)

Thin (4 to 12 ft thick), muddy, fine- to very fine-grained sandstones deposited in crevasse-splay or lacustrine delta environments commonly overlie or are interbedded with floodplain and lacustrine deposits. These sandstones can form both upward-coarsening and upward-fining sequences. As these sandstones are interpreted to have been deposited by traction processes during flood events, but later reworked by biogenic processes on the floodplain, their internal stratification can be extremely complex.

Planar cross-beds (Sp), planar- and trough-ripple laminations (Sr), and distorted beds (slumps and dewatering structures) are the most abundant physical structures. Normal-graded and reverse-graded beds 0.5 to 3.0 ft-thick are common. Depending on the intensity of the physical processes and the rate of burial, organisms can burrow through the entire sequence and destroy primary stratification (Sb). Rooting occurs at the top of some floodplain sandstones. Overbank sandstones commonly appear as sharp-based and sharp-topped beds on the GR-log.

Deltaic Facies

Deltaic deposits are recognized in the Travis Peak Formation based on the existence of progradational (upward-coarsening) well-log profiles (fig. 31 wells 8 & 9 and fig. 32 well 8). Additionally, cross sections and the isopach and percent-sandstone map patterns reveal that the braided-fluvial facies grades basinward into lobate depocenters (figs. 5-7, 12-16, 22-26). These depocenters are primarily located to the south and east of the study area.

Upward-coarsening deltaic cycles consist of vertically stacked shales, mudstones, and sandstones deposited in prodelta through distributary-mouth bar environments. Well-developed cycles reach thicknesses between 100 and 200 ft, indicating that rivers deposited sediments onto a fairly shallow, stable shelf. Through sea-level fluctuations, slow basin subsidence, or both, multiple deltaic cycles were stacked. Overlying many of the progradational deltaic sequences are intertonguing mudstones and sandstones that impart blocky, spikey, upward-coarsening, and upward-fining responses on the SP log (fig. 31 wells 8 & 9). As noted by Galloway and Hobday (1983), these intervals correspond to the aggradation of delta-plain deposits (channels with blocky to upward-fining curves; crevasse splays may exhibit both upward-fining and upward-coarsening curves; interdistributary bays exhibit shaley to spikey curves).

During the initial phases of Travis Peak deposition, deltas built out over the pre-Travis Peak shallow shelf formed by the Knowles Limestone. Through subsequent deposition, the deltas extended to the south and east as they prograded over, and interfingered with, laterally equivalent shale and sandstone deposited on the Travis Peak shelf (figs. 5-7). In the later stages of Travis Peak deposition, the locations of deltaic depocenters shifted progressively updip (north and northwest); transgressed deltaic deposits are overlain by the paralic facies (figs. 5-7).

Paralic Facies

Interbedded sandstones and mudstones in the uppermost portion of the Travis Peak Formation are characterized by thin spikey and upward-fining or upward-coarsening well-log responses (fig. 11 and fig. 33, wells 4-7). These sediments are interpreted to have been deposited in a paralic depositional setting that consisted of coastal-plain (fluvial meanderbelt, floodplain) and marginal-marine (estuarine, bay, marsh, tidal-channel, shoal) environments. In the proximal regions of the study area, paralic facies gradationally overlie and interfinger with the fluvial facies. Further downdip, they overlie deltaic deposits and grade into the shelf facies (figs. 5-7).

Cores of paralic deposits reveal the most diverse assemblage of lithofacies in the Travis Peak, and their diversity is strongly apparent along depositional dip (figs. 5 and 6). Coastal plain environments dominate in the updip regions (N/NE) of the study area and grade downdip (S/SE) into estuarine and marine deposits. The sedimentary character of each is discussed separately.

Coastal Plain

Fluvial channel (**Sr**, Sp, St, Sb): Sandstones in coastal-plain fluvial channels are fine- to very fine-grained and vary from 5 to 15 ft thick. They exhibit sharp to scoured bases that may be overlain by thin (< 0.5 ft) normally graded beds of sand and mud. Mud rip-up clasts (clast size may exceed 1.0 in) may be present at their base. Lithofacies Sr (planar, trough, and Type A climbing ripples) is most common in the sandstones; Sp is present but not as abundant as in the braided-fluvial sandstones. A prominent stratification style is the alternation of low-amplitude current ripples (0.6 inch sets form beds < 0.5 ft thick) with massive-appearing beds. Flaser bedding and wavy beds are also present. Ripples near the tops of sandstones tend to be symmetrical in form (wave-deposited or reworked ripples). Lithofacies Sp and St occur as thin beds (0.5 to 1.0 ft) near channel bases or as sandstone beds intercalated with mudstone. Soft-sediment deformation (faults, slumps, load and water-escape structures) is a pronounced feature in the channel sandstones. Bed thickness decreases and soft-sediment deformation structures increase in abundance approaching the tops of sandstones, where they grade upward into abandoned-channel deposits.

Abandoned channel (**Sr**, Sb, Fsc, Fl, Fb): Thin (ave. thickness 5.0 ft), stratified to unstratified sandstone and mudstone intervals overlie the channel sandstones. These fine-grained deposits accumulated in channels abandoned through avulsion or meander cut-off, and their sedimentary character attests to the diverse processes active during deposition. Trough-cross laminated, wave-rippled, to burrowed sandstone beds less than 1.0 ft thick are interbedded with laminated, burrowed, and rooted mudstones. Flaser beds, wavy beds, and starved ripples are common in these lithologically variable deposits. Due to the initially high water content of the unstable sediments, soft-sediment deformation features (load casts, slumps, faults) are abundant.

Floodplain and Overbank (**Fr**, Fb, Fsc, Fm, Sr): Interbedded sequences of rooted and burrowed mudstone and thin beds of rippled to cross-laminated sandstone separate the coastal-plain channel deposits and represent deposition in floodplains adjacent to the meanderbelts. Sandstone beds denote episodic periods of overbank deposition in natural-levee, crevasse-splay, or lacustrine environments.

Floodplain and overbank deposits are thicker (2 to 25 ft thick) and more laterally continuous than comparable deposits in the braided-fluvial facies of the Travis Peak. Biogenic structures (Fb) dominate, with burrows of multiple sizes and orientations more abundant than root traces. Preserved physical sedimentary structures include ripple and flaser bedding in the sandstone beds and parallel laminations, wave ripples, and starved ripples in the sandy mudstones. Soft-sediment deformation is common in the sandstones and mudstones. Pedogenic features, diagenetic mineralization (carbonate) associated with soil formation, burrows and root traces, and evidence of alternating oxidizing and reducing conditions are characteristic of floodplain deposits.

Marginal Marine

Many sandstones and mudstones of the paralic facies (especially in the distal parts of the study area) are interpreted to have been deposited in marginal-marine depositional environments. These sediments are finer grained and relatively mud-rich as compared to the rest of the Travis Peak section, therefore their log response is highly variable (fig. 33, wells 7-9). Sedimentary evidence of increased biogenic activity, indications of wave and tidal processes, and a greater content of fine-grained sandstone and mudstone indicate a depositional transition from coastal-plain to estuarine conditions. Estuaries occupy zones of gradation containing continental and marine facies. The lithologic, sedimentologic, and biogenic attributes of the fluvial-channel, tidal-flat, tidal-channel, and estuarine-shoal environments record the contrasting and dynamic depositional processes in estuaries.

Blocky to upward-fining sandstones 10 to 25 ft thick are composed of medium bedded (1.0 to 2.0 ft) trough- and planar-ripple cross-laminated beds. Except in thicker, sharp-based sandstones in which trough and planar cross-stratification prevail, current- and symmetrical-ripple laminations (0.2 to 1.2 inch sets; 2.0 to 4.0 inch beds), as well as horizontal laminations, are the most common physical sedimentary structures. Soft-sediment deformation, flaser beds, mud drapes, and rip-up clasts occur throughout all marginal-marine sandstones. Planar-cross stratification in several sandstone beds hints at the existence of bidirectional cross-stratification induced by opposing tidal currents, and mud drapes that separate foreset laminae into tidal bundles (Visser, 1980; Reineck and Singh, 1986) were observed.

All sandstones in this facies exhibit burrowing, and most are densely burrowed at their tops. Burrow traces are predominantly vertically to obliquely oriented (escape burrows), but many traces are horizontally oriented (grazing burrows). Coal streaks, organic debris, and rare shell material (gastropod and bivalve fragments) are present.

Mudstones and thin sandstones (0.5 to 2.5 ft thick) intercalated in intervals that average 5.0 ft thick (maximum thickness of 10 to 15 ft). These intervals do not exhibit upward-coarsening or upward-fining tendencies. Sandstone beds may have scoured bases, but many of the bedding contacts are burrowed. Shell debris (gastropod and bivalve) and clay clasts are concentrated in the coarser-grained beds. Howard and Frey (1973) described Georgia estuaries as having only a small amount of shell material, but they observed some local concentrations.

Owing to less energetic depositional conditions, biogenic sedimentary structures dominate in the mudstones and poorly sorted sandstones. Rooting and burrowing activity destroyed most physical sedimentary structures; those preserved include horizontal laminations, ripple-cross lamination, lenticular beds, and soft-sediment deformation (convoluted beds). Symmetrical ripples and starved ripples are evident. Burrow traces are primarily vertically oriented, and some mudstones contain disseminated organic debris and possible algal laminations.

Howard and Frey (1973), Howard and others (1973), Greer (1975), Freeman (1982), and McCants (1982) have described modern estuarine depositional sequences and assemblages of physical and biogenic sedimentary structures from Georgia and

South Carolina that compare favorably with the Travis Peak paralic cores. Because estuaries are stratigraphically and sedimentologically complex, interpretations of the Travis Peak deposits are admittedly general. However, thick, sharp-based sandstones in the Travis Peak paralic facies are interpreted as deposits of tidal channels and fluvial channels that drained into large estuaries. Other thick sandstones that have sharp to gradational bases are believed to be tidal-flat and estuarine-shoal deposits. Thinner sandstones accumulated in small tidal channels and in tidal flats. Mudstones in this sequence represent deposition in swamp, marsh, tidal-flat, and lagoon or bay environments.

Shelf Facies

The shelf is the most basinal of the depositional environments examined in this study, and it forms the distal equivalent to the deltaic and paralic facies (figs. 5-7). Shelf deposits are interpreted to occur at the base of the Travis Peak and onlap paralic deposits at the top of the formation. Based on logs, shale is the main sediment type found in the shelf facies, and it exhibits a high gamma-ray and high SP response (fig. 29 and fig. 33, wells 8 and 9).

Some sandstone beds of highly variable thickness (< 2.0 to 60.0 ft; figs. 29 and 30, wells 8 and 9) occur in the shelf facies, and the sandstone beds appear blocky, spikey, or upward-fining on the SP logs. Thus, they do not imply deposition under progradational conditions. Shelf sandstones generally thin upward and are confined to the lower and middle portions of the Travis Peak section in the area of northwestern Sabine Parish (figs. 6, 12, 13, 17, 18, 22, and 23). Stratigraphic correlations indicate that most of the sandstones are not continuous with the updip deltaic deposits, but instead are separated by an expanse of mudstone 8 to 10 miles wide (fig. 6).

TRAVIS PEAK PALEOGEOGRAPHIC EVOLUTION

Two prominent Early Cretaceous depocenters (regions of high sedimentation; Roberts, 1982) are present in the vicinity of the Sabine Arch and the Monroe Uplift along the Gulf Basin arc that extended eastward from East Texas through Arkansas, Louisiana, and into Mississippi (Cullom and others, 1962; McFarlan, 1977; Saucier, 1985). These depocenters were formed by alluvial systems that were confined within elongate basins oriented parallel to regional structural dip and perpendicular to the margins of the East Texas Basin. McFarlan (1977) attributed the Lower Cretaceous Travis Peak regression to uplift of the Appalachian and Ouachita Mountains. Saucier (1985) defined the fluvial system that fed the northwestern corner of the East Texas Basin as the ancestral Red River. It was localized in a structural break or downwarp between Dallas, Texas and the Arbuckle Mountains in southern Oklahoma (fig. 34).

Thinning of the Travis Peak to the northwest (fig. 8) suggests that the Ouachita, Arbuckle, and Wichita highlands were among the sources of Travis Peak sediments (McGowen and Harris, 1984; Saucier, 1985). The large volume of sediment in the Travis Peak Formation indicates that these areas were not the only source of sediments. Contemporary highlands in the Rocky Mountains and Triassic and Jurassic sedimentary terranes to the southwest may have been additional sources of Travis Peak sediments (Saucier, 1985; fig. 34). Moreover, textural and mineralogical maturity of Travis Peak sandstones (Dutton, 1987) imply a reworked sedimentary (multi-generation) source.

Despite rising sea-level conditions, rivers debouching into the basin initially had sufficient discharge and an ample supply of sediment to construct the Travis Peak depocenters. A series of maps (fig. 35) schematically illustrates the evolution of the

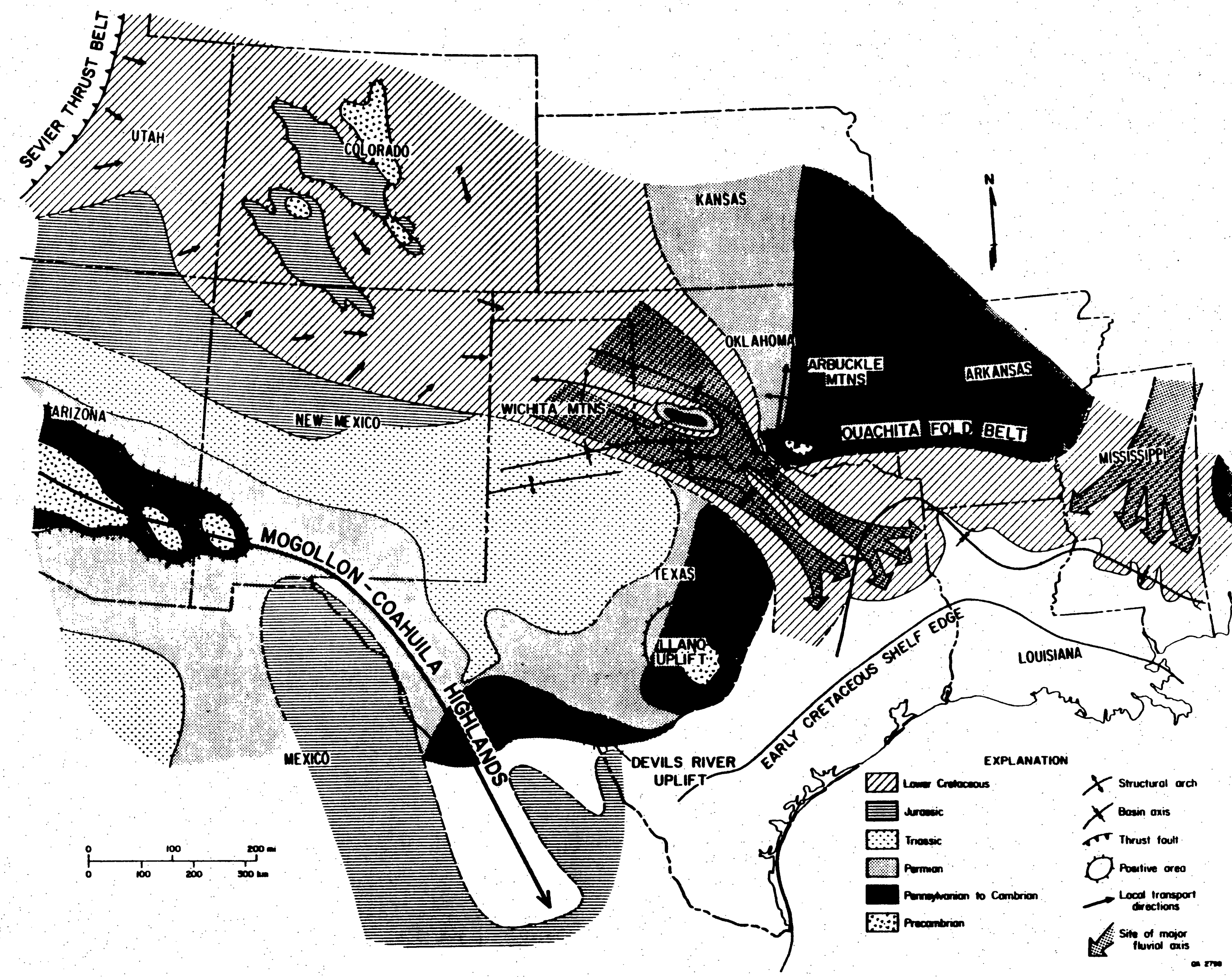

Figure 34: Schematic representation of Early Cretaceous paleogeography of the south-central and southwestern United States. Based on data from Mann and Thomas (1968), Hayes (1970), Gulf Coast Association of Geological Societies (1972), McGookey (1972), Saucier (1974, 1976, 1985), Reese (1976), Martin (1978), and Owen and others (1978).

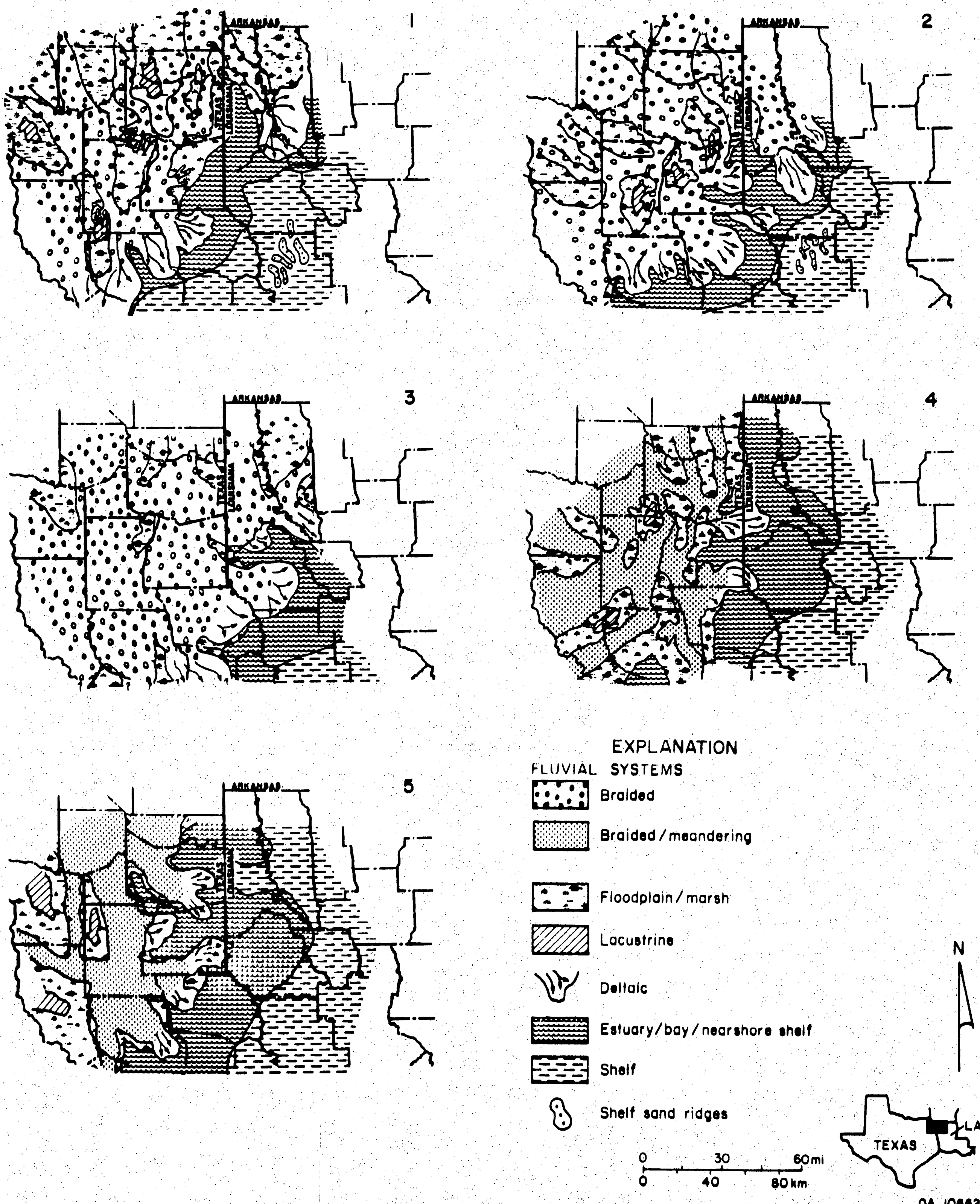

Figure 35. Hypothetical paleogeographic reconstructions for five time periods during Travis Peak deposition. Note initial development and progradation of fluvial-deltaic systems, followed by shoreline transgression. Interpretations are based on sedimentary patterns observed in figures 12-26 and core from wells shown on figure 4. Actual time span represented by each period is variable and unknown.

East Texas depocenter during its 15 my existence. Each map depicts the occurrence and distribution of sedimentary facies during a particular time of Travis Peak deposition. The time interval that each map represents is variable and cannot be ascertained, as no dated stratigraphic markers divide the Travis Peak. Refer to figure 35 for the following discussion of Travis Peak evolution.

Paleogeography: Time 1

Initial Travis Peak development is marked by the progradation of north-south to northwest-southeast oriented braided channelbelts. Channelbelts were separated by elongate interfluves that ranged from 10 to 20 mi wide. Floodplain (swamp), lacustrine and lacustrine delta, and overbank (levee, crevasse splay) environments occupied the interfluves. Large, elongate delta lobes fed by the braided channelbelts covered 100's of square miles in a band that extended from southern Cherokee through Nacogdoches and into northwest Shelby Counties. An additional delta formed to the northeast in Caddo, Bossier, and DeSoto Parishes. Shallow estuaries and bays separated delta lobes and extended seaward of the deltas and marshes to the southeast. A prominent northward extension of a large estuary is evident in Caddo Parish near the Texas border. To the east, a muddy shelf extended basinward, but in north-central Sabine Parish, shelf-sand ridges, perhaps representing reworked deltaic deposits, were present. Processes responsible for their deposition are discussed later.

Paleogeography: Time 2

Increased development and progradation of the braided-fluvial system is evident during Time 2 (fig. 35). Floodplains decreased in size, perhaps by channel migration and reworking, but also through overbank deposition and filling of swampy areas.

Concurrently, estuaries were drained and filled (particularly in Marion and Harrison Counties and Caddo Parish), thus creating floodplains and marshes between delta lobes.

Deltas increased in size and extended further basinward during Time 2. Existing deltaic deposits at the end of Time 1 were partially cannibalized during this phase of fluvial progradation and delta enlargement. Additional deltas developed in Panola and Shelby Counties near the Louisiana border. As in Time 1, a marine shelf was present eastward of Shelby County and DeSoto Parish, and shelf-sandstone deposits (derived from marine-reworked deltas and delta-front sediment-gravity processes) accumulated in north-central Sabine Parish.

Paleogeography: Time 3

The distribution of sedimentary facies during Time 3 illustrates the farthest basinward advance of the Travis Peak Formation. Continued development of braided channelbelts from Time 1 through Time 3 resulted in much fluvial reworking (erosion and redeposition) and a sharp reduction of floodplain deposits. At some point during Time 3, most of the western portion of the study area was occupied by a braided channelbelt (fig. 35). Previously deposited deltas in southern Cherokee, Nacogdoches, and San Angelo Counties were abandoned (they subsided and/or were reworked), and the braided-fluvial and deltaic systems extended south of the study area. Delta progradation extended the shoreline basinward in Shelby and Panola Counties and DeSoto, Caddo, and Bossier Parishes.

Estuarine, nearshore, and shelf environments were present in a very small portion of the study area at this time, although a large estuary did exist between two delta lobes in northern DeSoto Parish. If sand ridges were present on the shelf as in Times 1 and 2, they would likely have been deposited to the south in Trinity, Sabine, and Angelina Counties, and to the east in Natchitoches, Vernon, and Rapides Parishes.

Paleogeography: Time 4

Time 4 records a marked change in the geomorphology of the Travis Peak that was induced by the rising Cretaceous sea (figs. 2 and 35). Dominantly north-south and northwest-southeast oriented fluvial systems were present as braided to meandering channelbelts that were smaller in size than the previously deposited braided channelbelts. Floodplains, lakes, and marsh occupied interfluves between channelbelts.

The extent of deltaic deposition decreased drastically during Time 4. Braided-meandering fluvial systems were still feeding deltas to the south of Cherokee and Nacogdoches Counties, but only two small deltas were present in Panola and Shelby Counties. As river valleys were drowned, estuaries covering 10's to 100's of square miles developed between the delta lobes. Shelf environments became more widespread, but because of decreased sediment input and rising sea-level conditions, no sand-size sediment was transported to the shelf.

Paleogeography: Time 5

Maximum flooding of abandoned deltas and river courses, and formation of large estuaries characterizes the final stages of Travis Peak deposition. Fluvial systems that were present during early Time 5 deposition appear to have been larger than those present in Time 4. They fed a series of small deltas in southeast Henderson, northwest and southeast Panola, northwest Shelby, and southeast Nacogdoches Counties and were separated laterally by floodplain and lacustrine environments.

In figure 35, the estuaries are shown to extend as far north and west as Nacogdoches, Rusk, and Gregg Counties. However, cores near the top of the Travis Peak Formation in Smith (Dutton and Finley, 1988), Panola, and Shelby Counties described as tidal-flat and estuarine deposits, imply that at the end of Travis Peak deposition, the entire study area consisted of marginal-marine to marine environments.

DISCUSSION

Major components of Travis Peak paleogeography consisted of an alluvial plain that developed in front of a foldbelt (Ouachita Foldbelt fig. 34) and extended into the Cretaceous sea. River morphology and its termination character were determined by stream gradient, sediment load, discharge, and marine processes (Miall, 1981). As the type and intensity of fluvial and marine processes changed during the 15 my period of Travis Peak deposition and sea-level rise, the morphology of the alluvial plain adjusted accordingly.

Early Travis Peak Deposition

Early stages of Travis Peak deposition are characterized by high-gradient, braided streams possessing high competency and capacity, that prograded into the East Texas Basin and deposited a series of elongate to lobate deltas on a shallow stable shelf (fig. 35; Bushaw, 1968; McFarlan, 1977; Saucier, 1985). Map and core data indicate that during early Travis Peak deposition wave- and tidal-depositional processes were subordinate to fluvial processes.

Stratigraphic and core data from sandstones near the base of the Travis Peak Formation in Nacogdoches County (fig. 36-38) indicate that the thickest and most

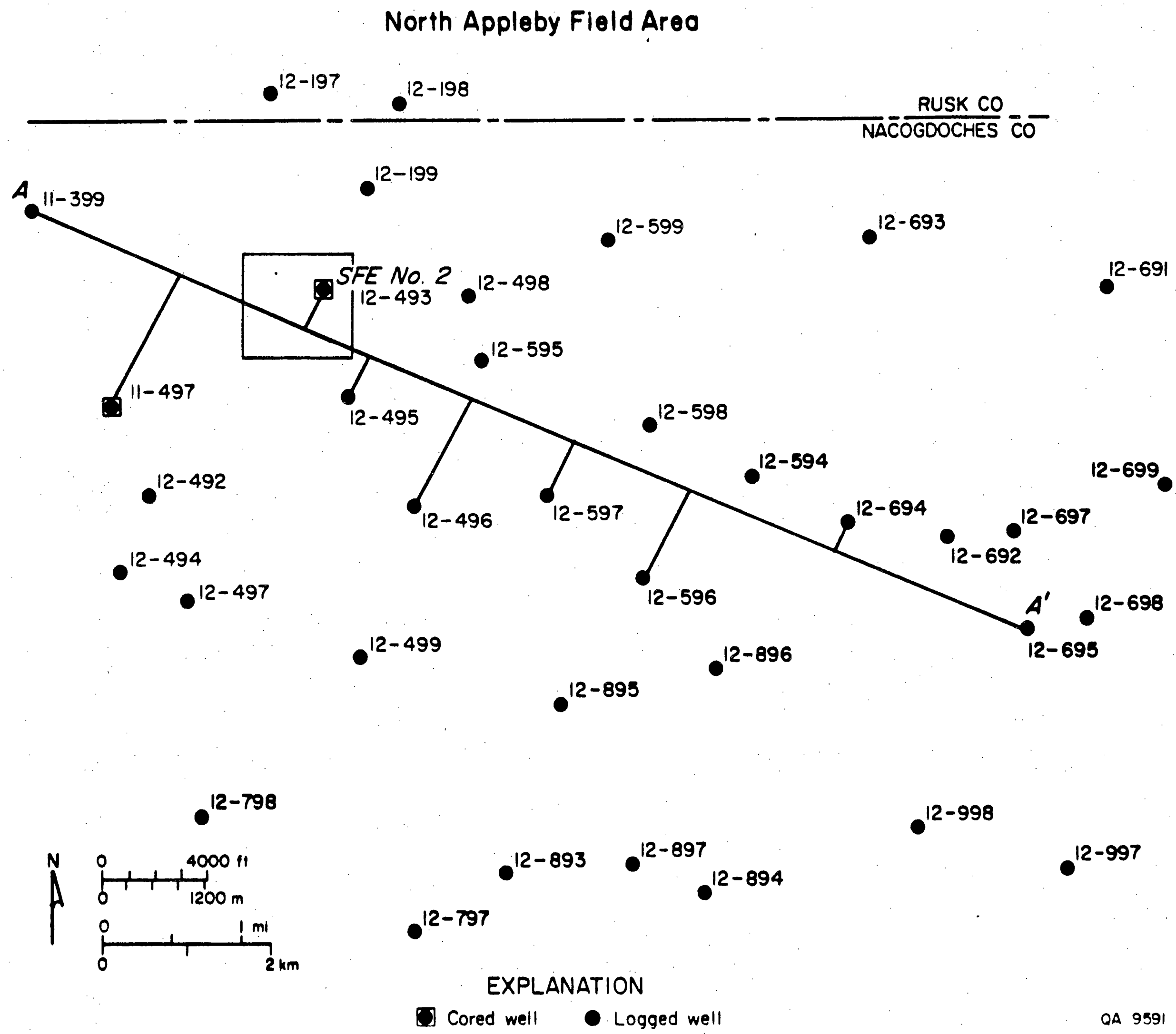

Figure 36: Location of North Appleby Field in northern Nacogdoches County, Texas. Thirty-six wells are included in the study of this field, and a total of 584 ft of core was recovered from the Prairie Production Mast No. 1-A (11-497) a cooperative well, and the S. A. Holditch & Assoc. SFE No. 2 well. Well SFE No. 2 occurs in the northeast quarter of the J. P. Collins survey. Line A-A' denotes the location of field-wide stratigraphic cross sections shown in figures 38 and 39.

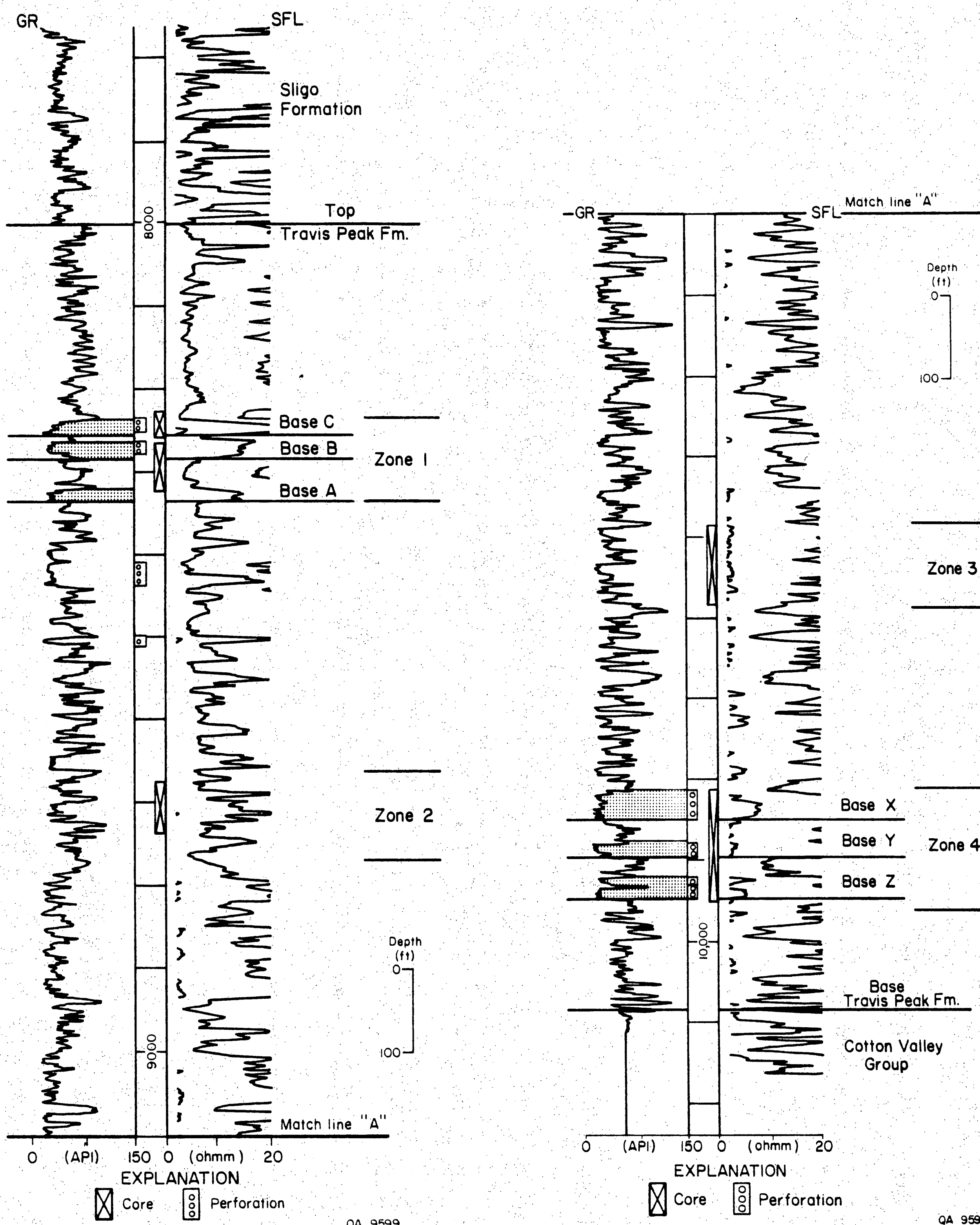

Figure 37: Gamma-ray and resistivity (SFL) logs for the Travis Peak Formation in the SFE No. 2 well. Zones 1 through 4 refer to cored stratigraphic intervals that were studied in detail. Three sandstones separated by mudstones are present in Zone 1, and these sediments are interpreted as poorly developed braided-channel sandstones, levee, splay, and lacustrine sandstones, and floodplain (swamp) mudstones. The three sandstones separated by mudstones in Zone 4 are interpreted as well-developed braided-channel sandstones, levee, splay, and lacustrine sandstones, and floodplain (swamp) mudstones.

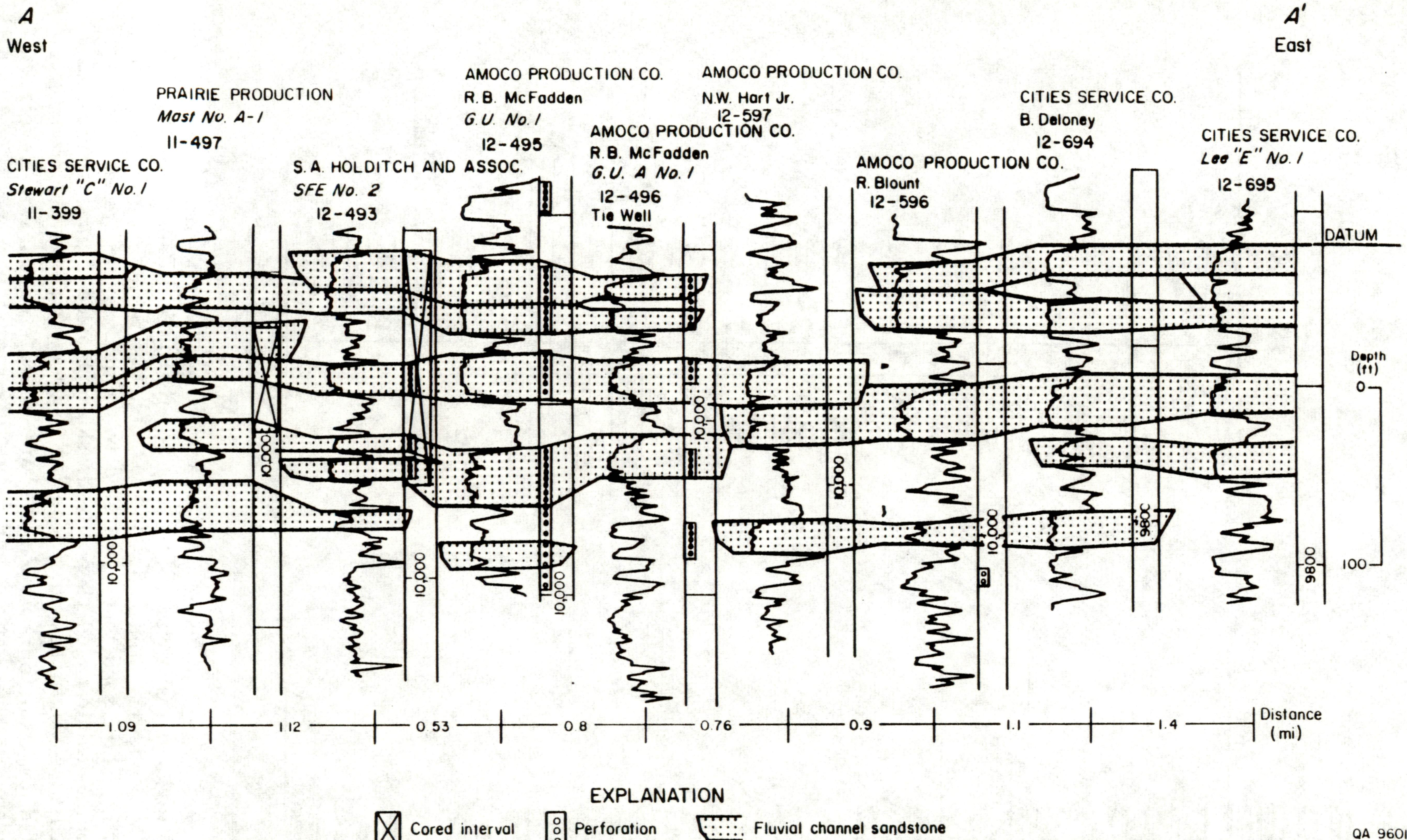

Figure 38: Stratigraphic cross section A-A' illustrates the occurrence and geometry of channel-belt sandstones in Zone 4. Note the relative increase in multilateral fluvial channel sandstones in Zone 4 as compared to Zone 1 (fig. 39). The braided channel-belt sandstone deposits reach maximum thicknesses of 35 to 45 feet, and their widths range from 2.5 to 5 miles. Sandstones are separated from each other vertically by floodplain deposits, and mudstones interfingering with the channel deposits result in some internal lithologic heterogeneity. Erosional juxtaposition of discrete sandstone lenses is greater in Zone 4 than in Zone 1, thus indicting a higher degree of channel scour and lateral migration. Gamma-ray log curves are shown.

continuous sandstones represent 3- to 5-mile wide channelbelts deposited by laterally migrating braided streams. On SP and gamma-ray logs, channelbelt sandstones appear as sharp-based and sharp-topped packages. Gradational contacts (upward-coarsening or upward-fining) on the logs can be caused by basal clay-clast lags and abandoned channel deposits, respectively, that cause high SP and high gamma responses.

Within a 150 ft thick interval located just 150 ft above the Cotton Valley Formation (correlates to Time 1), approximately eight channelbelts that range in thickness from 4 to 44 ft are present. Figures 36 and 38 illustrate their multilateral configuration and association with floodplain mudstones and overbank sandstones (muddy to serrate log response). Sediment grain size, textural and mineralogical maturity, and the preserved sequence of sedimentary structures suggest a distal braided-stream depositional setting for these channelbelts. Rivers had low sinuosity channels with poorly defined active and inactive regions that were dominated by linguoid (transverse) bars. Early Travis Peak channels in this part of Nacogdoches County probably resembled the Platte River, Nebraska (Smith, 1971; Miall, 1985a, model 9; 1985b).

Thin, laterally persistent deltas were formed on the stable, slowly subsiding shelf by braided streams that prograded directly into the basin. McPherson and others (1987) describe braid deltas as being 10's to 100's of mi^2 in extent, as consisting of braided-fluvial distributaries that lack muddy matrix and a subaerial delta plain composed of braided-stream or braidplain facies. McPherson and others (1987) offer no stratigraphic information, but it can be inferred that with delta abandonment and subsequent reworking and burial by regressive-fluvial systems, braided-stream deposits would be the most preservable and recognizable facies.

Unlike the present rapidly subsiding Gulf of Mexico basin, which is filled with many completely preserved deltaic depocenters (Woodbury and others, 1973; Roberts, 1982), the East Texas Basin was relatively stable. Therefore, many of the early

Travis Peak deltaic depocenters were destroyed by subsequent fluvial erosion. Identification of their remnants is dependent on facies associations and sediment distribution maps. McPherson and others (1987) also note that sediment-gravity processes are important in braid deltas due to the rapid deposition of large sediment loads; similar processes may have transported sand onto the early Travis Peak shelf (fig. 35, Times 1 and 2). Moreover, subaqueous-transport processes on the Brahmaputra delta front, East Pakistan, have transported a volume of material to the shelf that greatly exceeds the sediment volume of the subaerial delta (Coleman, 1969).

Late Travis Peak Deposition

Upon transgression of the Travis Peak, fluvial gradients and very likely sediment load decreased, thus producing a change in fluvial style from braided towards meandering streams (Miall, 1985a, models 9 to 6). Near the top of the Travis Peak, five channelbelts and the lateral extremities of four others were correlated in a 100 ft thick interval (figs. 36, 37 and 39). These channels are arranged in multistory fashion as are the lower channelbelts, but the upper channelbelt sandstones are thinner (8 to 29 ft thick), and vertically separated by thicker accumulations of floodplain and overbank (vertical accretion) deposits. Overbank deposition was a more commonly occurring process in this upper interval, and an increased content of trough-cross beds, mudstone, organic debris, and indications of point-bar deposition implies that these channels carried a mixed-sediment load and had a braided to meandering morphology (Miall, 1985a, model 6). Appropriate modern analogies might be the Amite River, Louisiana and the Colorado River, Texas (McGowen and Garner, 1970). McGowen and Garner (1970) state that without vegetation-stabilized banks, both of these rivers would assume a braided-channel morphology.

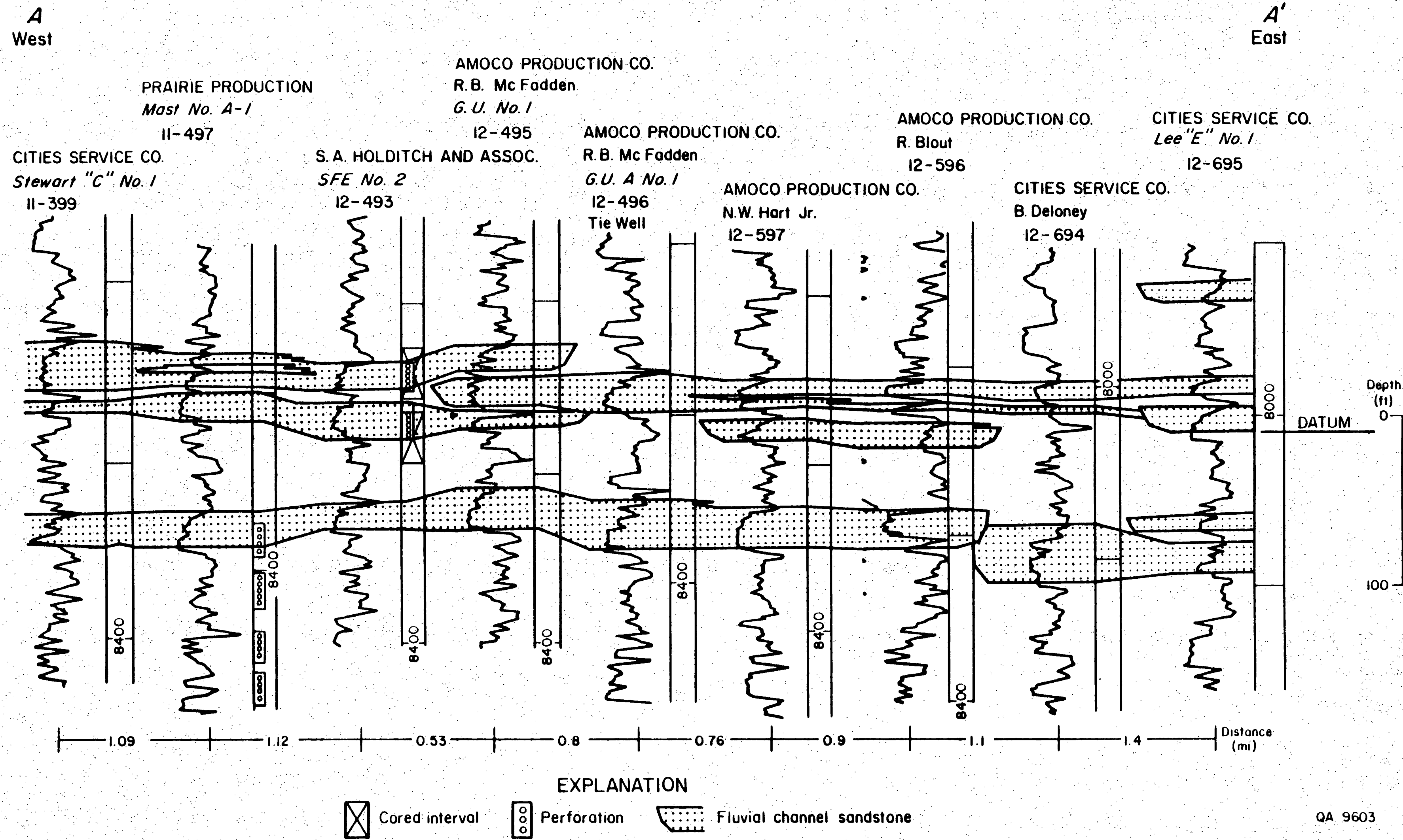

Figure 39: Stratigraphic cross section A-A' illustrates the occurrence and geometry of channel-belt sandstones in Zone 1. Multi-lateral fluvial channel sandstones occur in broad, flat-lying lenses. They reach maximum thicknesses of 25 to 40 feet, and their widths range from 1 to 6 miles. Sandstones are separated from each other vertically by floodplain deposits, and mudstones interfingering with the channel deposits result in some internal lithologic heterogeneity. Discrete sandstone lenses may be in horizontal contact due to lateral channel migration. Gamma-ray log curves are shown.

During Times 4 and 5 (fig. 35), Travis Peak paleogeography very likely evolved in a fashion similar to, and thus resembled, the post-Pleistocene evolution of the present southeast U. S. coast. Small river systems and associated swamps traversed a coastal plain (10's to 100's of mi wide) that was similar to the coastal plain of Georgia and South Carolina (Hoyt and others, 1964; Colquhoun and Pierce, 1971; Colquhoun and others, 1972; Staub and Cohen, 1979). The coastal-plain rivers drained into large estuaries that formed as their valleys were drowned by the rising sea level (Russell, 1967). A shallow shelf extended several 10's of kilometers seaward of the estuaries and attenuated wave energy along the Travis Peak shoreline.

Estuaries present along the Travis Peak shoreline contained channel, tidal-flat, and shoal (estuarine-sandbar and tidal-delta) environments. They existed throughout Travis Peak evolution, but reached their zenith in Times 4 and 5 (fig. 35). Small estuaries and lagoons located between delta lobes were ephemeral, and they formed and filled in response to delta-lobe fluctuations. However, a large estuary that formed early in Travis Peak evolution in Caddo and DeSoto Parishes and Harrison and Panola Counties, maintained its location during Travis Peak deposition, and evolved subject to changes in fluvial and marine (sea-level) conditions (fig. 35). This north-south to northwest-southeast oriented embayment closely follows a structural depression that is noticeable on the Cotton Valley surface despite movement of the Sabine Arch. Additionally, the Travis Peak section thins in this region (figs. 8 and 12-16).

Where sediment supply was sufficient, small deltas prograded into the sea (fig. 35, Times 4 and 5), but they were destined to be transgressed by the sea. The rapidly eroding mixed-energy Santee delta and Cape Romain shoreline in South Carolina (Hayes and Kana, 1976; Ruby, 1981) is a good example of such a retrogradational depositional setting. Hall (1976) discerned the presence of a coastal-barrier or strandplain facies that formed adjacent to "high-destructive" deltas he interpreted in the upper Travis Peak in north-central Texas. Coastal-barrier sandstones reached a maximum thickness of 50 ft; an aggregate thickness of stacked barriers equalled 200 ft. Sharp-based sandstones noted on SP - resistivity logs indicate a possible transgressive origin for the barriers. Although a coastal-barrier facies would be a likely component of a transgressive fluvial-deltaic systems tract (Fisher, 1969; Ruby, 1981; Penland and others, 1981), Hall (1976) offers only one cross section to support his interpretation, and to date, no maps of sufficient detail or cores of Travis Peak deposits have been described that indicate the presence of barrier-island sandstones.

A late Travis Peak shoreline regression is noticeable in comparison of the maps from Time 4 to Time 5 (fig. 35). This regression may represent a brief pause or decrease in the rate of sea-level rise, the rejuvenation of a sediment source, or both. If such a drop did occur, a Type 2 unconformity, an unconformity formed in response to a sea-level drop that does not fall below the shelf edge (Vail and Sangree, 1988; Posamentier and others, in press), occurred between Times 4 and 5, and the lowered base level prompted the final Travis Peak fluvial-deltaic advancement. Throughout the remainder of Travis Peak deposition however, sea-level rise continued to be greater than sedimentation, and ultimately estuarine, then marine, conditions prevailed across the East Texas Basin.

CONCLUSIONS

1. The Lower Cretaceous Travis Peak Formation in the East Texas Basin is a 1,400 to 3,200 ft-thick sequence of fine- to medium-grained sandstone, siltstone, and mudstone. This sedimentary wedge deposited during an Early Cretaceous rise in sea level records the second phase of terrigenous-clastic progradation following formation of the East Texas Basin during the Triassic and Late Jurassic deposition of the Cotton Valley Group.

2. Stratigraphic cross sections, isopach, net-sandstone, and percent-sandstone maps depict the northwest-southeast trend of the Travis Peak Formation in the East Texas Basin and development of a large depocenter in the vicinity of the Sabine Arch.

3. Five lithostratigraphic units, each representing a time-stratigraphic unit, were defined in the Travis Peak. Analyses of thickness, net-sandstone, and percent-sandstone values for each lithostratigraphic unit were combined with well-log and core data to determine that the Travis Peak consists of braided- to meandering-fluvial, deltaic, paralic, and shelf facies.

4. During early Travis Peak deposition, large north-south to northwest-southeast oriented braided streams emptied into the basin and constructed a series of braid deltas that developed and were abandoned within a southwest-northeast trending belt from southern Cherokee County through Nacogdoches, Shelby, and Panola Counties and into DeSoto Parish. Seaward of the deltas, isolated shelf sand-ridge deposits accumulated in north-central Sabine Parish.

5. Maximum basinward advancement of the fluvial-deltaic system occurred during middle Travis Peak deposition. Deltas extended south of Nacogdoches and Shelby Counties and into eastern DeSoto Parish. Because the East Texas Basin shelf was stable to slowly subsiding during Travis Peak deposition, previously deposited sediments were eroded and reworked by subsequent periods of fluvial-deltaic progradation.

6. Final phases of Travis Peak evolution are characterized by a change from braided to braided-meandering fluvial deposition, shoreline transgression, and development of

expansive coastal-plain and estuarine environments. Upper Travis Peak sandstones were deposited in coastal-plain, fluvial-deltaic, estuarine-tidal flat, tidal-channel, and estuarine-shoal environments.

7. Ultimate transgression of the Travis Peak resulted in onlap of the overlying marine Sligo Formation.

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