Regional Stratigraphic Cross Sections, Comanche Cretaceous (Fredericksburg–Washita Division), Edwards and Stockton Plateaus, West Texas:

Interpretation of Sedimentary Facies, Depositional Cycles, and Tectonics

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ABSTRACT

Six interlocking regional stratigraphic cross sections of Lower Cretaceous strata (middle Albian–lower Cenomanian) of the Edwards and Stockton Plateaus of West Texas illustrate the vertical and lateral extent of lithostratigraphic units and distribution of facies and facies tracts. Facies maps, prepared along selected horizons and thought to represent a brief period of time, and maps illustrating features along critical stratigraphic boundaries are interpreted to illustrate paleoenvironmental distributions through time, as well as stratigraphic relationships. The interval from the top of the Trinity division (top of the Glen Rose Formation) to the top of the Comanchean Series is considered to be a natural, physically defined stratigraphic division—the Fredericksburg–Washita—containing three subdivisions that define the regional stratigraphic framework. Three and one-half depositional cycles are identified within the lower-middle subdivisions and interpreted in terms of sedimentation, tectonics, and eustasy. The base of the division may be interpreted as a tectonically enhanced type-2 sequence boundary, whereas three other possible boundaries (one in the lower and two in the middle subdivision) would be considered transitional sequence boundaries if they are related to eustatic cycles.

KEYWORDS: depositional cycles, Lower Cretaceous, sedimentary facies, stratigraphy

INTRODUCTION

The purpose of this report is to (1) present previously unpublished data on the Fredericksburg–Washita Formations of the Comanche Series of the Cretaceous System from the Edwards and Stockton Plateaus and Marathon rim region of West Texas, (2) integrate these data with published and unpublished (thesis) data from the study area and adjacent regions, and (3) provide a regional stratigraphic framework and synthesis of the depositional history of this division of the Lower Cretaceous in West Texas.

Figures 1 and 2 illustrate structural and tectonic features and elements of the Comanchean geologic setting of the region. Geographic features, locations of measured sections, cores, and six interlocking stratigraphic cross sections (pls. 1 through 6) are shown in figure 3. Additional information concerning the measured sections and cores is provided in appendix A. Correlations with the Lower Cretaceous in North Texas and regions of South and West Texas, all stratigraphic nomenclature used, and areas of applicability of lithostratigraphic names and general stratigraphic relationships of the units are shown in figures 4 through 6. Maps in figures 7 through 18 (A through L) illustrate (1) division and subdivision boundary relationships (figs. 7, 11, 18), (2) distribution of major facies through time and inferred environmental interpretations (figs. 8 through 10 and 12 through 16), and (3) distribution and character of the Black Bed mapping horizon and equivalent units (fig. 17).

GEOLOGIC SETTING

Regional Tectonic and Structural Features

Tectonic activity and resulting structural features produced across the area of southwest Texas during and after Cretaceous deposition are illustrated in figure 1. In early Mesozoic time the entire region was tilted to the southeast, and the low-relief, gently sloping Wichita Paleoplain (Hill, 1901) was developed on truncated older rocks. Marine transgression from the opening Gulf of Mexico basin was initiated in the Jurassic (Salvador, 1987). By the late Albian or Cenomanian, inundation was complete over the total area of Texas, and a masking veneer of sediments had been deposited across preexisting topographic and structural elements (Adkins, 1933, p. 277).

The regional structure as contoured on the top of the Cretaceous Trinity division (fig. 1) comprises four principal elements: the Central Texas–San Marcos Platform (Adkins, 1933, p. 266), which was a positive tectonic element through the Early Cretaceous; (2) the Balcones Fault Zone, which did not experience major movement until the mid-Cenozoic (Weeks, 1945); (3) the Rio Grande Structural Embayment; and (4) the Burro and Marathon Uplifts, related to Laramide deformation (Böse and Cavins, 1927; King 1937).

Regional Sedimentary-Tectonic Features

The relationship between Cretaceous tectonic elements and a synthesis of Comanchean facies distributions across Texas is illustrated in figure 2 (Wilson, 1975; Winkler and Buffler, 1988; and Scott, 1933, provided comprehensive reviews of the cratonic setting and interregional character of the Cretaceous carbonate platforms of the Gulf Coast. During Trinity deposition (fig. 4), progradation of a shallow-water, high-energy carbonate ramp led to development of a platform margin (fig. 2) across Texas and northern Mexico (Stuart City Formation of Winter, 1961a, b, 1962; Smith, 1970a; Smith and Bloxsom, 1974). This platform margin persisted through the Comanchean along most of the Gulf Coast, separating the ancestral Gulf of Mexico basin from the shallower water depositional environments of the platform interior. However, in northeastern Mexico and South Texas the platform margin was terminated

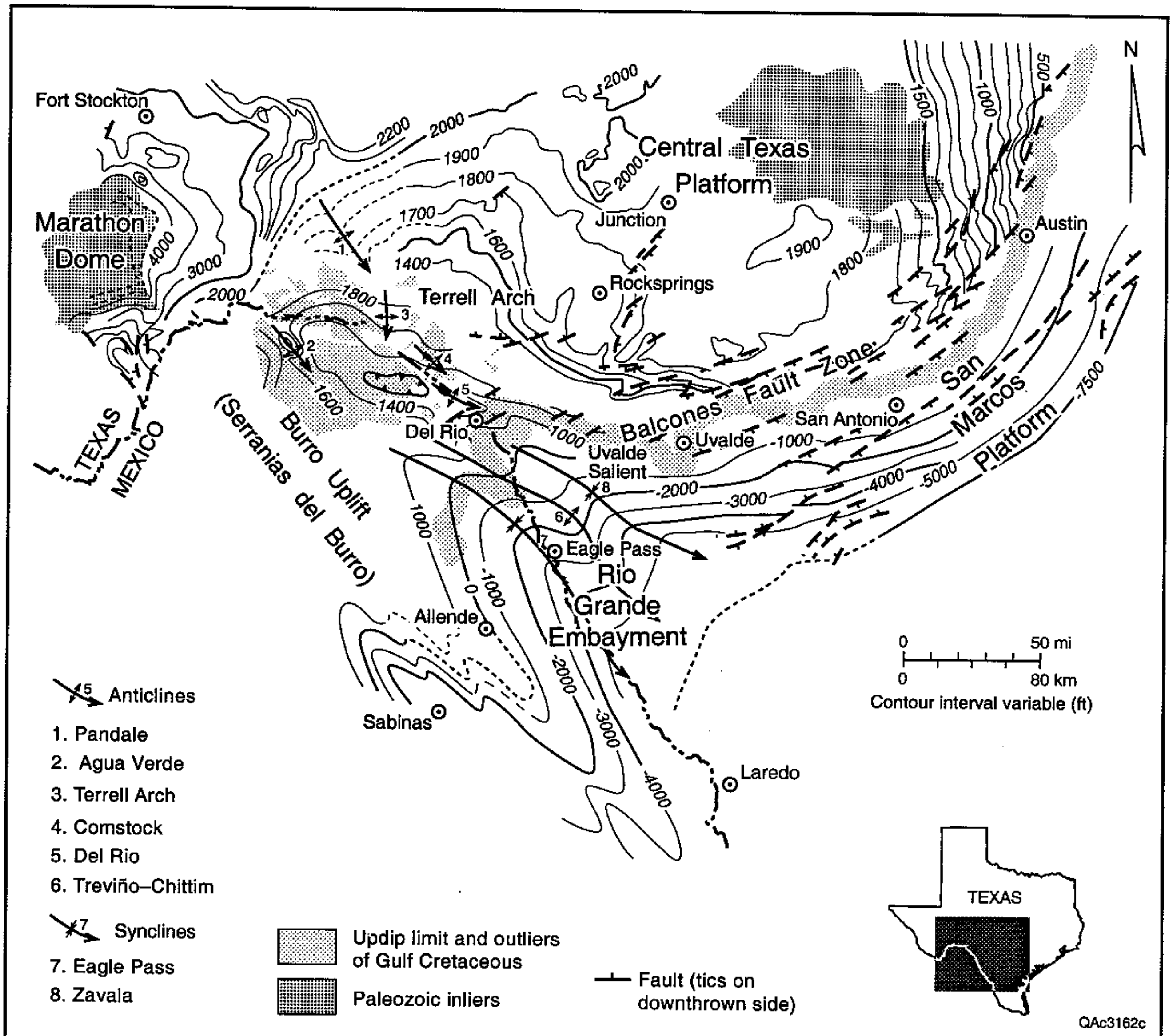

Figure 1. Post-Paleozoic tectonic and structural features; northern area contoured on top of Trinity division of the Comanchean, intervals 100, 200, and 500 ft; southern area contoured on top of Buda Limestone (Gulf–Comanche boundary), intervals 100 and 1,000 ft. Credits in appendix B.

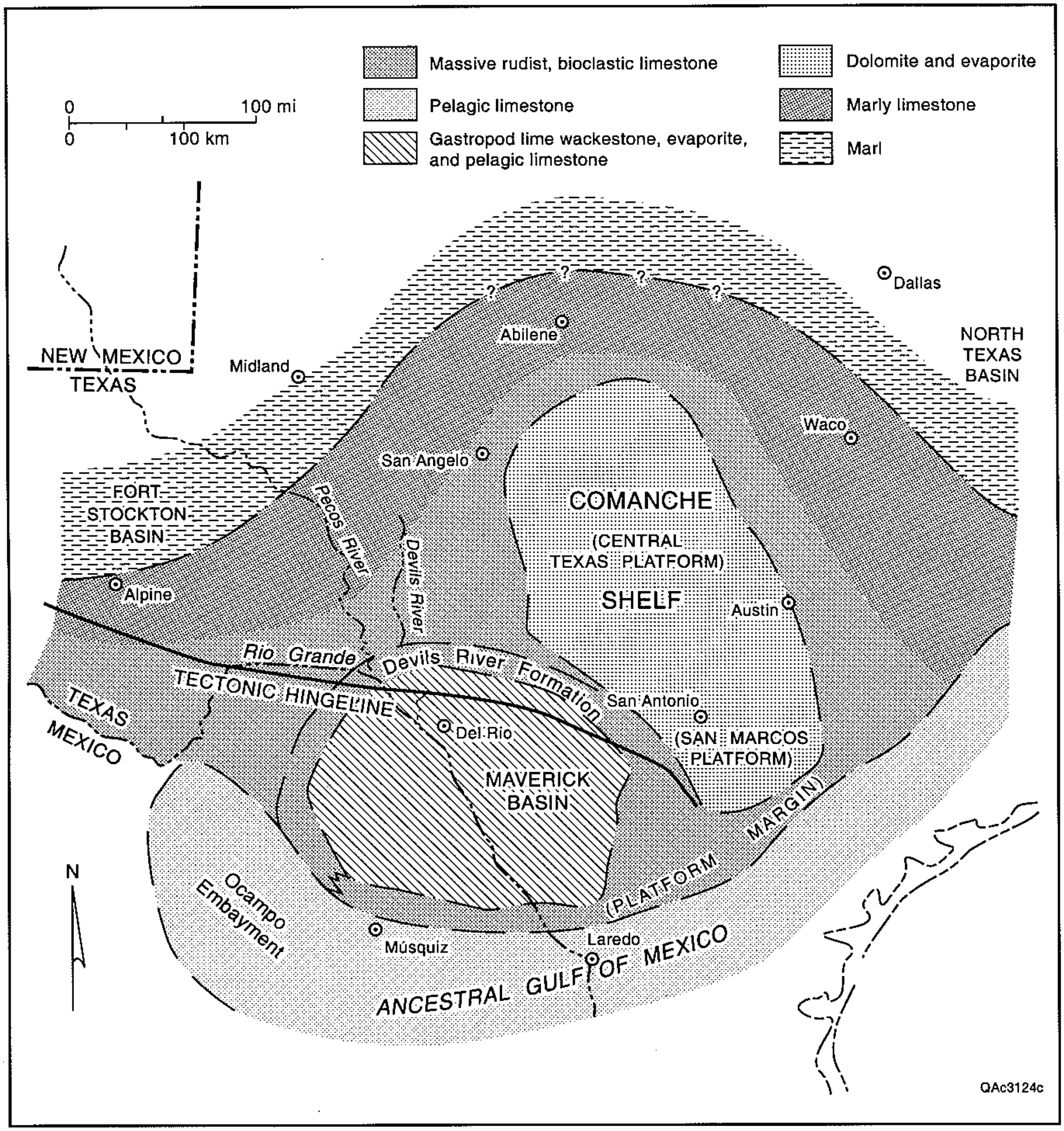

Figure 2. Regional sedimentary-tectonic elements, Fredericksburg–Washita division, South and West Texas. References cited in text.

as a barrier by the early Washita, allowing deeper, more open marine waters to penetrate the Maverick Basin (Smith, 1970a, 1981; Winkler and Buffler, 1988). South of the Big Bend region (in Mexico) data are unavailable for determining characteristics of the transition from platform to basinal environments, which prevailed to the south and southeast in the Ocampo Embayment of Mexico (fig. 2; Smith, 1970b, 1981).

South of a tectonic hingeline extending roughly east-west across the area (fig. 2), rates of subsidence

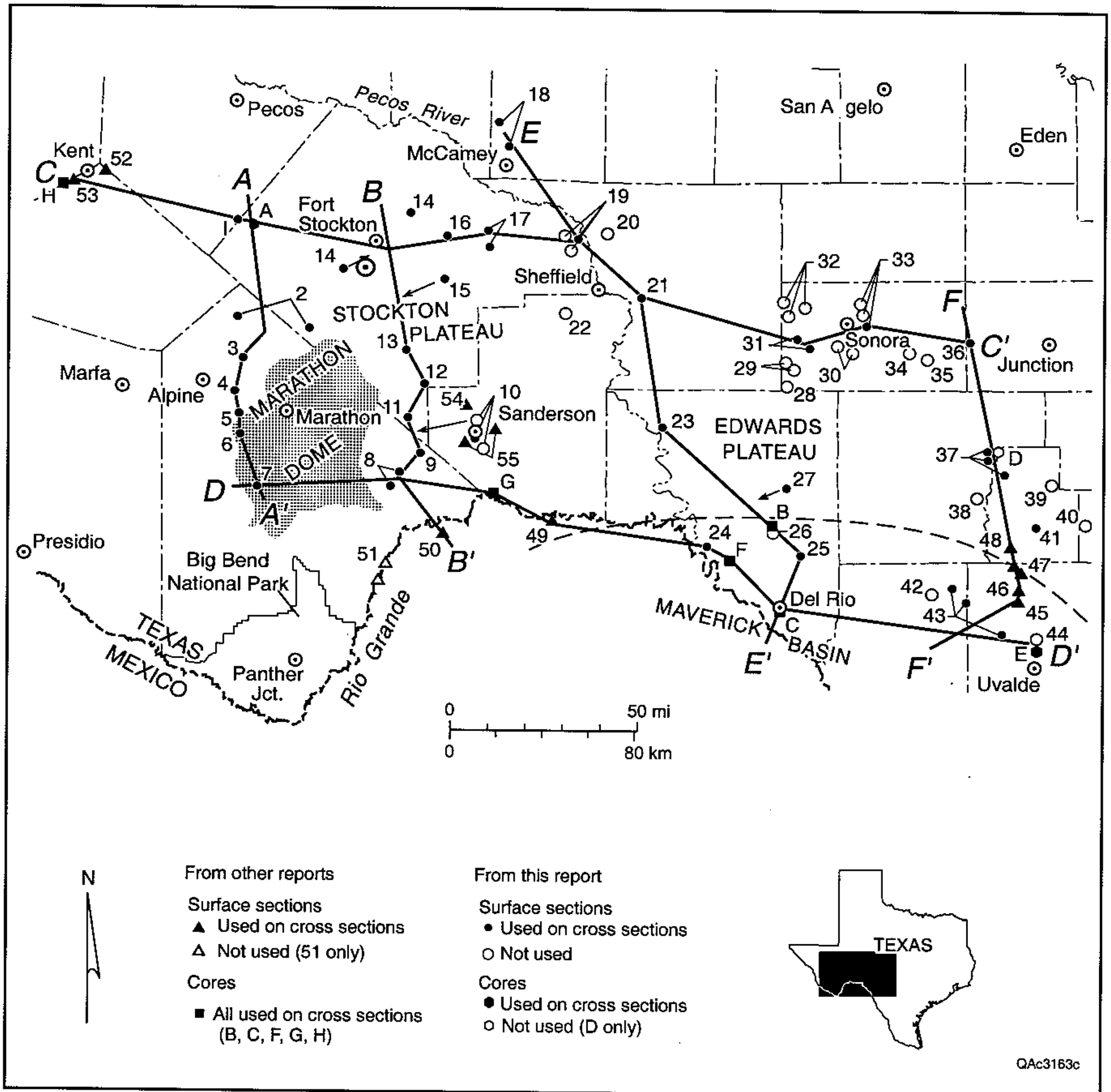

Figure 3. Index map showing geographic features, locations of measured sections, cores, and stratigraphic cross sections shown on plates 1 through 6. The Edwards Plateau extends across most of the area east of the Pecos River. The Stockton Plateau is its extension west of the Pecos to Fort Stockton and south to the Marathon Dome (fig. 1). See appendix A for additional information.

were faster, and the total section thickens (Smith, 1970b). Over the Central Texas–San Marcos Platform positive area, the section is thinner and is referred to as the Comanche Shelf (fig. 2; Rose, 1972). East, north, and west of the central Comanche Shelf area, intermediate rates of subsidence plus a source of fine, terrigenous clastics in those areas led to a gradual change to more open marine, muddy carbonate environments in the Fort Stockton and North (or East) Texas Basins.

STRATIGRAPHY

Stratigraphic Nomenclature and General Relationships

Following international practice, we subdivide the Cretaceous System of Texas into paleontologically defined lower and upper series at the Albian–Cenomanian boundary (fig. 4). We also divide it into two provincial, *physically defined* chronostratigraphic series—Comanchean (lower) and Gulfian (upper)—thought to be long-term cycles of deposition (Hill, 1887, 1901; Lozo, 1959a, b; Young, 1967). The Comanche–Gulf boundary is mid-Cenomanian in age (fig. 4; Scott and others, 1988).

The Comanche Series is subdivided into three subcycles—the Trinity, Fredericksburg, and Washita (fig. 4)—each comprising a basal-clastic–upper-carbonate couplet recognizable across North, East, and Central Texas and each referred to as a "division." Divisions are in concept identical to the provincial series and may also have "subdivisions" (Lozo and Stricklin, 1956; Lozo 1959a, b). These couplets, regional in distribution, apparently resulted from, or were coupled with, episodic rejuvenation of terrigenous clastic source areas with increased supply of clastics to the depositional basin, followed by carbonate deposition as clastic influx decreased; the boundaries may be unconformable or conformable (Lozo, 1959a).

The top of the Trinity and Washita divisions are clearly recognizable across the Edwards and Stockton Plateaus and in northern Mexico and thought to be synchronous with those in North Texas. The horizon separating the Fredericksburg and Washita in North Texas, however, identifiable in this area by paleontology only, does not meet the physical criteria of a division boundary (Rose, 1972). Rather, a somewhat older horizon (the contact between the Fort Terrett–Fort Lancaster or Segovia Formations; figs. 4 through 6) is identified as a subdivision boundary through this region. Accordingly, we combine rocks of Fredericksburg and Washita age into a single division and recognize lower, middle, and upper subdivisions (figs. 4 through 6). The provincial chronostratigraphic hierarchy used herein is therefore

Comanche Series
Fredericksburg–Washita division
Upper
Middle } subdivisions
Lower
Trinity division

The lower and middle subdivisions of the Fredericksburg–Washita division, principal topics of this report, generally comprise the Fort Terrett and Fort Lancaster Formations and their equivalents, respectively. The upper subdivision consists of the Del Rio and Buda Formations (figs. 4, 6).

Although we think that using the informal chronostratigraphic nomenclature just described is both valid and useful, it has been used only for the Texas Cretaceous and is not familiar to most stratigraphers outside this region. Rather, stratigraphic analysis by depositional sequences based on eustatic cycles (Mitchum and others, 1977), also representing natural, physically defined, chronostratigraphic units, has become standard practice. Most data in this report were collected well before the advent of sequence stratigraphy as part of a regional stratigraphic study, and many measured sections are not detailed sufficiently to attempt 4th- and 5th-order (parasequence) analysis (Osleger and Read, 1993), although thin, upward-shoaling intervals were noted in several sections. The data are, however, excellent for 2d- and 3rd-order-sequence recognition, if the stratigraphic consequences of long-term eustatic, as opposed to tectonic and sedimentologic, processes can be distinguished in this cratonic interior setting. We will

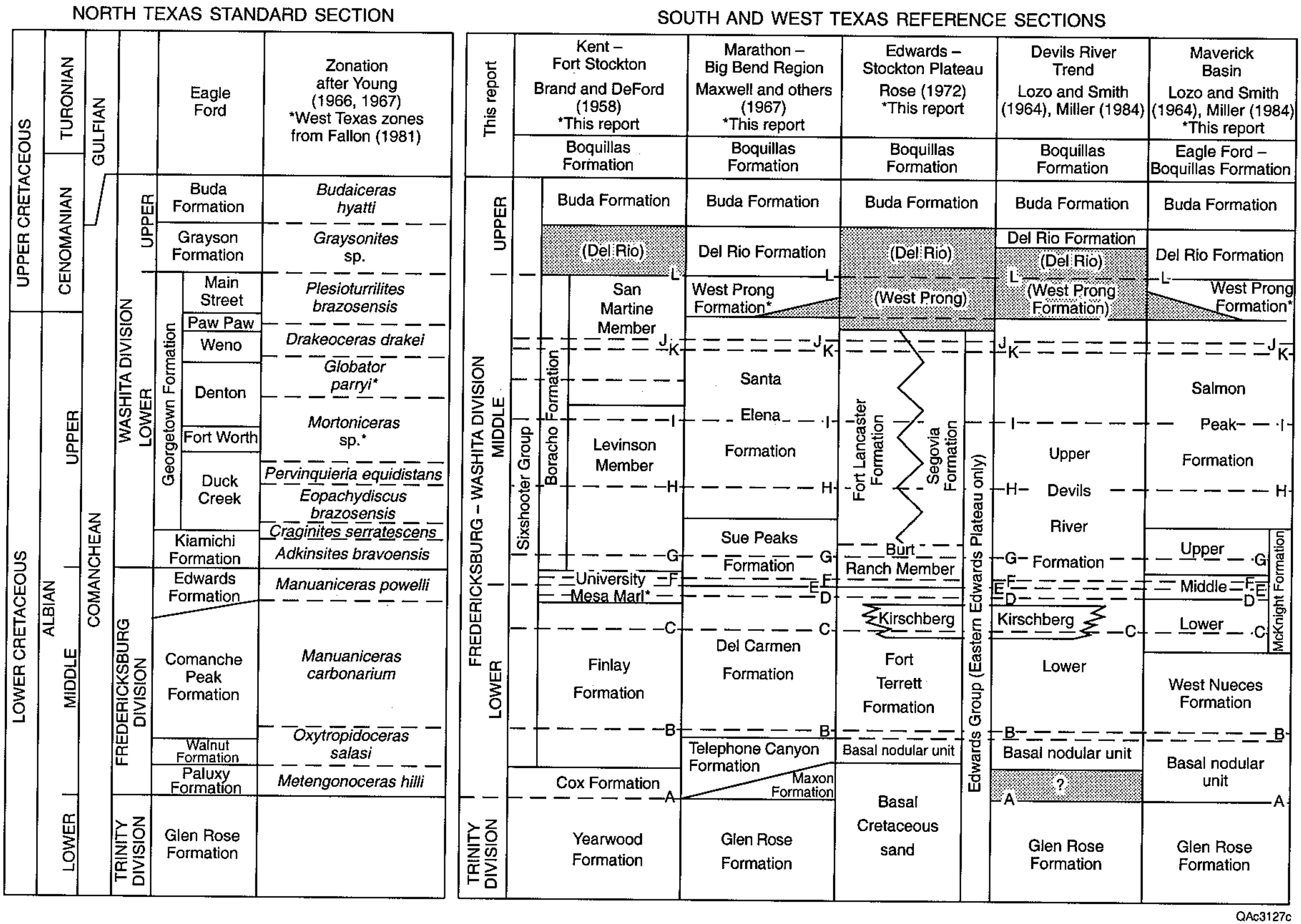

Figure 4. Comanche Cretaceous stratigraphic correlations between North Texas and regions of South and West Texas. Letters A through L refer to stratigraphic positions of horizon maps in figures 7 through 18. Shaded areas represent lacunae. Paleontologic zonation is from Young (1966, 1967) and Fallon (1981) and is based on ammonite and echinoid occurrences.

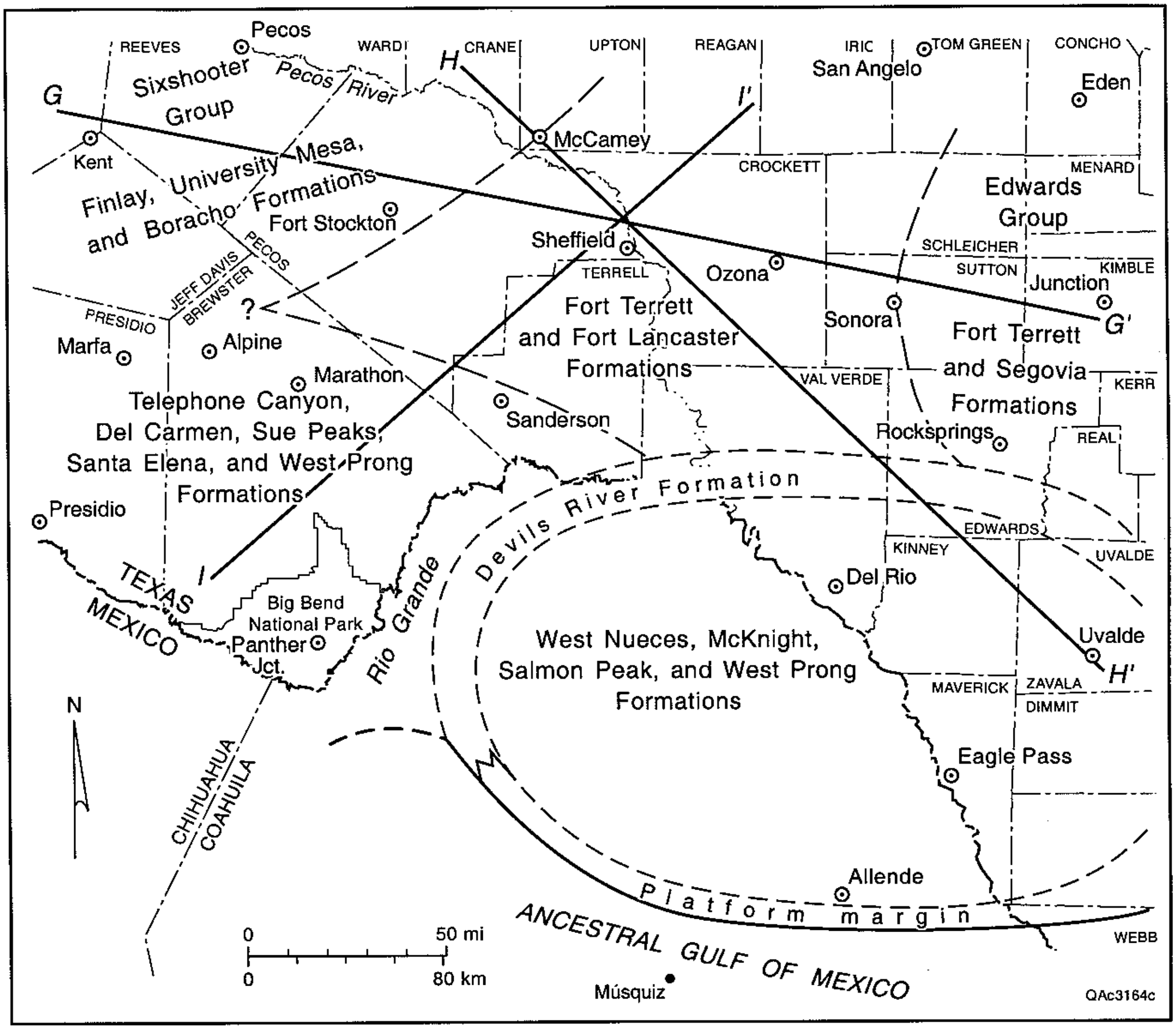

Figure 5. Areas of applicability of lithostratigraphic names for units within the Fredericksburg–Washita division. Distribution of Maxon Sandstone (lowermost unit) shown in figure 7. Modified after Smith and Brown (1983). Additional references cited in text. Cross sections G–G′, H–H′, and I–I′ shown in figure 6.

attempt to make this distinction in the interpretive sections of the text.

Scott and others (1988), using the graphic correlation method of Shaw (1964), paleontologically dated the boundaries of the Fredericksburg and Washita divisions of the western Gulf Coast in composite standard units. They then cross-plotted the composite standard scale to the absolute time scale of Palmer (1983) to obtain age dates for the three boundaries at about 108 Ma (early middle Albian), 104.3 Ma (early late Albian), and 94.6 Ma (mid-Cenomanian). Interpolated to the Haq and others (1987) time scale, these dates plot at about 104, 101, and 94 Ma, respectively, dates that we will use to relate potential sequence boundaries to their chart of sequences. The approximate time span for the Fredericksburg would therefore be 3 to 3.7 Ma and 7 to 9.7 Ma for the Washita, depending on the time scale used. The Fredericksburg division thus most closely corresponds in age range to one or two 3rd-

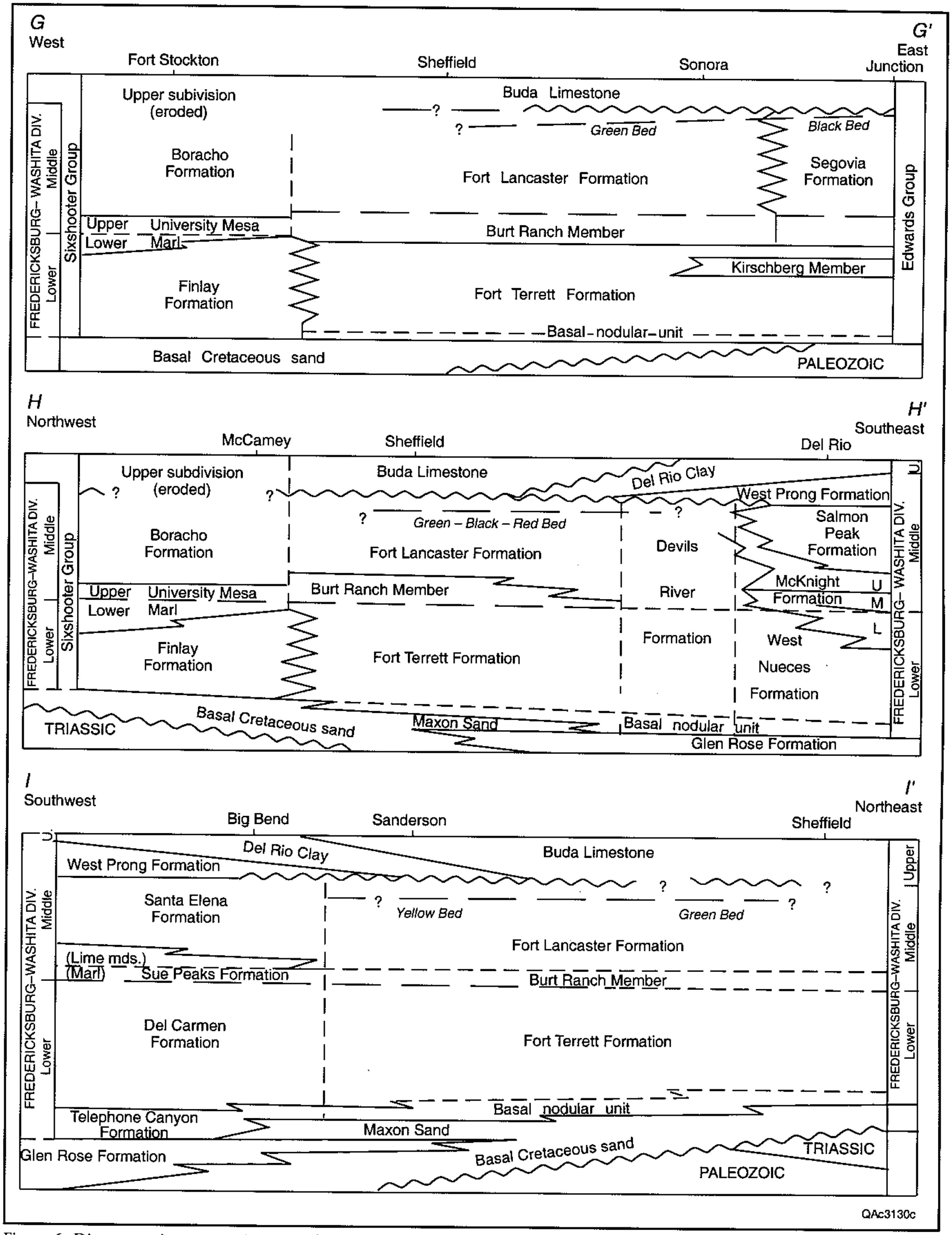

Figure 6. Diagrammatic cross sections G–G′, H–H′, and I–I′, illustrating applicability of lithostratigraphic names and stratigraphic relationships of units within the Fredericksburg–Washita division. Lines of sections shown in figure 5.

order sequences and the Washita to a composite 3rd-order sequence.

Goldhammer and Lehmann (1991) and Goldhammer and Wilson (1991) designated a lower Aptian to upper Albian interval as a supersequence comprising numerous 3rd-order sequences. They placed the upper boundary at the top of the McKnight Formation of the Maverick Basin, which they correlated with the Fredericksburg and Washita division boundary and which they compared with the 98-Ma 3rd-order sequence boundary of Haq and others (1987). Miller (1984) demonstrated that the top of the McKnight was not an unconformity and that it was younger than the Fredericksburg and Washita boundary. We do not consider the top of the McKnight to be a sequence boundary and suggest that the top of the proposed supersequence would more appropriately be placed at the mid-Cenomanian, 94-Ma position.

Lithostratigraphic units (fig. 4) are clearly defined at type localities and are easily identified in surrounding areas, but, in general, their lateral boundaries were not established when they were named. On the regional stratigraphic framework presented here, arbitrary cutoff boundaries have been established to define areas of applicability of different names given to correlative units of either different or similar facies (figs. 5, 6).

In this report, "facies" and "facies tract" are used following the Teichert (1958) interpretation of the original intent of Gressly and of Walther, who introduced and refined usage of the terms in the 19th century. The term "facies" (appearance) refers to a description of those primary features of a rock (physical, chemical, or paleontological) that determine its overall aspect or appearance (an abstraction) and *from which the environment of deposition may be inferred.* "Facies tract" refers to a system of different, contemporaneous, but genetically interconnected, facies and includes areas of erosion (Teichert, 1958). To refer to a vertical, conformable set of different facies Teichert suggested "sequence," but to avoid confusion with stratigraphic "sequence" we will use "succession" as suggested by reviewers of this manuscript. Stratigraphic onlap and overstep, and stratigraphic facies overlap and offlap are used as defined by Krumbein and Sloss (1963).

Discussion of Stratigraphic Cross Sections and Stratigraphic Analysis

Section-to-section correlations on the cross sections (pls. 1 through 6), based mostly on physical stratigraphic criteria, are subject to question in several areas—particularly through the Devils River–Maverick Basin facies changes. Ammonites are, however, found just below and above the lower-middle subdivision boundary across parts of the area, and they provide biostratigraphic horizons to support physical stratigraphic correlations and interpretations through this critical interval (fig. 4; pls. 1 through 6). Each of the facies–paleoenvironmental maps (figs. 8 through 10 and 12 through 16) is inferred to represent a relatively brief period of time centered on horizons shown in figure 4 and on plates 1 through 6.

Lower Subdivision

Description

Lower Boundary

In the Big Bend–Marathon region and northern Coahuila, Mexico (fig. 3; pls. 1, 2), the Fredericksburg–Washita division begins with the abrupt but conformable basal contact of the Maxon Sandstone (King, 1930; Butterworth, 1970; Thompson, 1977) or Telephone Canyon Formation marly limestone (St. John, 1965; Maxwell and others, 1967; Smith 1970a) with the Glen Rose Formation of the Trinity division as shown on map A (fig. 7). Over the southeastern and eastern Edwards Plateau (fig. 3), the boundary is placed at a disconformity or correlative conformity at the top of the Glen Rose Formation below the basal nodular unit of overlying formations (pl. 6, fig. 7; Lozo and Smith, 1964). Some dissolution of upper Glen Rose dolomite occurred over those parts of the area subaerially exposed (fig. 3, sec. 38). Farther to the south (Kinney and Uvalde Counties), the top of the Glen Rose was not subaerially exposed, and the lower division boundary is sharp but conformable (pl. 6; fig. 7).

Basal Formations and Facies Tract

The basal Cretaceous formations and informal lithostratigraphic units of the lower subdivision (fig. 6; pls. 1 through 6) are partly laterally gradational with one another. The basal Cretaceous sandstone (Antlers and Trinity sands of Eifler, 1976; McKalips and others, 1981, 1982) overlies Triassic or Paleozoic rocks (Armstrong and McMillion, 1961 [from Small and Ozuna, 1993]) and ranges in thickness from 35 to 350 ft in Pecos and Crockett Counties (Iglehart, 1967). Major facies are planar and trough-crossbedded sandstone and ripple-laminated sand to siltstone; sandstone bodies are multistory and multilateral (Romanak, 1988). The Maxon Sandstone (pls. 1, 2; fig. 7) is the southward extension of the

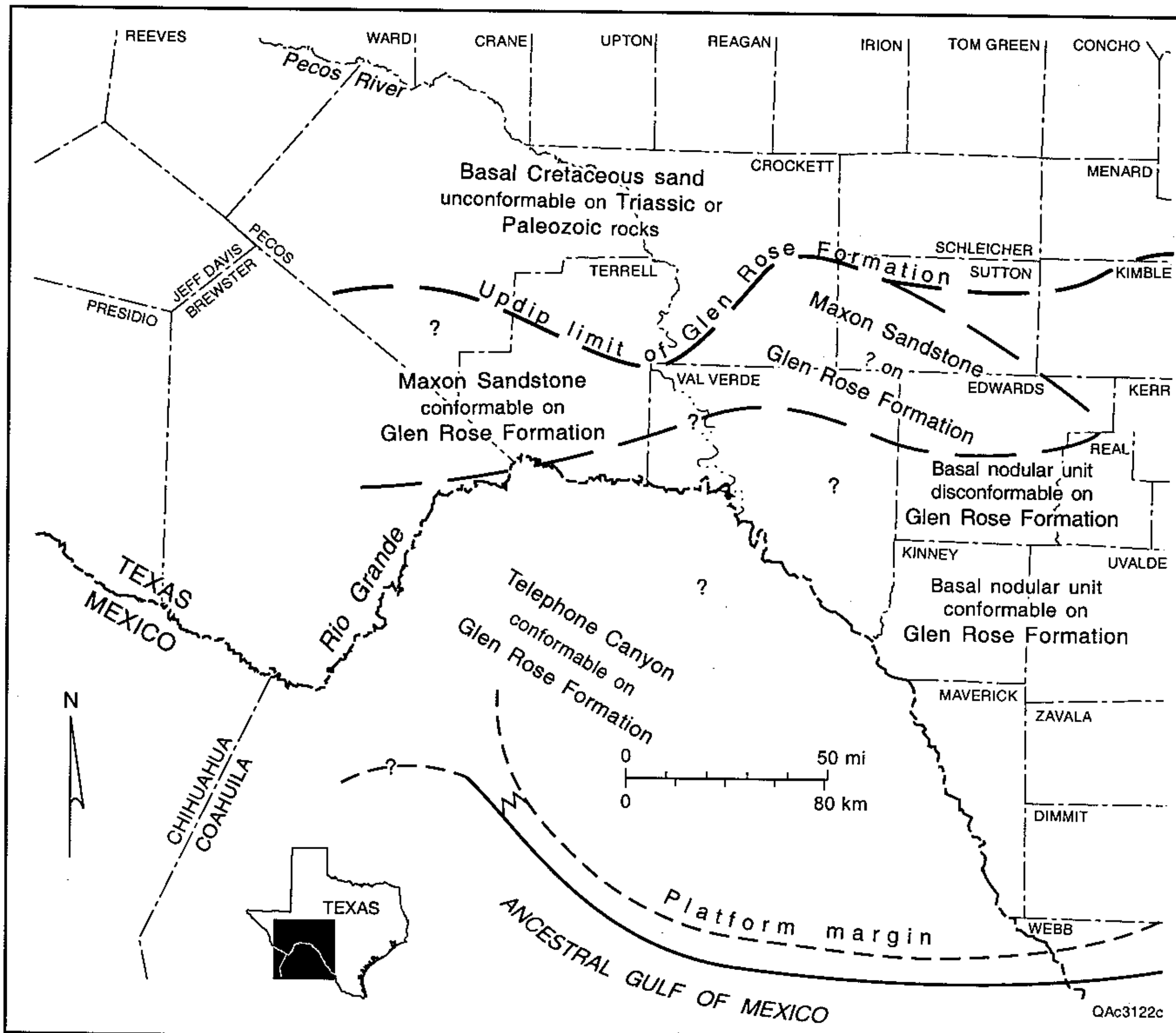

Figure 7. Map A, Fredericksburg–Trinity boundary relationships. Stratigraphic horizon of map shown on cross sections.

basal sand (Butterworth, 1970; Thompson, 1977). It overlies the Glen Rose, ranging between 80 and 200 ft in thickness across the Marathon Basin. In the north and central parts of the basin, the Maxon is an upward-coarsening succession of thin-bedded siltstones having laminations and climbing ripples to trough-crossbedded sandstone. Farther to the south (just north of Big Bend National Park, fig. 3) these facies change to thin siltstone and fine-graded sandstone containing basal flute casts and other sole markings (Thompson, 1977). The upper contact of the Maxon (or basal Cretaceous sandstone) with the Telephone Canyon (or basal nodular unit) is scoured, iron stained, and irregular in places but transitional elsewhere (pls. 1 through 3).

The Telephone Canyon conformably overlies the Glen Rose in the Big Bend National Park and across northern Mexico (fig. 7; Maxwell and others, 1967; Smith, 1970a). The lower part of the formation is the downdip, marine equivalent of the Maxon (pls. 1, 2, 4; Smith, 1970a; Thompson, 1977). The formation consists mostly of marl and marly, nodular wackestone having a rich molluscan fauna, averaging about 75 ft in thickness throughout the park (Maxwell and others, 1967) and 130 ft in Mexico (pl. 1, sec. 50; fig. 7; Smith, 1970a). The uppermost part of the Telephone Canyon extends northwest over the Maxon Sandstone and basal Cretaceous sand (pls. 1, 2) and northeast over the Glen Rose (pls. 4 through 6; fig. 7) as the basal nodular unit of overlying limestone formations. Thickness of the basal nodular unit ranges from 60 ft in the south to less than 10 ft in the north. It is either very thin or absent north of cross section C–C′ (fig. 3; Iglehart, 1967).

Upper Formations and Facies Tracts

The upper part of the lower subdivision is divided laterally into five formations and two groups (figs. 4, 6), reflecting facies changes and historical development of nomenclature. Cutoff limits between areas of usage for the various names are either entirely arbitrary or based on facies changes and pinch-out of key horizons (middle McKnight, basal Burt Ranch and equivalents), as shown in figure 6. Geographic limits for use of each term are shown in figure 5; thickness variations and general descriptions are provided on plates 1 through 6 and figures 8 through 10.

Horizon B (fig. 8; see also pls. 1 through 6) lies within the lower part of the Fort Terrett Formation just above the Telephone Canyon (or basal nodular beds). It is characterized by a single primary facies of burrowed lime wackestone to packstone that has a benthic fauna and stretches across the entire central part of the region (fig. 8; pls. 1 through 6). Carbonate mud is more abundant and burrowing less common toward the southwest, and thin, crossbedded, lithoclast grainstone and laminated dolomite become dominant to the northeast. To the west the facies changes to sandy, fossiliferous marl and then to crossbedded, nonfossiliferous sandstone (pl. 3, secs. 1, 52). Rudist mounds and their associated facies formed along the north boundary of the incipient Maverick Basin (pl. 5, core B [(Bloxsom, 1976b]; pl. 6, secs. 45 through 47 [Miller, 1984]) and now grade basinward into gastropod, clam, texigryphaeid wackestone and mudstone. Large (+100-ft) caprinid mounds are found behind the platform margin in Mexico (fig. 8; Smith, 1970a).

A more complex facies pattern is found at the time represented by horizon map C (fig. 9). An extensive sheet of evaporite, the Kirschberg Member of the Fort Terrett Formation (Barnes, 1943; Rose, 1972), was deposited across the central Comanche Shelf and is found both as evaporite and extensive collapse breccia. Thin breccias are found as far west as Yates Mesa (sec. 19, pl. 5; fig. 3) interbedded with laminated to thin-bedded dolomite containing gastropod molds and calcite-lined vugs after evaporite nodules. Farther west (and southwest) the facies changes to miliolid, rudist lime wackestone to grainstone of the Del Carmen and the sandy, nodular, mollusk marl and wackestone of the Finlay Formation in western Pecos and Reeves Counties (fig. 9; pls. 1 through 3) with a line of rudist mounds and grainstone beds along the latter facies change (pl. 3, sec. 16).

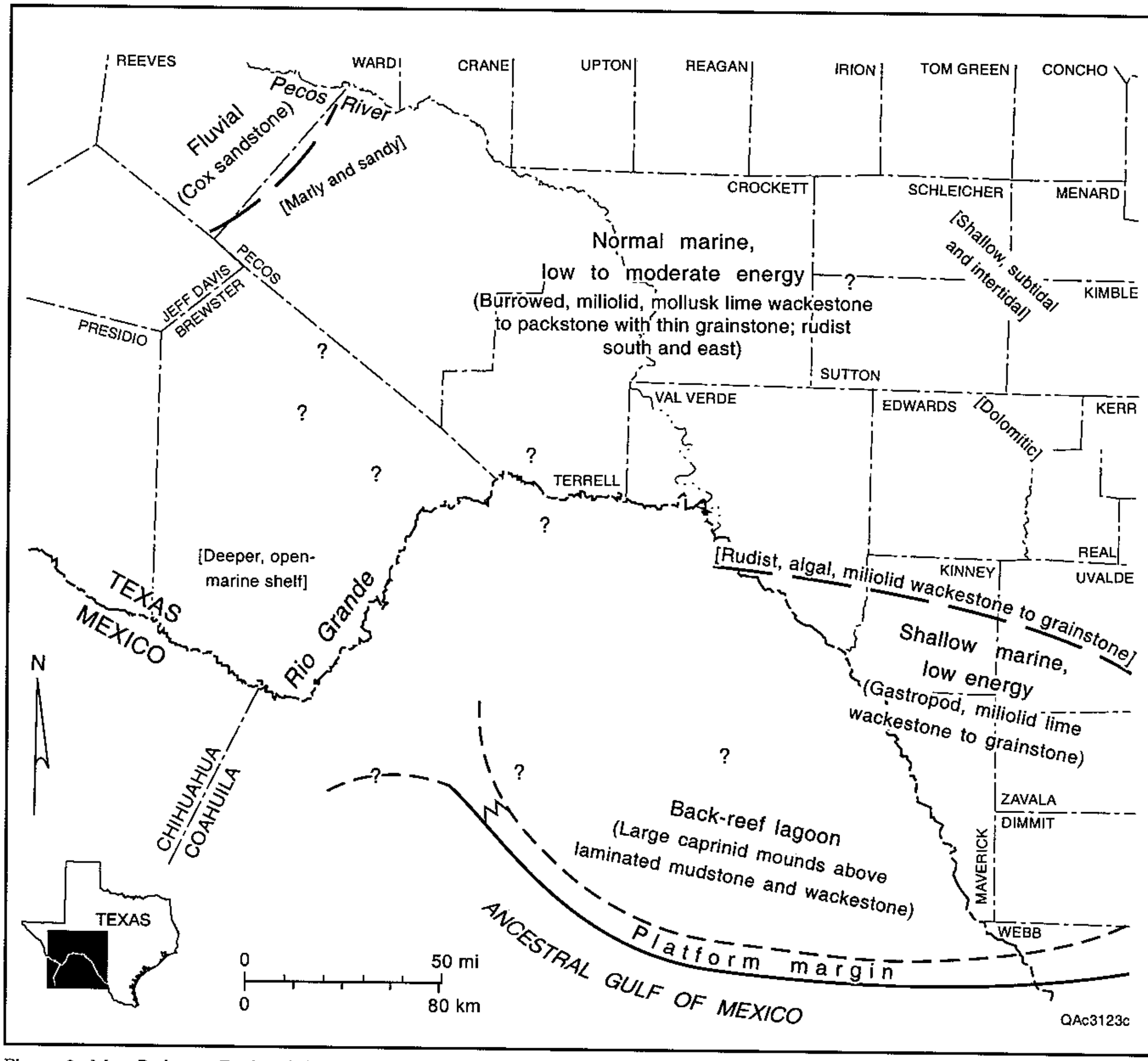

Figure 8. Map B, lower Fredericksburg–Washita subdivision facies tracts and environmental interpretation. Stratigraphic horizon of map shown on cross sections.

The Maverick Basin was bordered on the north (Val Verde County) by upward-shoaling sequences of laminated dolomite having crusts and rootlets over requieniid, miliolid wackestone of the lower Devils River Formation (pl. 5, core B; Bloxsom, 1976b). Within the basin, coeval facies of the lower McKnight Formation are nodular and mosaic anhydrite alternating with thin layers of dolomitic, intraclast, shell fragment or pellet packstone grading upward to mudstone (core C, pls. 4, 5; Carr, 1987). Lower McKnight evaporite is present throughout the east (Texas) part of the Maverick Basin (Winter, 1961a, b; 1962), but it is not found in the west (Mexico) part of the basin (fig. 9; Smith, 1970a).

The stratigraphic horizon about which map D (fig. 10) is constructed lies just below the boundary between lower and middle subdivisions. In the west (Jeff Davis–Brewster Counties) there was a period of nondeposition and disconformity development at this time (pls. 1, 3; McAnulty, 1955; Brand and DeFord, 1958; Fallon, 1981). To the east the disconformity dies out, where brown clay of the lower University Mesa Marl (Adkins, 1933; figs. 3 through 5; pls. 1 through 3, 5) was deposited. The clay onlaps the disconformity to the west and south and changes facies to the east and southeast to crossbedded, skeletal, lithoclast grainstone (pls. 1, 3; fig. 10). Farther to the east, the latter facies is replaced by dense lime mudstone and miliolid, lithoclast wackestone to grainstone. In the Maverick Basin, facies resemble those of map C, although the restricted, evaporite environments of the northeast part of Maverick Basin expanded northward 5 to 10 mi (pl. 6, secs. 43, 45, 46; Miller, 1984).

Interpretation

Lower Boundary, Formations, and Facies Tract

The Fredericksburg–Washita division cycle of sedimentation was initiated by uplift and erosion of

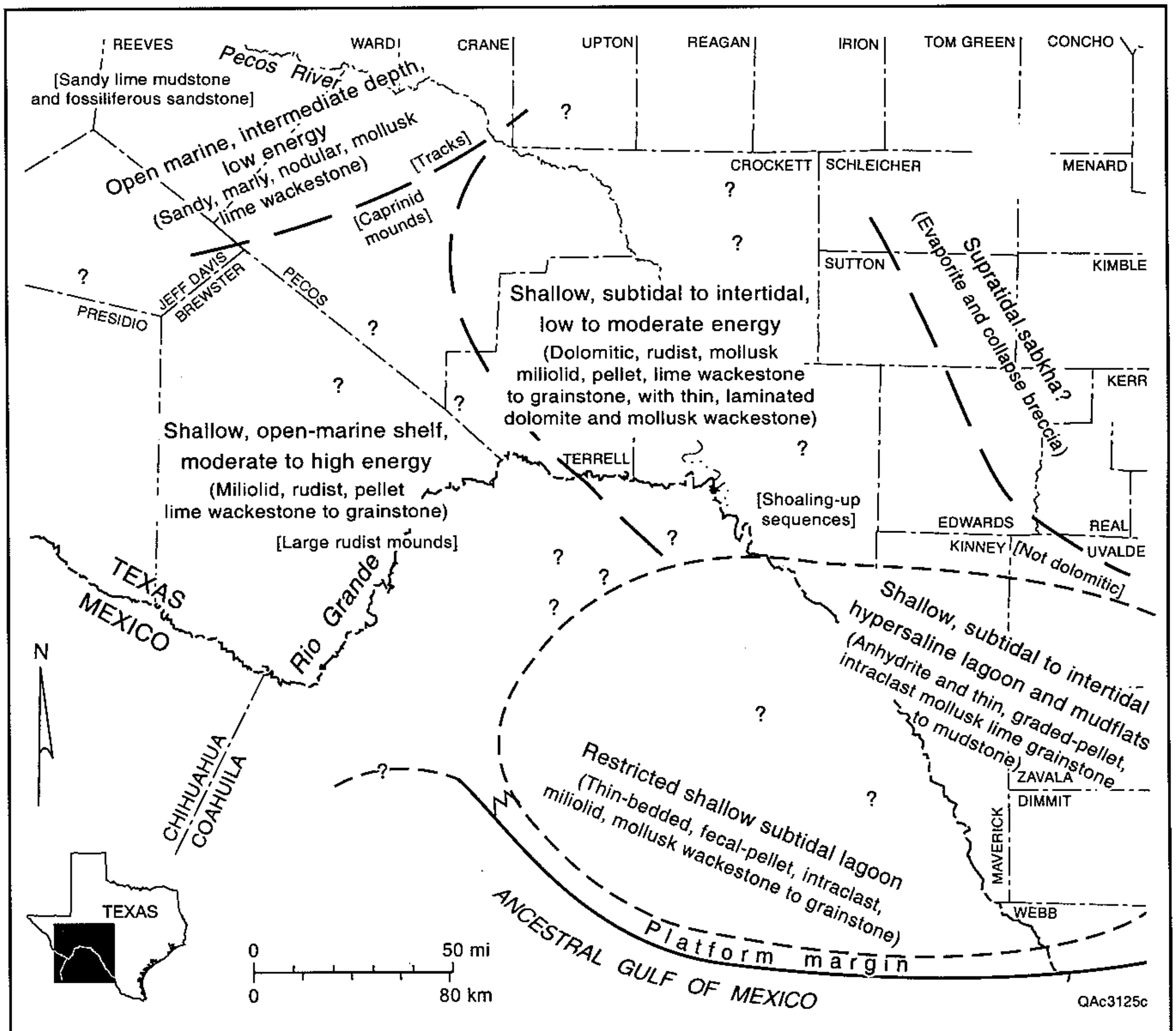

Figure 9. Map C, lower Fredericksburg–Washita subdivision facies tracts and environmental interpretation. Stratigraphic horizon of map shown on cross sections.

pre-Cretaceous rocks to the northwest and a moderate base-level fall across the Central Texas Platform (figs. 1, 2). Relative sea level may have dropped slightly in the southwest part of the area (Thompson, 1977) or, more likely, came to a standstill. Basal Cretaceous sand was deposited progradationally over an eroded surface of Paleozoic or Triassic rocks by low-sinuosity, bed-load-dominated, braided streams (Romanak, 1988), which extended southward as Maxon mixed-load meandering stream deposits over the Glen Rose and terminated just north of Big Bend National Park in a fluvial-dominated, lobate delta (Thompson, 1977). South of the delta front, prodeltaic sand, siltstone, and mudstone grade to lower Telephone Canyon marly, nodular carbonate (Thompson, 1977; fig. 7).

The Telephone Canyon Formation was deposited in somewhat deeper shelf waters below effective wave base, where fine terrigenous clastics and carbonate mud could settle and burrowing and plowing mollusks were common. As the rate of terrigenous clastic influx decreased, northward transgression of the shoreline over the Maxon deltaic complex began. The coarse, burrowed, uppermost sandstone of the Maxon Formation and the abrupt upper contact with the Telephone Canyon are the product of wave reworking of shallow-marine sand and deposition of the Telephone Canyon (or basal nodular unit) marly wackestone as water deepened.

Slight emergence and shoreline regression terminated Trinity sedimentation in the eastern Edwards Plateau over the Central Texas Platform. This broad, flat, exposed area served to divert and confine the fluvial systems responsible for the Maxon–Telephone Canyon terrigenous clastics to the southwest part of the region. Some part (probably short) of the time span represented by the lower Maxon–Telephone Canyon is represented within the lacuna recorded by the Glen Rose–basal nodular unit disconformity in this area. To the south, in Uvalde and Kinney Counties, the correlative conformity is thought to be essentially the same age as the Glen Rose–Maxon (or Telephone Canyon) contact in Brewster County (fig. 7). Renewed submergence led to rapid marine flooding and deepening across the flat Glen Rose surface and deposition of the open-marine basal nodular beds of the Fredericksburg–Washita division as a transgressive systems tract northeastward across the Glen Rose, Maxon, and basal Cretaceous sandstone (pls. 3, 5, 6; fig. 7).

The lower boundary closely resembles a type-2 sequence boundary (Van Wagoner and others, 1988) except for the presence of the Maxon progradational fluvial-deltaic complex. Presence of these clastics may be attributed to tectonic rejuvenation of source areas to the north and west, which provided sufficient sediment for shelfward progradation in the face of stable sea level seaward of the depositional-shoreline break. The Trinity–Fredericksburg boundary therefore has characteristics of both a provincial division boundary and an interbasinal depositional-sequence boundary within this area. Dated at about 104 Ma on the Haq and others (1987) time scale (as interpolated from Scott and others, 1988), it most closely corresponds to the 103-Ma type-2 boundary of Haq and others (1987; Goldhammer and Wilson, 1991). Scott and others (1988) found no evidence of a hiatus at this horizon in their comparative study between the Early Cretaceous on the Texas Gulf Coast and that in Arabia. Yurewicz and others (1993) considered the top of the Glen Rose in the northeast Gulf of Mexico to be middle Albian (Young, 1972) and referred it to the 100.5-Ma sequence boundary.

Upper Formations and Facies Tracts

After submergence and transgression of upper Telephone Canyon–basal nodular units over the Maxon–basal Cretaceous sandstone in the Marathon region or division boundary in the eastern Edwards Plateau, sources of coarse terrigenous clastics were mostly covered, relative sea-level rise stabilized at low rates, carbonate production increased, and the entire Edwards–Stockton Plateau became a vast flat, shallow, but normal, marine carbonate platform (fig. 8).

Water depths were somewhat shallower to the northeast and deepened to the southwest. Continued influx of fine terrigenous clastics inhibited carbonate production in the northwest and a shallow shelf basin, referred to herein as the Fort Stockton Basin (figs. 2, 9, 10), developed.

Subsequently sediment aggraded to or near sea level over much of the region—particularly across the Comanche Shelf, where the rate of subsidence was less (figs. 1, 2; Rose, 1972). This situation, along with an arid climate, resulted in the subtidal to intertidal and supratidal evaporite-dominated environments across that area (fig. 9). Throughout the lower subdivision, deeper waters persisted to the southwest, and now the entire section of rocks thickens south of the tectonic hingeline in the Big Bend area (figs. 2, 3, 9; pls. 1, 2).

North of the platform margin across Coahuila, Mexico, and South Texas (fig. 2), an ovate area of restricted water movement, the Maverick Basin, be-

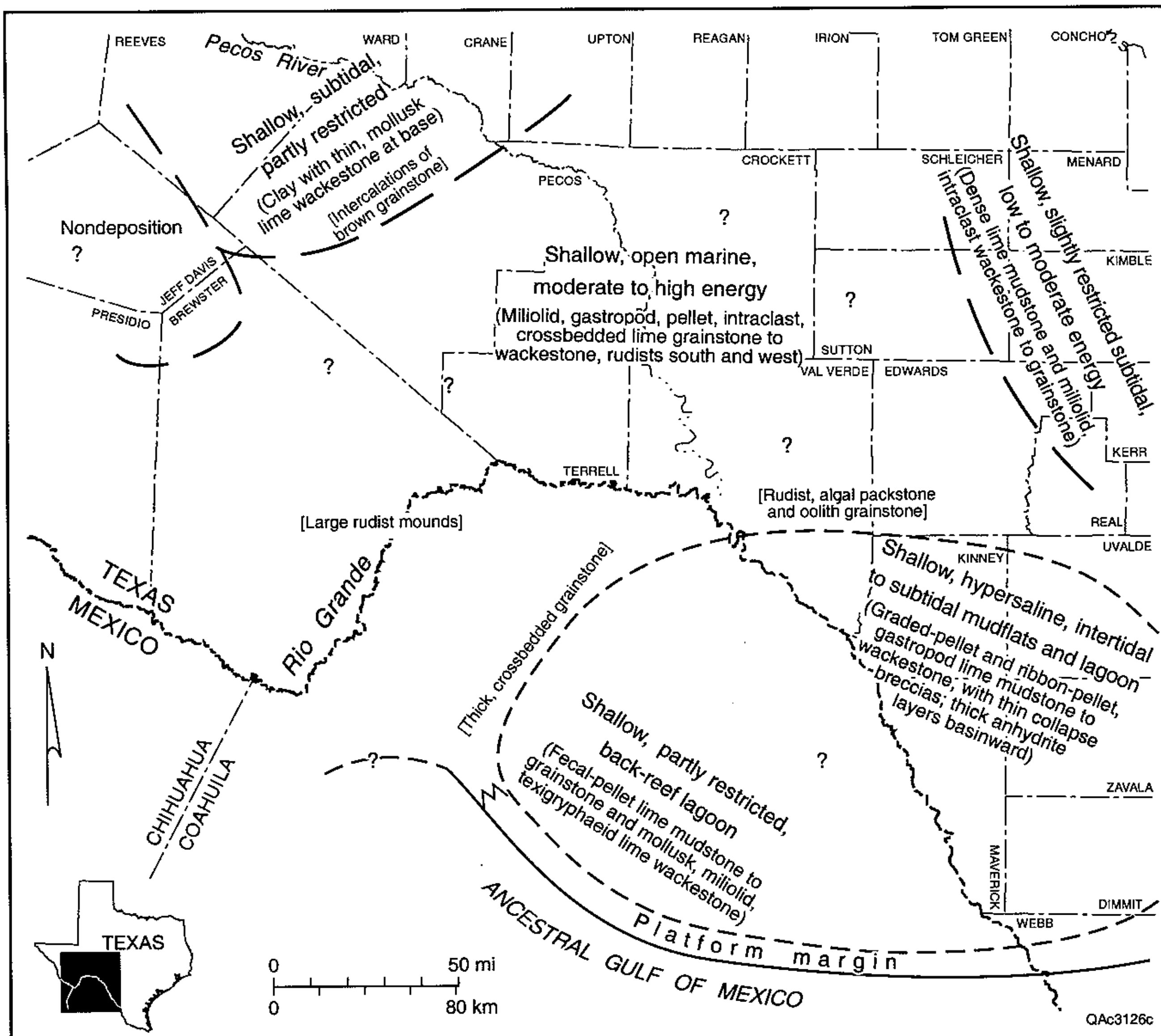

Figure 10. Map D, lower Fredericksburg–Washita subdivision facies tracts and environmental interpretation. Stratigraphic horizon of map shown on cross sections.

gan to develop during the time of map B (fig. 8). Rates of subsidence were greater and carbonate production lower to the south (in Mexico), and lagoonal conditions accompanied by isolated caprinid mounds developed behind the margin (Smith, 1970a). Eventually the basin became separated from the platform to the north and west by a band of shallow-water shoals that produced the lower Devils River Formation. These shoals extended westward and southward into Mexico to connect with the western terminus of the platform margin (figs. 9, 10; Smith 1970a). Through the remainder of the lower subdivision, waters of the basin became more restricted, leading to deposition of the lower McKnight evaporite, but high-salinity evaporite conditions were confined to the north and east along the margins of the Central Texas and San Marcos Platforms (fig. 2). Evaporitic intertidal to shallow subtidal mudflat and lagoonal environments interrupted by storm events (fig. 9; Miller, 1984; Carr, 1987) developed through this area and began to expand to the north over shallow, normal-marine, moderate to high-energy carbonates (pl. 6; fig. 10). Much if not most of the nonevaporite sediment for the expanding tidal flats was probably transported there from the north by flood tides and trapped.

The area of nondeposition that developed in the west (Jeff Davis and Brewster Counties) just before horizon D and that persisted through horizon G (figs. 11 through 13) may have been related to uplift of the east end of the Paleozoic Diablo Platform (Fallon, 1981). However, the basic data along this stratigraphic horizon (pl. 1, secs. 2 through 5) need careful reevaluation and supplementation before interpretations can be made with reasonable confidence.

To the northeast, in Pecos County, the Fort Stockton Basin began to fill with the lower brown clay of the University Mesa Marl (fig. 10)—possibly derived locally from the suggested area of unconformity to the west. Concurrently, rates of submergence increased sufficiently so that slight deepening and increase in wave and current energy occurred across most of the region to the east and southeast to produce the change from facies of map C to those of map D (figs. 9, 10). The eastern Comanche Shelf remained shallow but protected from wave and current energy, permitting deposition of the fine miliolid lime muds characteristic of the facies there. This protection was probably a function of distance from open-marine waters and dissipation of strong wave and current energy across the shelf to the west and south.

The time of maximum flooding following Telephone Canyon–basal nodular beds transgression probably coincides with, or is slightly later than, that of horizon B (fig. 4; pls. 1 through 6). Thereafter, and up to the time represented by the Kirschberg evaporite, the section constitutes an aggradational highstand systems tract (Van Wagoner and others, 1988). Subsequently, falling relative sea level led to extensive supratidal or sabkha conditions of the Kirschberg Evaporite across the Comanche Shelf (Rose, 1972) and shallow subtidal to intertidal environments westward across the central part of the region. Shallow-marine, high-energy, intraclastic grainstone overlying Kirschberg or equivalent strata followed by deeper, open-marine deposits of the Burt Ranch Member of the Fort Lancaster Formation indicate subsequent rising relative sea level. Elsewhere we have found no evidence of a relative sea-level fall through this stratigraphic interval, and Rose (1972) demonstrated by isopach mapping that this area (Central Texas Platform; figs. 1, 2) was persistently more positive than surrounding areas through Fredericksburg–Washita time. Apparently there was a low rate of sea-level rise, a stillstand, or a low rate of fall approximately equal to the rate of subsidence across the Central Texas Platform and less than subsidence elsewhere. In either case, aggradation to sea level could have occurred over the platform. If there had been a eustatic fall, a transitional rather than unconformable sequence boundary would have formed (Goldhammer and Dunn, 1991). It would probably be placed within the Kirschberg (maximum rate of fall position), which would fall at about 101.5 Ma or earlier on the Haq and others (1987) sequence chart, well below the 100.5-Ma type-2 boundary.

Middle Subdivision

Of the nine formation names applied in this report to units within the middle subdivision (figs. 4 through 6), three need clarification.

(1) The Fort Lancaster Formation has not been formally defined. The type locality is designated herein as the exposures in road cuts along U.S Highway 290 on Lancaster Hill, east of old Fort Lancaster, Crockett County, and the type section is shown on plates 3 and 5 (sec. 21). A small-scale, more detailed graphic section is given in Smith and others (1974). The area of application is bounded by arbitrary cutoffs illustrated in figures 5 and 6. The basal Burt Ranch Member of the equivalent Segovia Formation (Rose, 1972) is also the basal member of the Fort Lancaster.

(2) The University Mesa Marl (Adkins, 1933, p. 339, 347) is a third (medial) formation of the Sixshooter Group missing by nondeposition in the Kent area where the group was named (Brand and De Ford, 1958).

(3) Greenwood (1956) named the West Prong Lentil of the Del Rio Formation for exposures along the West Prong tributary of the West Nueces River in Uvalde County. Here we elevate the West Prong to formation rank and designate the interval between 86 and 56 ft in the Shell Development Company, George Pardi Corehole No. 1, as the key reference section. Detailed description of the core and location of the site were given by Humphreys (1984a). Stratigraphy and area of distribution of the formation are shown in figure 6, as well as in plates 1 and 4 through 6.

Description

Middle-Lower Subdivision Boundary and Relationship to Overlying Strata

West of Fort Stockton, the middle-lower subdivision boundary is placed at the contact of the lower clay and upper nodular marl of the University Mesa (figs. 6, 11; pl. 3). Across the central and southwest parts of the area, the Fort Terrett or Del Carmen Formation of the lower subdivision is overlain by nodular, marly lime wackestone of the Burt Ranch or Sue Peaks of the middle subdivision as shown on maps E and F (figs. 11, 12; pls. 1 through 6). The contact is sharp over most of the area, becoming transitional to the south and west, and is an iron-stained, generally bored, surface below most of the Burt Ranch (fig. 11). Throughout most of the area (except in the Sue Peaks), the lower part of the nodular unit contains ammonites representative of the *Manuaniceras powelli* zone. The zone (including the index species; Young, 1966; Bloxsom, 1972) is also present in the middle McKnight of both Texas and Mexico.

The boundary between the middle and lower subdivisions cannot be mapped as a discrete horizon through the Devils River Formation and into the Maverick Basin. Miller (1984) was, however, able to project a phantom horizon through these complex facies changes in Uvalde and Real Counties (pl. 6, horizon E). Projection of the subdivision boundary position through the Devils River and into the basin in Val Verde County (pls. 4, 5), based on the relationship proposed by Miller (1984), is less certain. Facies equivalent to the Burt Ranch marly lime wackestone (fig. 12; pls. 4 through 6) vary from rudist wackestone to packstone and crossbedded, oolitic grainstone on the north and west margins of the Devils River, to laminated mudstone and pellet packstone containing intraclasts, mud cracks, and bored surfaces along the north margin of the Maverick Basin in Uvalde County (pl. 6; Miller, 1984), to carbonaceous, argillaceous, laminated lime mudstone having a pelagic fauna in the middle McKnight of the Maverick Basin (pls. 4 through 6).

Upper Formations and Facies Tracts

Lateral cutoff boundaries that define areas of usage for the various names applied to rocks of the middle subdivision below the West Prong Formation and above the basal Burt Ranch (figs. 5, 6) coincide with those of the lower subdivision and are, for the most part, based on the same criteria. Exceptions are

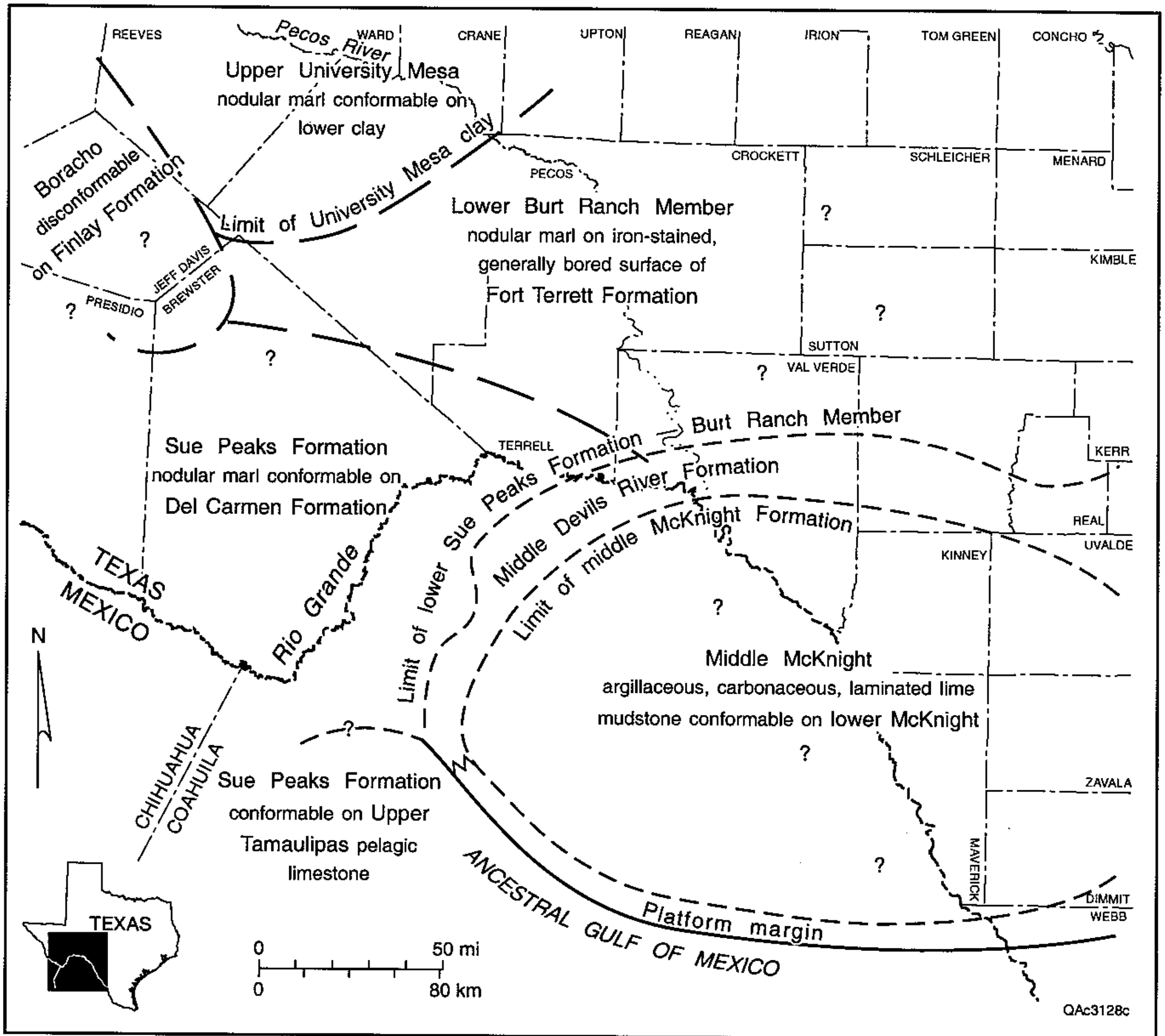

Figure 11. Map E, middle-lower subdivision boundary relationships. Stratigraphic horizon of map shown on cross sections.

that the Fort Lancaster–Boracho cutoff is entirely arbitrary and located for mapping purposes to coincide with the Finlay–Fort Terrett facies change (figs. 5, 6; pls. 1 through 3); and the Fort Lancaster–Segovia boundary is located about halfway through the change from predominant limestone of the Fort Lancaster to limestone, dolomite, and evaporite of the Segovia (figs. 5, 6; pl. 1). Formation thicknesses and generalized lithologic descriptions are given on plates 1 through 6 and supplemented by facies tract descriptions in figures 13 through 17.

The stratigraphic horizon of map G (fig. 13) is above the first occurrence of *Adkinsites bravoensis* and below *Craginites serratescens* in West Texas outcrops (fig. 4; pls. 1, 3). In the Maverick Basin, *Adkinsites* is not found, but *Craginites* occurs at the base of the Salmon Peak in section 25 (pl. 5). The projection of horizon G (basal Kiamichi age) into the middle of the upper McKnight (above *Manuanicera*s and below *Craginites*) thus seems well constrained (pls. 4 through 6).

The dominant facies of richly fossiliferous clay and clay marl to the west (lower Boracho) extends south-

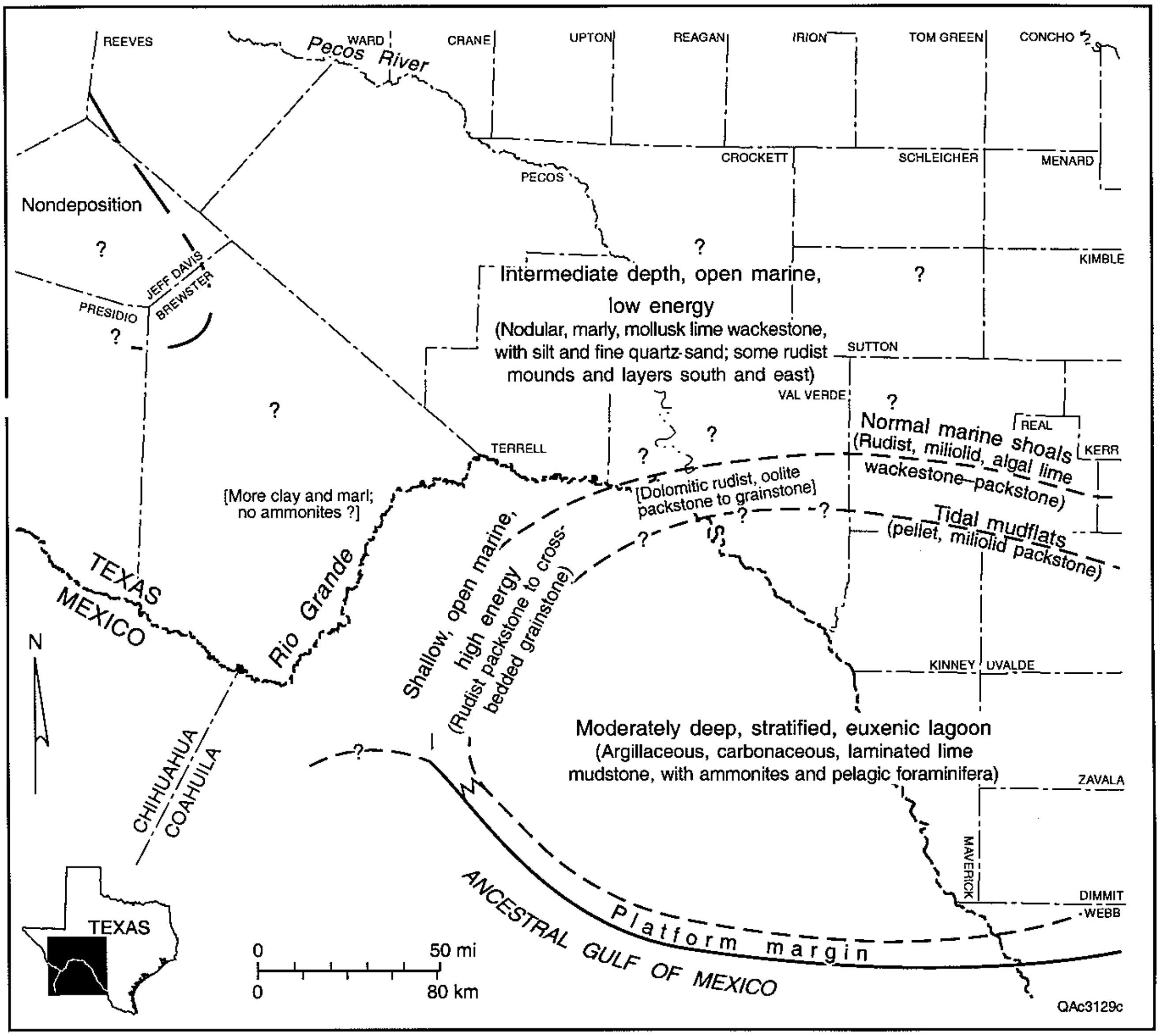

Figure 12. Map F, middle Fredericksburg–Washita subdivision facies tracts and environmental interpretation. Stratigraphic horizon of map shown on cross sections.

ward as the upper part of the lower, marly Sue Peaks (pls. 1, 2, 4) and eastward (pl. 3) with loss of clay content to become the upper nodular marl of the Burt Ranch Member of the Fort Lancaster and Segovia Formations. The upper marl is separated from the lower Burt Ranch by 1 ft to several feet of more resistant grainstone or packstone (Brown Trigonia lime of Adkins, 1927, and equivalents; pls. 1 through 3, 5). In eastern Pecos County these beds are directly overlain by the *Adkinsites bravoensis* and *Texigryphaea navia* zones. Paleontologically the upper marl is equivalent to the Kiamichi (basal Washita) of North Texas (Young, 1966; Fallon, 1981; fig. 4). According to Rose (1972), the unit continues eastward and becomes the Regional Dense Member of the Person Formation over the San Marcos Platform as the lower Burt Ranch changes facies to become the upper grainstone member of the Kainer Formation.

Through the Devils River Formation and margin of the Maverick Basin, facies along horizon G re-

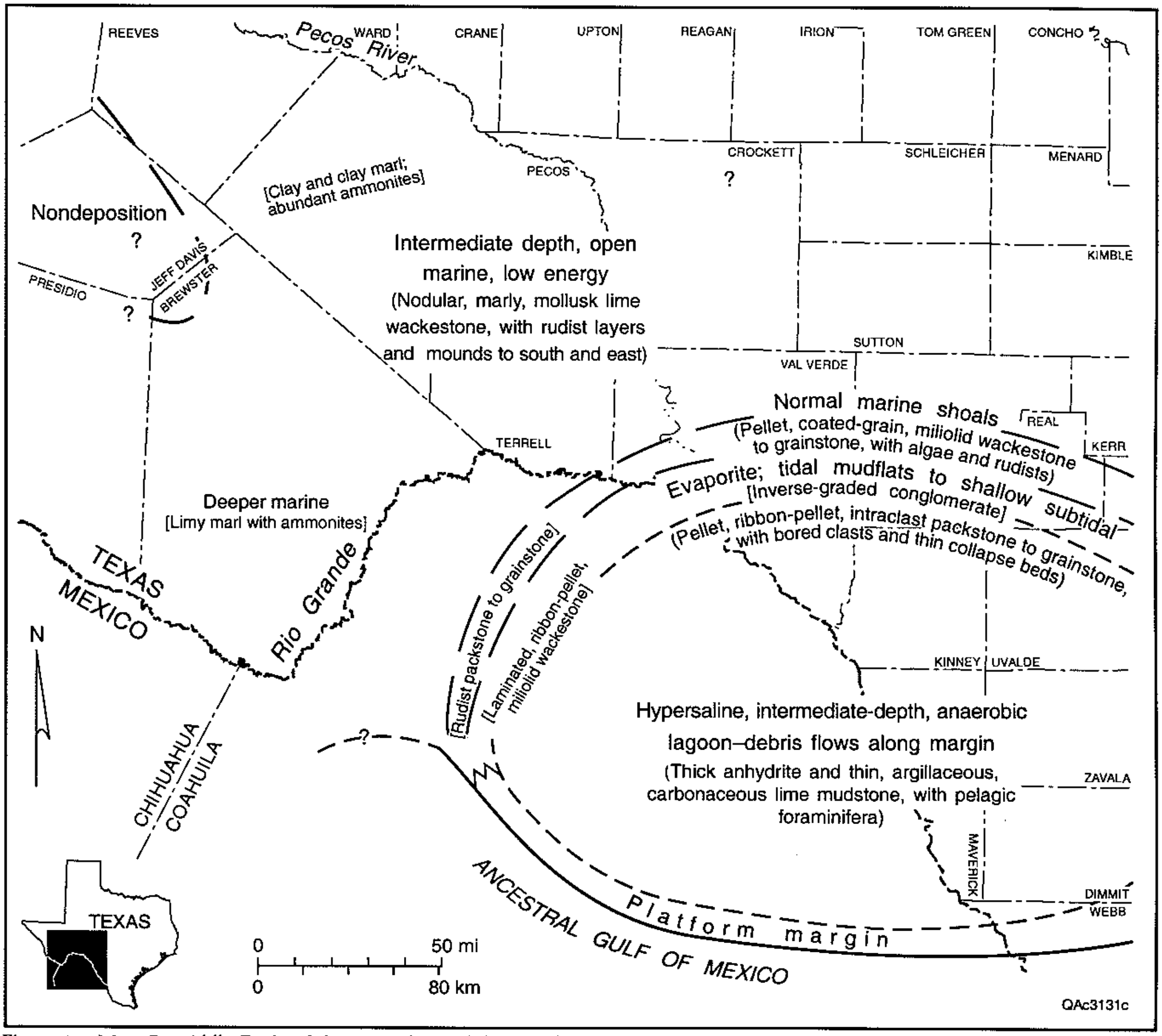

Figure 13. Map G, middle Fredericksburg–Washita subdivision facies tracts and environmental interpretation. Stratigraphic horizon of map shown on cross sections.

mained essentially the same as those described for horizon F (figs. 12, 13), but marginal Maverick Basin facies extend farther north and west over those of the Devils River (pls. 4 through 6). Farther into the basin, the upper McKnight comprises thick beds of mosaic anhydrite interbedded with thin layers of black, laminated, argillaceous lime mudstone containing rare pelagic foraminifera and a few thin layers of graded peloid, intraclast packstone (fig. 13; Carr, 1987). In contrast to evaporites of the lower McKnight, these extend across the entire Maverick Basin (Smith, 1970a). Within the upper 40 ft of the McKnight, several 2- to 13-ft-thick layers of matrix-supported, inverse-graded, bored lithoclast (as long as 12 inches), peloid packstones (conglomerates) having irregular upper surfaces (as much as 2 ft of relief) are found; the clasts are mostly pellet packstones and grainstones similar to those present along the north margin of the basin (pls. 4 through 6; Miller, 1984; Hudson, 1986; Carr, 1987).

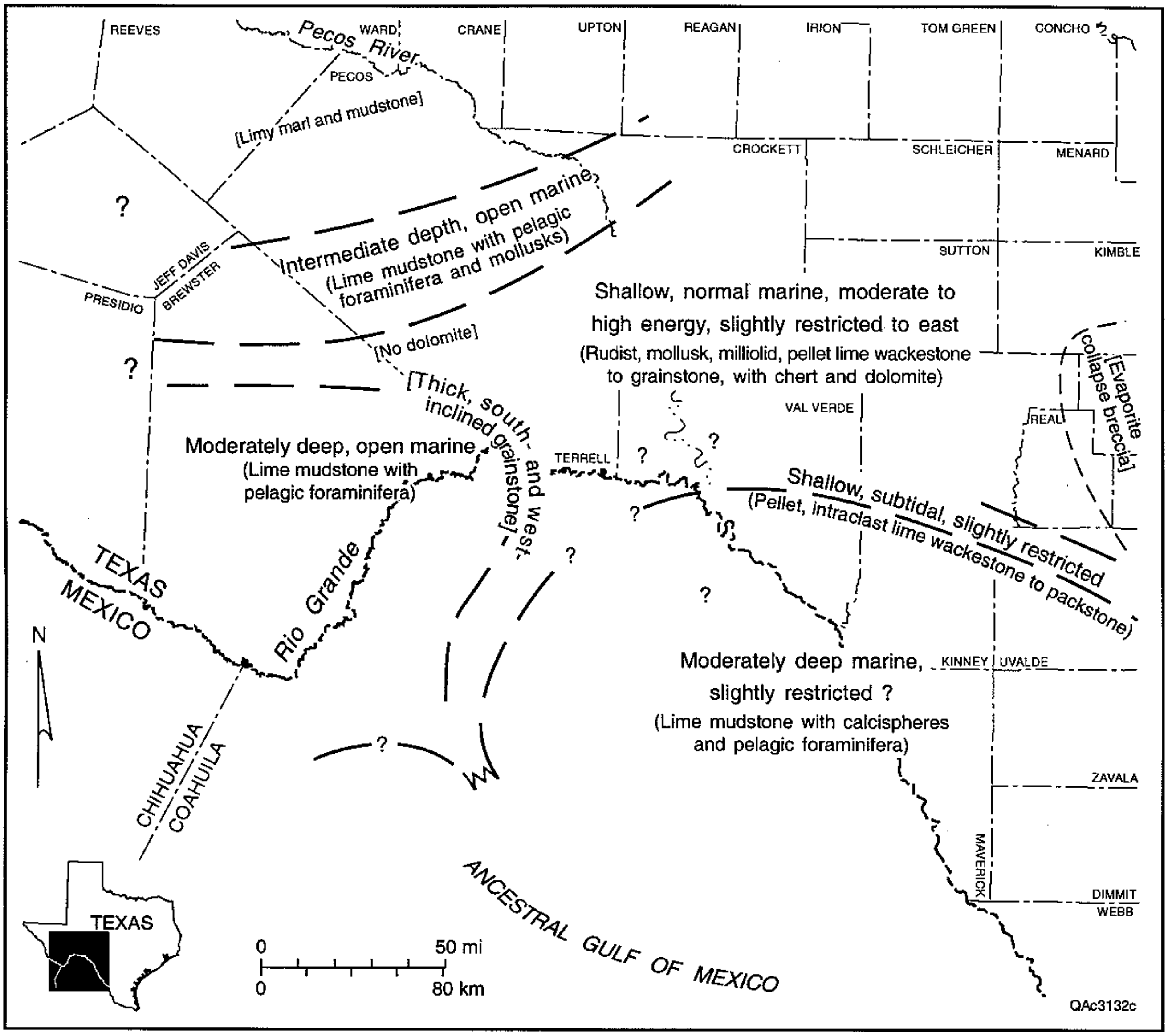

Figure 14. Map H, middle Fredericksburg–Washita subdivision facies tracts and environmental interpretation. Stratigraphic horizon of map shown on cross sections.

Horizon H (fig. 14; pls. 1 through 6) is based on the last occurrence of *Eopachydiscus brazosensis* in West Texas outcrops (fig. 4; pl. 3; Young, 1967). *Eopachydiscus* is abundant in the Fort Stockton Basin and to the east through most of Pecos County in marl and lime mudstone, is common in the Big Bend area in the basal part of the upper Sue Peaks lime mudstone (Maxwell and others, 1967), and is also found in the lower 60 ft of the Salmon Peak in the Maverick Basin (pl. 5, sec. 25; pl. 6, sec. 43) in globigerinid lime wackestone to packstone (fig. 14).

Ammonites are rarely found in the rudist, miliolid wackestone and associated facies that extend across the central part of the area (fig. 14; pls. 3 through 6) and form a body of rock that is strongly resistant to weathering. Lying above (Burt Ranch) and below slope-forming units, it is referred to as the "middle caprock" across most of the region (pls. 3, 5, sec. 21; the top of the Fort Terrett forms the lower caprock). The middle caprock extends to the southeast and thickens while retaining its characteristic facies to become part of the Devils River Formation (pls. 4, 6).

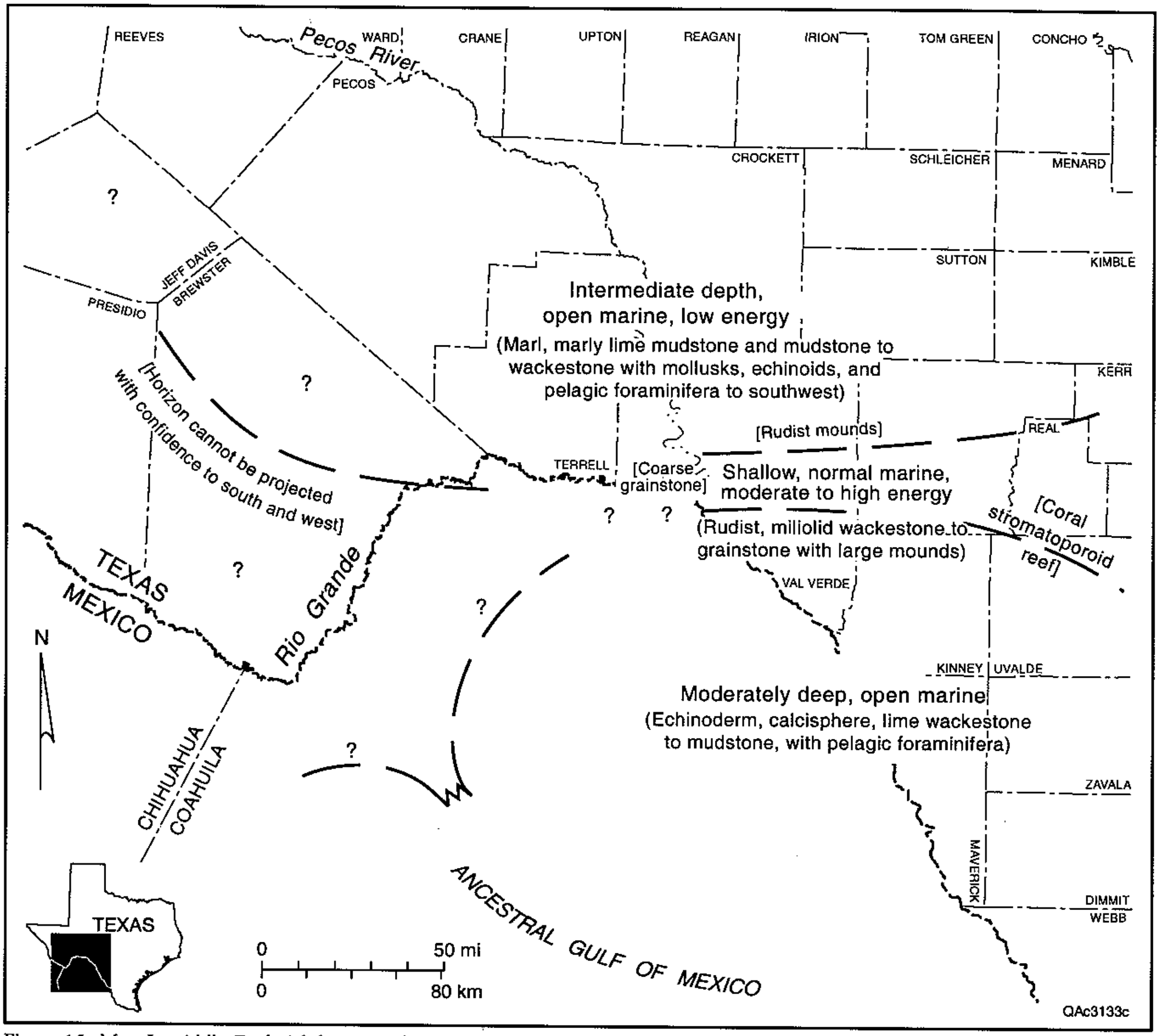

Figure 15. Map I, middle Fredericksburg–Washita subdivision facies tracts and environmental interpretation. Stratigraphic horizon of map shown on cross sections.

Data are sparse at this horizon along the margin of the Maverick Basin, but the Devils River–Salmon Peak transition is probably similar to that depicted in figure 13 (map G) as inferred from plates 4 through 6. To the southwest, the unit prograded over upper Sue Peaks lime mudstone (fig. 14; pls. 2, 4) containing, in places, large (+100-ft thick) inclined grainstone sets (pl. 2, sec. 9). Eastward, over the Central Texas Platform (fig. 1), the middle caprock becomes dolomitic and contains an evaporite collapse breccia named "Allen Ranch breccia" by Rose (1972). Elsewhere (pl. 5, sec. 23) the middle part of the caprock is thin-bedded, dolomitic, requieniid wackestone, and large caprinid mounds are found at both the bottom and top (pl. 5, secs. 21, 23).

Distribution of facies on map I (fig. 15) contrasts strongly with that of map H (fig. 14). Marl and lime mudstone containing a sparse pelagic fauna cover the entire Comanche Shelf and western regions, and the facies stratigraphically overlaps the middle caprock to the Devils River Formation (pls. 3 through 6). The lime mudstone may possibly extend through the

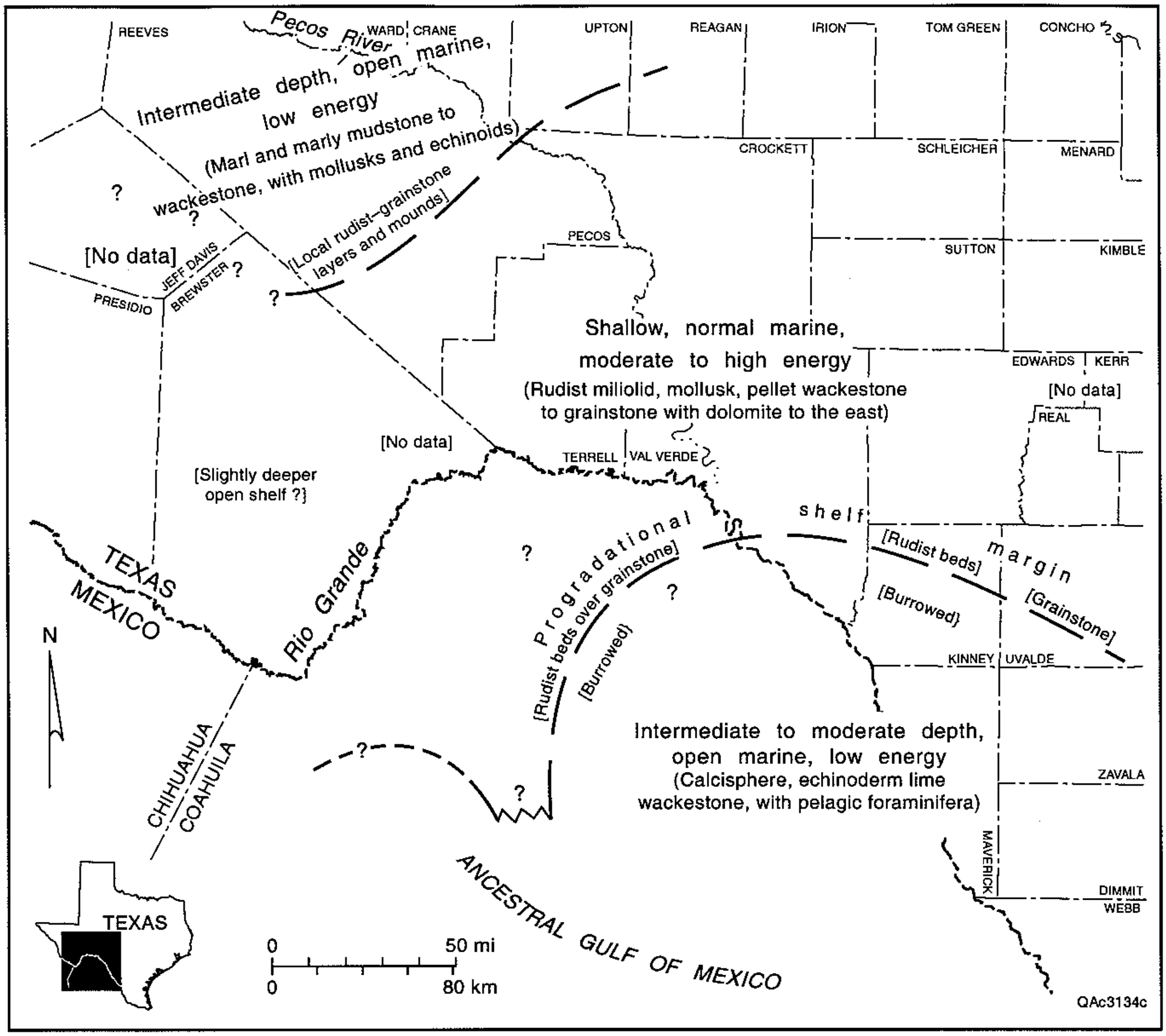

Figure 16. Map J, middle Fredericksburg–Washita subdivision facies tracts and environmental interpretation. Stratigraphic horizon of map shown on cross sections.

Devils River Formation along the Rio Grande in southeastern Terrell County (fig. 3) and into the Maverick Basin (pl. 4, secs. 49, 24; core F). Facies within the Maverick Basin are the same as those depicted on map H (fig. 14), but along the Devils River margin facing the basin at section 47 (pl. 6, Uvalde County), thin-bedded to laminated, pellet lime mudstones are replaced vertically by coral, stromatoporoid packstone and boundstone (Miller, 1984). Few data points occur along the basin margin in Kinney County, but large rudist mounds appear just back from the margin in Val Verde County (pl. 5, sec. 27).

With minor exceptions, the facies distribution illustrated on map J (fig. 16; pls. 1 through 6) is almost identical to that on figure 14 (middle caprock). Rudist, miliolid, peloid wackestone to grainstone again covered the Comanche Shelf to form a resistant upper caprock (pls. 3, 5, sec. 21), which forms the surface of most of the Edwards Plateau and south part of the Stockton Plateau. It overlies the weakly resistant marly lime mudstone of

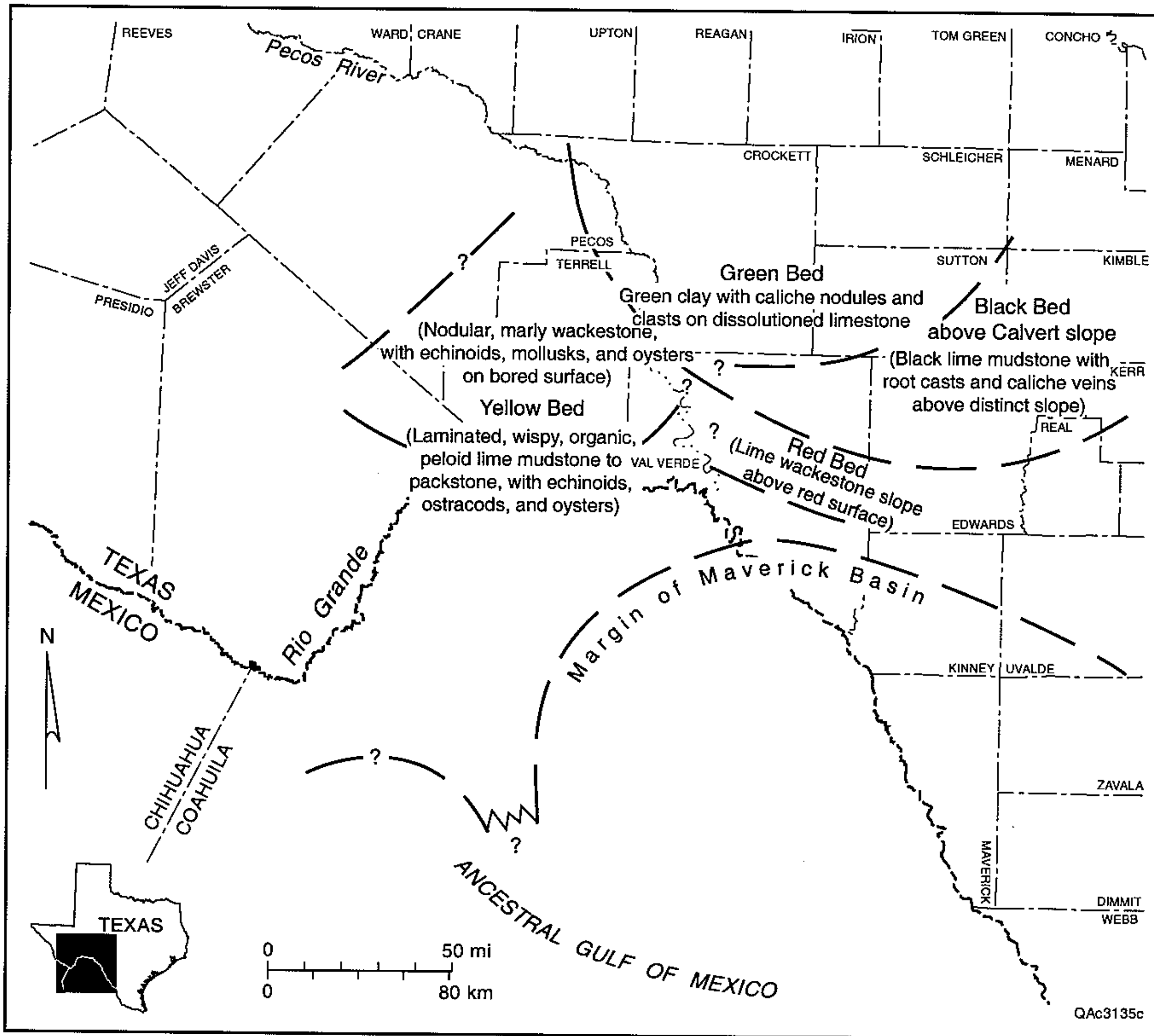

Figure 17. Map K, distribution and character of Black Bed and equivalent units. Stratigraphic horizon of map shown on cross sections.

horizon I (fig. 15) in a stratigraphic facies offlap relationship from the Devils River north and west (pls. 3, 5, 6). In contrast to the middle caprock, the Devils River equivalent of the upper cap formed a strongly progradational margin around the north and west sides of the Maverick Basin over the Salmon Peak lime mudstone (pls. 4 through 6; Smith and Bloxsom, 1974; Humphreys, 1984a; Kerans, 1997).

Horizon K lies within the lower part of the upper caprock and depicts distribution and character of the stratigraphically equivalent Black, Green, Yellow, and Red Beds (figs. 6, 17; pls. 2 through 6). In association with the "Calvert slope" (Calvert, 1928), these beds form the most reliable mapping horizon over the central part of the study area (Smith and Brown, 1983, p. 19–23). The Black Bed is a freshwater black, lime mudstone (Halley and Rose, 1977); the Green Bed is a relict soil of green clay as much as 2 to 3 ft thick; the Yellow Bed is a shallow-marine wackestone to lagoonal peloid packstone (Bowles 1986; Dellinger, 1987); and the Red Bed is an iron-stained surface, probably a diastem. Our physical stratigraphic correlations demonstrate that the horizon is above the West Texas zone of *Globator parryi* (fig. 4; pl. 3, sec. 16; Fallon, 1981) and below *Plesioturrilites brazosensis,* which would strongly suggest a late Albian age and equivalence to the Weno or Pawpaw of North Texas (fig. 4).

West Prong Formation

The West Prong Formation (figs. 4 through 6, 18; pls. 1 through 6), a calcisphere lime mudstone to wackestone containing *Plesioturrilites brazosensis,* sparse *Ilmatogyra arietina,* echinoids, and globigerinids and present in the subsurface throughout the Maverick Basin, is essentially indistinguishable from the Salmon Peak (Humphreys, 1984a). It appears in outcrop around the north margin of the basin above the upper progradational unit of the Salmon Peak but disappears by onlap onto a disconformity to the north (pls. 4 through 6; Freeman, 1968) and over the Burro Uplift in Mexico (figs. 1, 18; Smith, 1970a). It is also found onlapping a disconformity at the top of the Santa Elena Formation in the Big Bend–Marathon Basin region (pl. 1, secs. 6, 7), and in the Kent area (pl. 3, sec. 53; Brand and DeFord, 1958; Fallon, 1981), where it is a nodular to massive shell fragment, texigryphaeid wackestone containing *Plesioturrilites.*

Over the San Marcos Platform (figs. 1, 2), a thin (20- to 60-ft-thick) unit similar to the West Prong and referred to as the Georgetown Formation underlies the Del Rio Formation and unconformably overlies the Edwards Group (Rose, 1972). Rose concluded that the unconformity was equivalent to the Black Bed horizon across the eastern Edwards Plateau and that the Georgetown and the section above the Black Bed were of the same age but different facies (fig. 6, cross section G–G′; fig. 17, pls. 3, 6). By our correlations, the Georgetown and West Prong are the same age (and facies) and are entirely younger than the section above the Black Bed and below the basal West Prong unconformity (fig. 6, cross section H–H′; pl. 6). The lacuna at the unconformity is probably at a maximum in northern Edwards County, where the middle Buda overlies the Segovia Formation (pl. 6, secs. 36, 37), and strata equivalent to the Mainstreet, Paw Paw, and probably part of the Weno Formations of North Texas are missing. At section 37 (pl. 6), the unconformity surface is clearly erosional and has stair-step erosional relief of 2 or 3 ft. The only other area where significant erosional features are found on this unconformity is at the U.S. Highway 90 crossing of the Pecos River, where the Del Rio overlies the Devils River (pl. 4, sec. 24; Smith and Brown, 1983, p. 11–15).

Interpretation

Middle-Lower Subdivision Boundary and Overlying Strata

Submergence and deepening begun near the end of the lower subdivision continued into the middle subdivision and, coupled with an influx of fine clastics and decrease in rate of carbonate production, led to deposition of the basal middle-subdivision nodular marl (Burt Ranch, fig. 12). Judging from both physical and biostratigraphic evidence, the marl appears to be essentially the same age across the entire area—probably because of the flat upper surface of the lower subdivision, across which it was deposited. The bored surface at the top of the lower subdivision limestone below the Burt Ranch (fig. 11) probably represents a submarine hardground and diastem (Rose, 1972) formed as the seafloor passed through wave base.

Through the Devils River Formation in Texas and Mexico (figs. 11, 12) and across the San Marcos Platform (fig. 2) (Rose, 1972), grainstones and associated facies thought to be equivalent to the basal subdivision nodular beds are inferred to represent open, shallow-marine deposition with local shoals (Miller, 1984). Apparently the rate of carbonate production matched that of subsidence, even though this was a period of more rapid submergence and flooding elsewhere. Along the margin of the Maverick Basin in Texas, the grainstone shoals graded into tidal mudflats basinward (Miller, 1984) and which, as a result of much more rapid subsidence south of the tectonic hingeline, graded into relatively deep, strati-

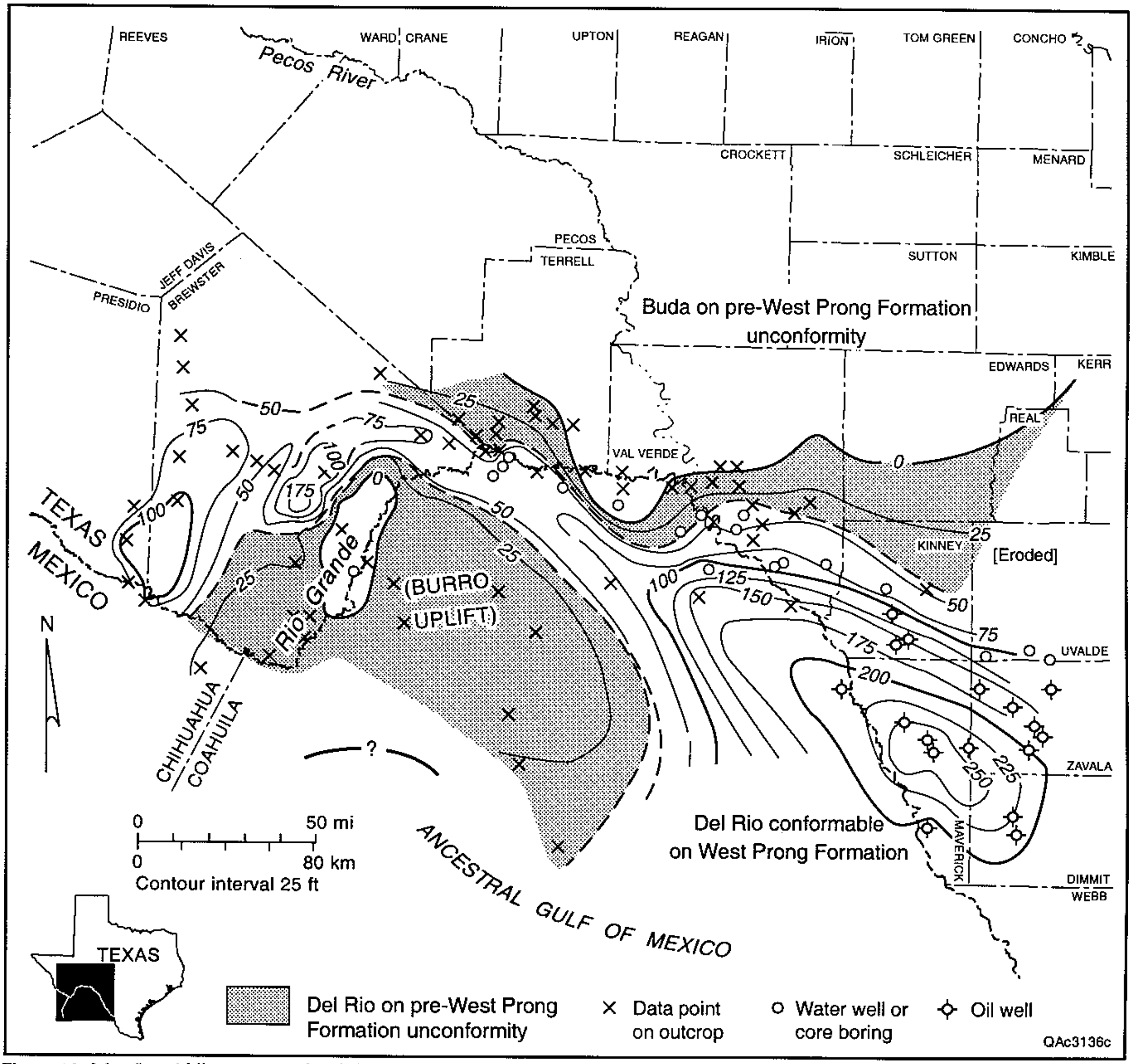

Figure 18. Map L, middle-upper Fredericksburg–Washita subdivision boundary relationships with Del Rio isopachs. Stratigraphic horizon of map shown on cross sections.

fied, euxenic waters of the middle McKnight (Carr, 1987), which extended throughout the Maverick Basin (figs. 11, 12). Progressive expansion of the lower oxygen-depleted zone of the stratified water column northward, up depositional dip, produced an apparent onlap of the middle McKnight onto lower McKnight tidal mudflats (pl. 6, secs. 43 through 45; Miller 1984; Carr, 1987). The fine silt and clay of the middle McKnight was probably bypassed across Devils River shoals—particularly at the west (Sue Peaks) margin of the basin.

Upper Formations, Facies Tracts, and the West Prong Formation

The middle subdivision probably represents about twice as much time as the lower subdivision, as suggested by the time spans derived by Scott and others (1988). These differences seem to be reflected reasonably well by thickness differences across the region, which in turn would suggest that overall rates of eustatic sea-level rise, tectonic subsidence, and sedimentation were relatively constant overall through the

Fredericksburg–Washita division. However, the lower subdivision represents a time of stability across the entire area, whereas the middle (and at least the lower part of the upper) subdivision was characterized by differential rates of subsidence that served to emphasize primary tectonic elements (fig. 1). For example, an increase in rate of subsidence south of the hingeline at the subdivision boundary is suggested by abrupt deepening of waters in the Maverick Basin (middle McKnight) and of the shelf in the Big Bend region (Sue Peaks). Upper McKnight matrix-supported conglomerates interpreted as debris flows, along with intraformational folding (pl. 5, sec. 25) during the late McKnight, may also suggest that this increase in rate subsidence was accompanied by abrupt tectonic activity. Eventually, as higher subsidence rates continued, the platform margin facing the ancestral Gulf of Mexico, the west margin of the Maverick Basin, or both, was breached sufficiently to allow increased circulation in the basin, leading to deposition of Salmon Peak pelagic lime mudstone (Smith, 1970a, p. 51).

Tectonism also became more active across the Central Texas Platform near the end of the middle subdivision, as demonstrated by development of the Black Bed–Green Bed fresh-water limestone and soil horizon and the basal West Prong unconformity. Anomalous thicknesses along the Rio Grande (pl. 4, secs. 49, 24) appear to involve the entire division and may be related to persistently lower and higher subsidence rates over the respective Treviño–Chupadero–Agua Verde Anticline and Zavala Syncline of the Rio Grande Structural Embayment (fig. 1).

Tidal mudflats bordered the Maverick Basin from the time of horizon G (fig. 13) through much of the time represented by the upper subdivision. They migrated northward, progressively overlapping McKnight evaporitic tidal flats and then shallow, normal-marine carbonates of the Devils River, and were, in turn, overlapped by deeper water pelagic deposits of the Salmon Peak—without an intervening facies of shallow-marine, skeletal carbonate (pls. 5, 6; figs. 12 through 15; Miller, 1984). This intertidal to deep-water transition without an intervening facies, representing a shallow-water, high-energy environment, suggests that during lower Salmon Peak deposition (1) the Maverick Basin was not very deep, (2) wave and current energy was low, and (3) tide-transported fine sediment from the north and west or from the basin was trapped in the shallow-water zone along the basinward side of the Devils River Formation—much like along the lagoon side of a coastal barrier bar. This interpretation is supported by a microfossil assemblage dominated by calcispheres (fruiting bodies of floating algae) and a reasonably diverse but low-abundance population of pelagic foraminifera (Humphreys, 1984a).

Shallow, moderate- to high-energy deposition persisted through the Devils River, with some variations, from horizon B of the lower subdivision throughout the upper subdivision. Initially it was just the margin of the Comanche Shelf facing a broad, shallow lagoon in the Maverick Basin area (figs. 8 through 10); with regional submergence and lower carbonate productivity on either side, it became a low, linear, submarine ridge enclosing the north and west sides of the basin (figs. 11 through 13). By the time of horizon H (fig. 14), the Devils River environments extended far to the west (middle caprock) over the open-marine, upper Burt Ranch nodular marl. Expansion into the Maverick Basin was prohibited by deeper waters and rapid subsidence—facies of the McKnight transgressively overlap the Devils River to the north (pl. 6). A major period of submergence followed (fig. 15), and pelagic lime mud facies now transgressively overlap the middle caprock from the west to the south and east. The Devils River depositional area remained as a linear high (fig. 15), probably with relief greater than it was previously (figs. 12, 13), except along the Rio Grande, where it may have been breached by the rapid marine flooding. Deeper, more open marine conditions developed in the Maverick Basin, as suggested by the appearance of the coral, stromatoporoid reef at this horizon in Uvalde County on the basin margin (fig. 15; Miller, 1984). The second and last period of expansion of shallow, high-energy deposits from the Devils

River area (fig. 16; upper caprock) occurred both to the north and west and southward over the Salmon Peak into the Maverick Basin as a (secondary) prograding platform margin (pls. 4 through 6; Humphreys, 1984a; Hudson, 1986). The West Prong Formation represents the final episode of submergence of the middle subdivision after formation of an erosional unconformity having significant hiatus.

Previously we concluded that there may be a transitional depositional-sequence boundary (Goldhammer and Dunn, 1991) within the lower subdivision just above horizon C (Kirschberg), and the interval from there through horizon G (upper Burt Ranch) in the middle subdivision would therefore constitute a transgressive sequence tract. (The subdivision boundary, base of the Burt Ranch, lies within the middle of this tract and resulted from a rapid influx of fine clastics across the region). Including this tract, therefore, we can identify two and one-half depositional cycles to the top of the middle subdivision: (1) Kirschberg through Burt Ranch submergence (horizons D through G) followed by middle caprock emergence and shoaling (horizon H), (2) submergence with maximum flooding along horizon I followed by upper caprock shoaling (horizon J), and (3) West Prong submergence. Both caprock events (relative sea-level fall) are centered over the Central Texas Platform.

As noted previously, rates of regional tectonic subsidence or uplift, differential subsidence between the Central Texas Platform and surrounding areas, variations in rate of eustatic sea-level rise or long-term eustatic cycles, and rates of carbonate production may all have played some process role in production of these stratigraphic responses. According to Scott and others (1988), there is evidence in the western Gulf Coast of a significant hiatus at the boundary between the Fredericksburg and Washita divisions, which plots at about 101 Ma on the Haq and others (1987) scale. It could very well coincide with their 100.5-Ma type-2 sequence boundary. In the Edwards–Stockton Plateau this horizon occurs within the lower Burt Ranch transgressive succession with no evidence of hiatus. A persistent Brown Bed of worn grainstone to packstone at that horizon (Brown Trigonia lime of Adkins, 1927), however, suggests a brief period of shallowing. The Haq and others (1987) cycle chart shows four sequence boundaries above the one at 100.5 Ma within the middle subdivision period. Two of them, at 98 and 95.5 Ma, the result of fairly large amplitude cycles (Yurewicz and others, 1993, placed the boundary between the Fredericksburg and Washita at the 98-Ma position). Rates of eustatic fall during these two cycles may have been roughly equal to the rate of subsidence in the Edwards–Stockton Plateau region and produced transitional sequence boundaries (Goldhammer and Dunn, 1991), which lie within the middle and upper caprocks, at the time of maximum sea-level fall. Emergent phases would have been emphasized over the Central Texas Platform and obscured elsewhere. Amplitudes of the other two cycles may have been too low to offset opposing effects of the other factors just outlined.

On the other hand, a perfectly reasonable account of the depositional cycles observed can be made by using rates of subsidence versus rates of eustatic rise and rates of carbonate production as the primary processes. The Black Bed–Green Bed exposure was probably related to a short-term tectonic or eustatic spike, whereas the basal West Prong unconformity, which is present across the Burro Uplift (Smith, 1970a) and San Marcos Platform (Rose, 1972), as well as the Central Texas Platform, most likely represents a regional tectonic event.

Middle-Upper Subdivision Boundary and Overlying Strata

The Del Rio Clay–West Prong Formation gradational contact forms the middle-upper subdivision boundary of the Fredericksburg–lower Washita division of southwest Texas where the West Prong is present. The West Prong is absent by onlap where thickness of the Del Rio is less than about 35 ft (fig. 18). It is overstepped by the Del Rio, which then overlies and onlaps the unconformity northward in Texas to where it pinches out and over the Burro Uplift in Mexico (fig. 1; shaded area, fig. 18). From there across the remainder of the area in West Texas, the division boundary lies at the unconformity between the Buda and Fort Lancaster or Segovia Formations.

Influx of the Del Rio Clay (basal clastic phase of the upper Fredericksburg–Washita subdivision) terminated shallow-marine carbonate production on the platform in southwest Texas and northern Mexico for a significant period of time. The clay filled the Maverick Basin and covered most of the rest of the area except, perhaps, the highest part of the Central Texas Platform (figs. 1, 18). Del Rio clasts are found in the basal Buda (pl. 6, sec. 37), well north of the Del Rio updip limit shown in figure 18. Isopach thicks and thins in the area between the Central Texas Platform and the Burro Uplift and in the Big Bend region (fig. 18; St. John, 1965) suggest local tectonic activity during Del Rio deposition, but the significance or cause is unknown to us.

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APPENDIX A.

Names and thicknesses of measured sections and cores shown in figure 3.

Level of detail in which sections were measured is indicated. Originals of all graphic sections of outcrops and cores from this study are on file in the F. E. Lozo Center for Cretaceous Stratigraphic Studies at The University of Texas at Arlington. All cores are stored at the Well Sample and Core Library of the Bureau of Economic Geology, The University of Texas at Austin.

SECTIONS DESCRIBED FOR THIS REPORT

Measured sections (Sections in composite)	Total section measured (ft)		
	A Detail with samples	B Detail with no samples	C Reconnaissance
1. Lee Peak (Graff Ranch)			214
2. Hovey Comp. (2)			567
3. Emerson Ranch			129
4. Ord Mountain			439
5. Del Norte			132
6. Doubtful Canyon			761
7. Santiago Mountains			133
8. San Francisco Creek Comp. (2)			729
9. Maxon Creek			326
10. Sanderson Comp. (3)	31(1)		259(2)
11. Longfellow Siding			293
12. Downie Draw			261
13. Big Canyon			589
14. Fort Stockton Comp. (2)		892	
15. Robbins Ranch			316
16. Tunis Springs	226		
17. Squawteat–Sherbino Comp. (2)	490		
18. King Mountain Comp. (2)	442		
19. Yates Mesa Comp. (3-N,E,S)	931	(2, north and east)	428(1)
20. Iraan Road Cut	518		
21. Fort Lancaster	644		
22. Ranch Road 2400		195	
23. Pandale	431		
24. Pecos River Bridge	365		
25. Slaughter Bend	369		
26. Hinds Ranch (Dead Man Creek)	36		
27. Dolan Creek	486		
28. Velma Hunt			253
29. Karnes–Magruder Comp. (2)			425
30. East Devils River Comp. (4)			552
31. Whitehead-Hill Comp. (3)			468
32. North Devils River Comp. (2)			300
33. Sonora Comp. (3)		140(1)	168(2)
34. Wilson Ranch			72
35. Sentell Ranch			128
36. Fort Terrett		457	
37. East Nueces River Comp. (3)	683		
38. Little Hackberry Creek	65		
39. Frio River	351		
40. Sabinal River	184		
41. Leakey Road Cut	653		
42. Upper West Nueces	226		
43. West Nueces River Comp. (3)	543		
44. Indian Creek	185		
	7,859 ft	1,684 ft	7,942 ft

Total: 17,485 ft
Total sections (individual + composite) = 66

CORES		Detail	Preliminary
A.	Graff Ranch (Lee Peak)	237	
B.	Hinds Ranch		400
C.	I.B.W.C., ID-22		772
D.	Lee Hyde	50	
E.	George Pardi	110	
		397 ft	1,172 ft

COMPOSITE SECTIONS

2	Hovey Comp.	Hovey Dome Pyramid Butte
8	San Francisco Creek Comp.	McNutt Ranch Garner Ranch
10	Sanderson	Sanderson Canyon Hwy. 285 north Five Mile Hill
14	Fort Stockton Comp.	University (East) Mesa Twelvemile Mesa
17	Bakersfield	Squawteat Peak Sherbino Mesa
30	East Devils River Comp.	Shurley Ranch South Hwy. 277 Galbreath Ranch Morris Ranch
31	Whitehead–Hill Comp.	Whitehead Ranch Hill Ranch Aldwell Ranch
32	North Devils River	North Devils River I, II Glasscock Road
33	Sonora Comp.	Graveyard Meckel Draw Sonora I-10
37	East Nueces River	East Nueces Hackberry Creek Lee Hyde quarry and core
43	West Nueces River	Chapman Ranch Bitter Bluff Chalk Bluff

SECTION AND CORE DESCRIPTIONS DERIVED FROM OTHER REPORTS

Measured sections

From Miller (1984)		
45.	Sycamore Mountain	597
46.	Sycamore Creek	400
47.	Rawhide Mtn./Williams Ranch Comp.	575
48.	Caprock Mountain	554
From Smith (1970a, b)		
49.	Agua Verde	695
50.	San Rosendo	1,090
From St. John (1965)		
51.	Black Gap	1,640
From Malott (1991)		
52.	Kent (Finlay section)	44
From Fallon (1981)		
53.	Kent (Boracho section)	450
From Dellinger (1987)		
54.	Hwy. 285 road cut (Big Hill)	325
55.	Sanderson Composite Quarry Section	119
	Austin Nance Ranch	61
		6,550 ft

Core descriptions

From Walter E. Bloxsom (1971a, b, 1976a, b)		
B.	Hinds Ranch detail	400
F.	IBWC ID-1	496
C.	IBWC PH-4V (with ID-22)	200
From Bowles (1986) and Walter E. Bloxsom (1976)		
G.	IBWC FI-15	965
From Carr (1987) and Humphreys (1984)		
C.	IBWC ID-22 detail	772
From Malott (1991)		
H.	Kent	45
		2,878 ft

APPENDIX B.

Credits for figure 1.

Tectonic features of the San Marcos Platform–Rio Grande Embayment–Balcones Fault Zone area are based on the tectonic maps of the United States (U.S. Geological Survey, 1961) and Mexico (Geological Society of America, 1961), with updip control from Pettit and George (1956); the upper end of the Rio Grande structural embayment, east of the Burro Uplift, is contoured on the basis of mapping by Petroleos Mexicanos, International Boundary and Water Commission boring data, and these studies. The north part of the area, dominated by the Central Texas Platform and flanking areas, is based directly on unpublished Shell Oil Company reports of Curry (1933), Stever (1954), Rives (1954), and the authors' work on the east and south flanks. The west flank and Trans-Pecos areas are compiled from Fritts (1933) and later Shell Oil Company–Midland office data and from the published studies of Cartwright (1932), Jager (1942), and Armstrong and McMillion (1961); the Marathon Dome contours are from the structural map of Texas (Sellards and others, 1934).