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# Chronostratigraphic Relationships of the Woodbine and Eagle Ford Groups across Texas

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## ABSTRACT

**Four depositional sequences (allomembers), each geochemically, petrophysically, and chronostratigraphically distinct, were defined within the outcrops and shallow subsurface of the Eagle Ford Group in West Texas. The lower two depositional sequences occur within the Lower Eagle Ford Formation, while the upper two depositional sequences occur within the Upper Eagle Ford Formation. These four depositional sequences can be correlated into the subsurface of South Texas to get an understanding of the distribution and thickness variations of each chronostratigraphic unit within the Eagle Ford Source Rock Play Fairway. The four depositional sequences can also be correlated into the East Texas Basin in order to gain an improved understanding of the chronostratigraphic relationships between the Eagle Ford and Woodbine groups in this basin. The regional sequence stratigraphic correlations indicate that the Eagle Ford Group of West and South Texas, including the Lower and Upper Eagle Ford formations and the four depositional sequences contained within, can be correlated into the outcrops and shallow subsurface of the Eagle Ford Group along the western flank of the East Texas Basin. These correlations also indicate that the Woodbine Group is an older chronostratigraphic unit that is generally absent in South and West Texas due to erosion and/or non-deposition.**

## INTRODUCTION

The Upper Cretaceous Eagle Ford Group is a prolific source rock and important unconventional reservoir in the Gulf of Mexico Coastal Plain of South Texas (Fig. 1). In the East Texas Basin (Fig. 1), the Eagle Ford Group is the primary source rock for hydrocarbons found in underlying Woodbine conventional reservoirs, such as in the giant East Texas Field (Halbouty, 1991). While the Eagle Ford Group can be readily mapped from the Dallas area in East Texas to the Lozier Canyon region in West Texas (Fig. 1), the directly underlying lithologic Woodbine Group is, in general, restricted to the East Texas Basin. Classic biostratigraphic work (Adkins, 1932) suggested that the Eagle Ford Group is a distinct chronostratigraphic unit that can be mapped across Texas and that the underlying Woodbine Group is an older chronostratigraphic unit absent in South and West Texas due to non-deposition and/or erosion (Fig. 2A). Recently, however, some researchers (Hentz and Ruppel, 2010; Hentz and Ambrose, 2013; Hentz et al., 2014) have suggested that all or part of the organic-rich Lower Eagle Ford Formation in South Texas is coeval to the Woodbine Group in the East Texas Basin, and that the overlying Eagle Ford Group in the East Texas Basin is actually coeval to the Upper Eagle Ford Formation in South and West Texas (Fig. 2B). Clearly only one of the proposed correlation schemes between East Texas and South Texas can be correct. The purpose of this paper is to see how the depositional sequences (chronostratigraphic units) defined within the Eagle Ford Group in South Texas correlate into the outcrops and shallow subsurface along with the western flank of the East Texas Basin (Fig. 1).



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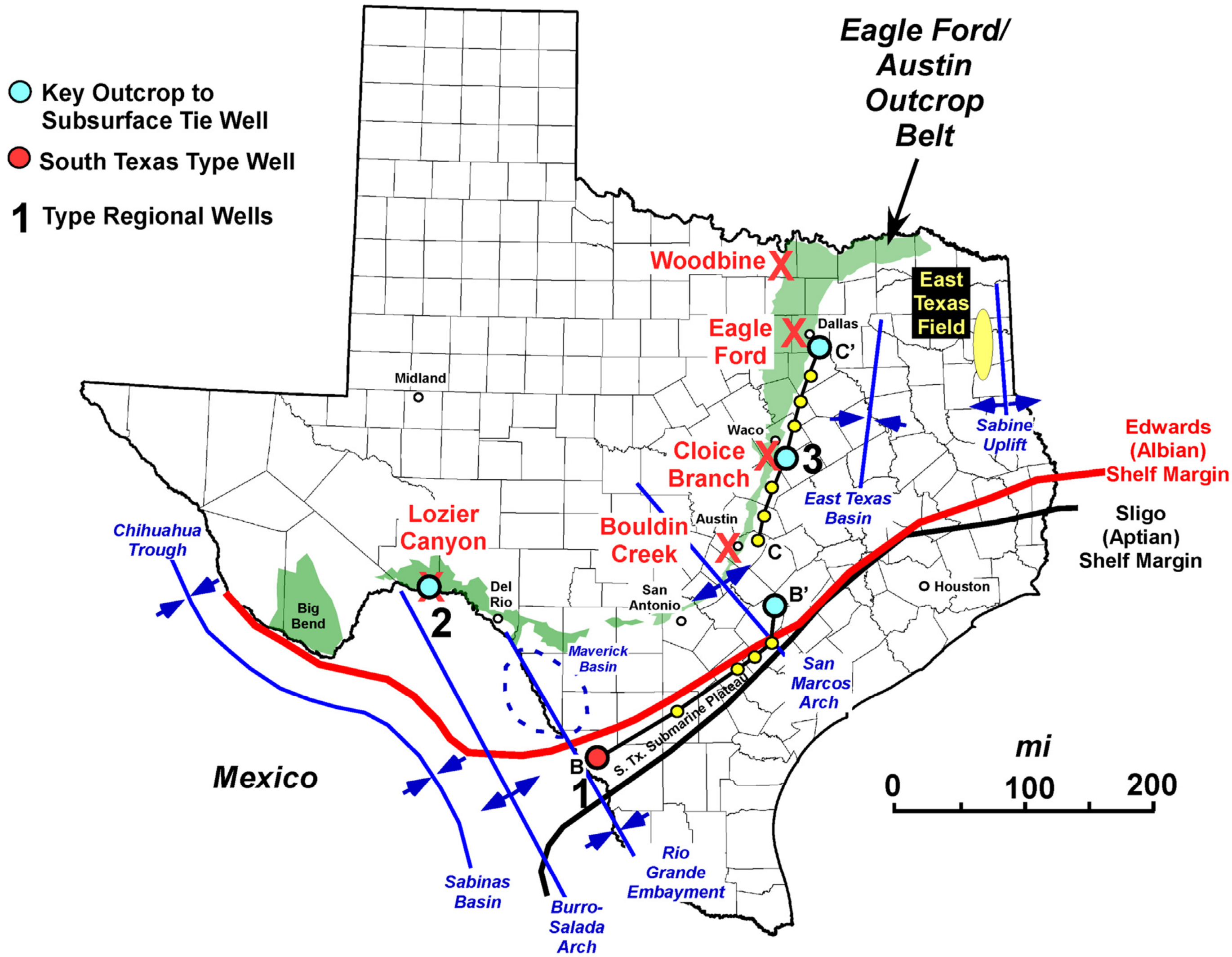


**Figure 1. Major structural and physiographic features of Texas, illustrating location of outcrop belt (green), cross sections, key subsurface ties, and outcrop localities. Cross-section A–A' connects wells 1, 2, and 3.**

## GEOLOGICAL SETTING

The major structural features affecting the Coastal Plain succession of Texas consist from east to west of the Sabine Uplift, East Texas Basin, San Marcos Arch, and Rio Grande Embayment (Fig. 1). Other key physiographic features affecting coastal plain deposition across Texas include the shelf margins of the Lower Cretaceous (Aptian) Sligo Group and younger (Albian) Edwards Group (Fig. 1). Within the lower portions of the Upper Cretaceous succession in the Texas Coastal Plain the vertical succession of units from the base upwards consists of the Del Rio (Grayson) Formation, the Buda Formation, the Woodbine Group, the Eagle Ford Group, and the Austin Chalk (Fig. 3). Within this succession, the Eagle Ford is a major source rock, as well as unconventional source rock play, south of the San Marcos Arch in South Texas (Tian et al., 2012). Along the eastern flank of the East Texas Basin, Woodbine strata are the primary reservoirs in East Texas Field (Fig. 1) sourced by hydrocarbons migrated out the overlying Eagle Ford from deeper portions of the basin (Halbouty, 1991). Classic Eagle Ford exposures are present around Dallas, Waco, and Austin, along the western flank of the East Texas Basin, and in the Lozier Canyon region in West Texas (Fig. 1).

## METHODS

In order to evaluate how the Eagle Ford Group of West and South Texas correlates into the Eagle Ford and Woodbine groups of the East Texas Basin, a study of the Eagle Ford outcrops and shallow subsurface along the western flank of the East Texas Basin was conducted (Fig. 1). The goal was to see if the chronostratigraphic units defined in the Eagle Ford in South and West Texas could be defined and correlated in this area.

A key aspect of our research was to collect spectral gamma ray (SGR) profiles of the measured sections using a hand-held gamma ray spectrometer (GRS). SGR information was sampled at the stratigraphic vertical spacing of one foot. The SGR data were used to generate a gamma ray (GR) profile that could be directly tied to Eagle Ford wells in the subsurface. These data also provided key chemostratigraphic information on the vertical variability in uranium (U), thorium (Th), and potassium (K) within the succession. U, Th, and K content are commonly used respectively as the generalized proxies for organic matter, bentonites, and clay content. A handheld x-ray fluorescence (XRF) tool, calibrated with x-ray diffraction (XRD) data, was used to provide compositional information. Samples for total organic carbon (TOC) and biostratigraphy (foraminifera and calcareous

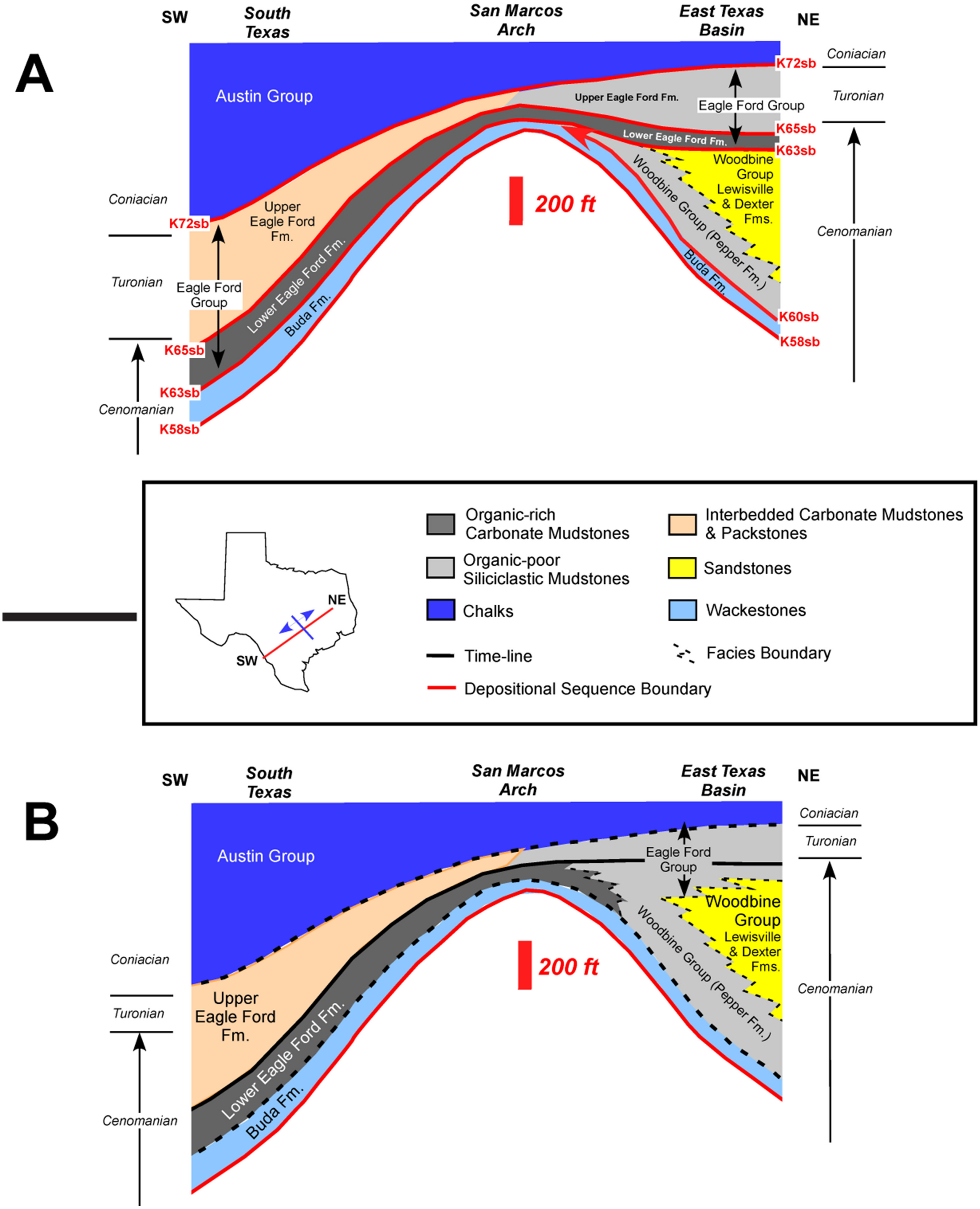


**Figure 2. Cenomanian/Turonian chronostratigraphic relationships commonly proposed between South Texas and the East Texas Basin. (A) The Eagle Ford Group is coeval across the Texas and strata coeval to the Woodbine Group are absent in South Texas. (B) Some or all of the Lower Eagle Ford Formation in South Texas is coeval to the Woodbine in the East Texas Basin.**

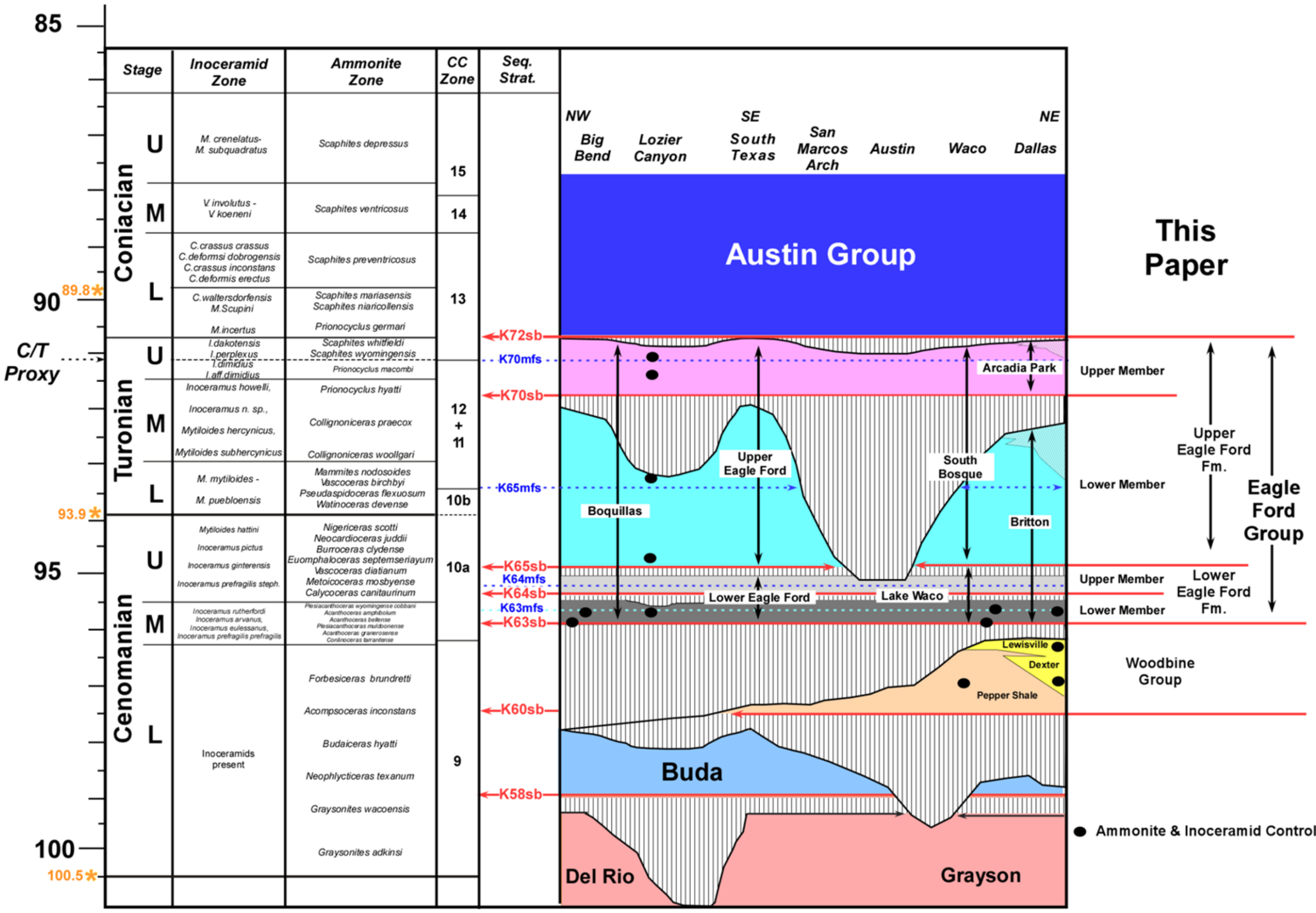


**Figure 3. Chronostratigraphy of the Cenomanian through Coniacian stratigraphic succession from West Texas to the East Texas Basin based on published molluscan data and the stratigraphic nomenclature followed in this paper. Zonation after Ogg and Hinnov (2012), while ammonite control from Kennedy and Cobban (1990) and Cobban et al. (2008). Genera abbreviations: *I* = *Inoceramus*, *C* = *Cremnoceramus*, *M* = *Mytiloides*, and *V* = *Volviceramus*.**

nannofossils) were also collected and analysed for the Lozier Canyon outcrops in West Texas, the cored well in South Texas, and the outcrops at Bouldin Creek in Central Texas. Carbon isotope ($\delta^{13}$C) analysis, for comparison to the geochemical signature at the Cenomanian-Turonian (C–T) global strata-type section and point (GSSP) located near Pueblo, Colorado (Ogg and Hinnov, 2012), was also conducted. This stage boundary is unique in having a distinct positive $\delta^{13}$C excursion, interpreted as ocean anoxic event 2 (OAE2), associated with this boundary. The maximum peak of the positive $\delta^{13}$C excursion associated with this event is taken as the geochemical proxy for the base of the Turonian. Another key aspect of our research was a borehole located a few hundred feet behind the measured outcrop section in Lozier Canyon. This well was cored and a full suite of modern geophysical logs was collected.

In terms of the geophysical logs, the term "bell-shaped" log pattern refers to intervals of decreasing log values, while "funnel-shaped" log pattern refers to intervals of increasing log values. For defining and mapping regional surfaces, this paper utilizes an alphanumeric scheme that starts with an abbreviation for each geologic period (K for Cretaceous) and then goes from 0 to 99 from the base up. The modifiers sb (sequence boundary), ts (transgressive surface), and mfs (maximum flooding surface) are also added to provide clarity to the surface type. In terms of the Eagle Ford Group, it is bounded by the K63sb at its base and the K72sb at its top. Throughout this paper, the following abbreviations are also used: LST (lowstand systems tract), TST (transgressive systems tract), and HST (highstand systems tract). This paper follows the bed classification scheme of Campbell (1967) of lamina, laminaset, bed, and bedset. Thus, very thin beds are those less than 3 cm thick, thin beds are 3 to 10 cm thick, medium beds are 10 to 30 cm thick, thick beds 30 to 100 cm thick, and very thick beds are those greater than 100 cm thick.

A detailed chronostratigraphic chart for the Cenomanian through earliest Coniacian strata across Texas is offered as Figure 3. In general, this chronostratigraphic chart follows the times, fossil zonations, and stage boundaries outlined in the Cretaceous section (Ogg and Hinnov, 2012) of the *Geologic Time Scale 2012* (Gradstein et al., 2012). However, on that 2012 time scale, a proposed (non-approved) placement for the Turonian/Coniacian stage boundary was used. In Texas, the new proposed criteria, the lowest occurrence of the inoceramid *Cremnoceramus deformas erectus*, occurs well into the Austin Group. Because this proposed boundary placement offers no clear lithologic or petrophysical proxies, it was rejected for our work. In contrast, the traditional macro-faunal boundary for the base of the Turonian, the first occurrence of the ammonite *Prionocyclus germani* or inoceramid *Mytiloides incertus*, coincides with the base of the Austin Group in the outcrops of West (Cobban et al., 2008) and Central (Kennedy and Cobban, 1990) Texas. Unfortunately, this macro-faunal criterion is less useful in the subsurface and as such the micro-flora CC12/13 boundary, which occurs at or near the interpreted mfs of the upper member of the Upper Eagle Ford, was used as the proxy for the Turonian/Coniacian boundary

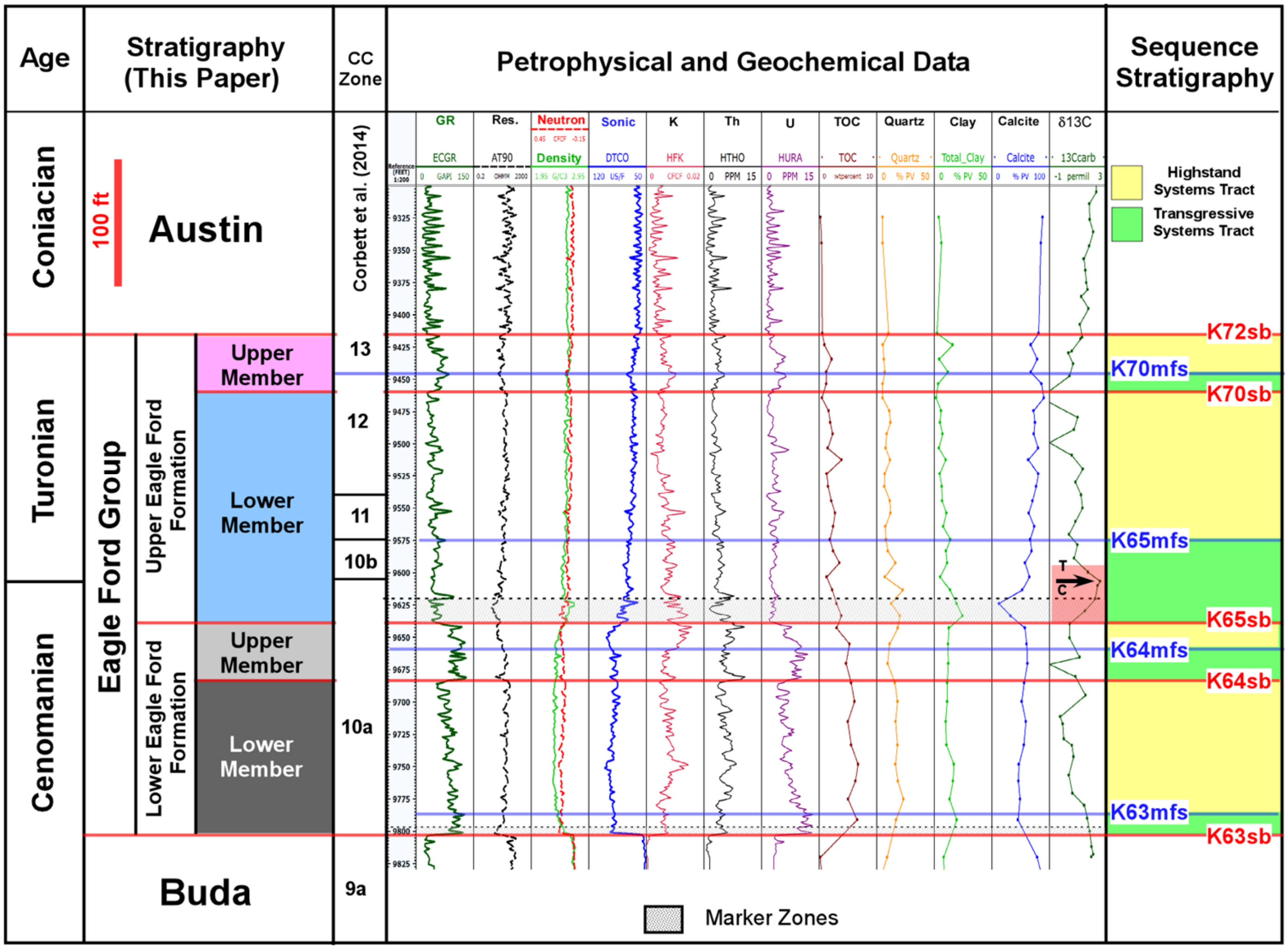


**Figure 4. Type Eagle Ford well from Webb County in South Texas. Please note petrophysical, geochemical, and biostratigraphic characteristics of formations, members, and sequence stratigraphic surfaces proposed in this study. Geochemical and petrophysical data presented courtesy of Core Lab and Swift Energy. Well location on Figure 1.**

in our study. This biostratigraphic proxy can also be readily defined in outcrop and subsurface samples by industry biostratigraphers, and has an associated well log signature that most geoscientists can readily define and map as well (Fig. 4).

## PREVIOUS WORK

### North Texas

Hill (1887a) referred to the sandstone-prone strata at the base of his "Gulfian Series" (1987b) the Timber Creek Group, a name subsequently changed to Woodbine (Hill, 1901), when the type locality for this unit was defined near the town of Woodbine in in eastern Cooke County, Texas approximately 60 mi north of Dallas, Texas (Fig. 1). Adkins (1932) divided the Woodbine into a basal (mudstone-prone) Pepper Formation, a middle (sandstone-prone) Dexter Formation, and upper (lignite- and fossil-bearing) Lewisville Formation (Fig. 3). He reported Woodbine thickness of 300 to 500 ft in the outcrops and shallow subsurface Dallas area.

The term Eagle Ford also came from the Dallas area where Hill (1887a) used this nomenclature to define the mudstone-prone strata situated between Timber Creek (Woodbine) and Austin. The type locality outcrops in, what was then, the town of Eagle Ford located on the south bank of the Trinity River in western Dallas County (Fig. 1). In the 1950s, the town of Eagle Ford was incorporated within the limits of the City of Dallas. Adkins (1932) elevated the Eagle Ford to group level, and based on input from W. L. Moremon, defined three formations in the outcrop belt along the northwest flank of the East Texas Basin. From the base up, these formations were the: (1) Tarrent, which was a thin (15–20 ft) fossiliferous unit containing mudstones with sandstone interbeds; (2) Britton, which was mudstone-prone in its lower third and interbedded in its upper two-thirds; and (3) Arcadia Park Formation, which was mudstone-prone (Fig. 3). Adkins (1932) reported Eagle Ford thickness of 350 ft to 450 ft in North Texas. Moremon (1942) provided additional information on the stratigraphy and molluscan biostratigraphy of the three Eagle Ford formations outlined by Adkins (1932). A slight modification of Adkins (1932) and Moremon's (1942) Eagle Ford Group stratigraphy was proposed by Stephenson (1952). Stephenson was able to demonstrate that the Tarrent Formation of North Texas was actually older and stratigraphically lower than the basal strata of the Eagle Ford Group in Bell and McClennen counties to the south, and were faunally identical and stratigraphically equivalent to the Lewisville Formation of the underlying Woodbine Group. Based on these finding, Stephenson (1952) suggested dropping the term Tarrent, and simply including these strata as part of the underlying Woodbine Group (Lewisville Formation). This paper follows Stephenson's (1952) stratigraphic framework for the boundaries between, as well as strata contained within, the Woodbine and Eagle Ford groups in North Texas.

### Central Texas

The classic work on the Woodbine and Eagle Ford groups in Central Texas is Adkins and Lozo (1951). For the Eagle Ford Group, Adkins and Lozo (1951) defined a Cenomanian-age Lake Waco Formation, which they labeled as Lower Eagle Ford on their maps and cross sections, and a Turonian-age South Bosque Formation, which they labeled as the Upper Eagle Ford on their maps and cross sections (Fig. 3). The Lake Waco Formation was described as wavy-bedded limestones interbedded with dark silty shales and bentonites, while the overlying South Bosque Formation was described as dark gray mudstones that contain more abundant thin limestone interbeds in its lower half. At the Cloice Branch section near Waco (Fig. 1), Adkins and Lozo (1951) recorded: (1) 55 ft of Woodbine (Pepper) strata situated between the Eagle Ford and Del Rio, with the Buda being absent along this portion of the outcrop; and (2) 188 ft of the Eagle Ford strata, 68 ft of the Lake Waco Formation and approximately 120 ft of the overlying South Bosque Formation. Clearly both the Woodbine and Eagle Ford in the Waco area are much thinner than around Dallas, and the Woodbine is dominated by the mudstone-prone Pepper facies.

### South Texas

Between Austin in Central Texas and Del Rio in South Texas outcrops of the Austin and underlying Eagle Ford Group are rare and most of our knowledge comes from the subsurface in this area. In this area, the classic work is Grabowski (1995) who was the first to introduce the concept of an organic-rich, Cenomanian-aged, Lower Eagle Ford, and a carbonate-rich, Turonian-aged, Upper Eagle Ford (Fig. 3). This is the stratigraphic framework commonly followed today in the Eagle Ford unconventional source rock play in South Texas (Hentz and Ruppel, 2010). Interestingly, in the subsurface of South Texas, the lithostratigraphic Woodbine Group is absent and strata mapped as the Eagle Ford Group sits directly on the Buda (Fig. 4).

### West Texas

The Devils River, which enters the Rio Grande just northwest of Del Rio, marks the classic geographic and geological boundary between South and West Texas (Fig. 1). West of the Devils River in West Texas, the strata situated between the Buda Formation and Austin Group have been referred to as Boquillas (Udden, 1907; Freeman, 1961, 1968), as well as Eagle Ford (Adkins, 1932; Hazzard, 1959). In this paper we will simply refer to these strata as the Eagle Ford Group. In the Lozier Canyon region in Terrell County (Fig. 1), Hazzard (1959) outlined a three-fold division for the Eagle Ford: (1) a lower shaly member, (2) middle interbedded calcareous mudstones and limestone member; and (3) an upper shaly member. Freeman (1961, 1968) outlined a four-fold division for these strata which from the base he named: (1) pinch and swell, (2) flagstone, (3) ledgy, and (4) laminated. Freeman's upper two members were equivalent to Hazzard's middle and upper members, while his lower two units represented a simple subdivision of Hazzard's lower shaly member (Fig. 5). In order to more quickly convey the vertical facies succession identified by these and other workers Donovan and Staerker (2010) introduced a simple A to E designation for units from the base up. Their lower three units (A–C) were identical to Freeman's lower three, while their upper two units were simply a division of Freeman's uppermost (laminated) member into a lower mudstone-prone unit (D), and an upper very-thinly interbedded unit (E). With the collection of spectral gamma ray and geochemical data for a type section in Lozier Canyon, Donovan et al. (2012) were able to port the traditional subsurface stratigraphy of South Texas into the outcrops of West Texas, and defined a Lower Eagle Ford Formation, consisting of units A and B, and Upper Eagle Ford Formation consisting of units C, D, and E. Donovan et al. (2012) also subdivided the basic five-fold (A–E) facies succession within the Eagle Ford Group of West Texas into a more detailed vertical succession of 16 subunits, which they named: A1/A2/A3/A4; B1/B2/B3/B4/B5; C1/C2/C3; D1/D2; and E1/E2. These 16 sub-units were then used to define four genetically-related depositional sequences (allostratigraphic members or allomembers), two within the Lower Eagle Ford Formation and two within the Upper Eagle Ford Formation. From the base up, Donovan et al. (2013) named these units the K63 (Lozier Canyon) member, the K64 (Antonio Creek) member, the K65 (Scott Ranch) member, and the K70 (Langtry) member. Each of these depositional sequences has distinct petrophysical and geochemical characteristics, as well as chronostratigraphic properties, that make them particularly useful for regional correlations. In order to more easily convey superposition and stratigraphic relationships, as well as to gain regional terminology portability, Donovan et al. (2015) introduced the terms Lower and Upper members of the Lower Eagle Ford Formation and Lower and Upper members of the Upper Eagle Ford Formation for these four depositional sequences (allomembers). This updated nomenclature will be used in this paper.

## EAGLE FORD SEQUENCE STRATIGRAPHIC UNITS AND SURFACES

### Lower Member of the Lower Eagle Ford Formation

The Lower (Lozier Canyon) Member of the Lower Eagle Ford Formation in West Texas is an organic-rich (TOC typically >4%), bentonite-poor, mudstone-dominated depositional sequence. It is characterized by a bell-shaped GR profile in its lower portions and funnel-shaped GR profile in its upper portions (Fig. 6A). Geophysical logs from a research borehole illustrates that this member (depositional sequence) is characterized by an overall high resistivity. A thin (2.5 ft) clay-rich low resistivity marker zone denotes its base (Fig. 7).

The K63sb at the base is marked by a change from a (Buda) wackstones with low-GR values, along with low-U and low-TOC content (below), to a mudstone-dominated unit (above) with elevated U and TOC content, and higher GR values. The K64sb at the top is marked by a change from high-resistivity, TOC-rich mudstones with moderate-U content (below) to U- and Th- (bentonite) rich mudstones with more moderate TOC content that exhibit higher GR values and decreasing resistivity values (Fig. 7). An interpreted mfs, labeled the K63mfs, is placed at the maximum GR inflection which also marks the change from a bell-shaped GR profile (below) to an overall funnel-shaped GR profile (above). Transgressive deposits are interpreted below the mfs and highstand deposits above (Fig. 7).

Work by Corbett et al. (2014) on calcareous nanno-flora for this interval were indeterminate; however, Cobban et al. (2008) reported ammonites of the late middle Cenomanian *Acanthoceras amphibolum* Zone from unit A at Lozier Canyon (Figs. 3 and 5). In Big Bend, Cobban et al. (2008) reported similar late middle Cenomanian *Acanthoceras amphibolum* Zone ammonites 17 ft above the base of this member (sequence), as well as older mid-middle Cenomanian *Acanthoceras bellense* Zone fauna from 10 ft to 12 ft above the top of the Buda (Fig. 3). Interestingly, Cobban et al. (2008) reported that the basal 18 in of the Eagle Ford (Boquillas) in the Big Bend area contain ammonites of the early Cenomanian *Acompsoceras inconstans* Zone; however, they also noted that the intervening three overlying early Cenomanian ammonite zones are missing at all the localities they studied in southern New Mexico and West Texas (Fig. 3). These observations suggest that either: (1) the early Cenomanian ammonites in

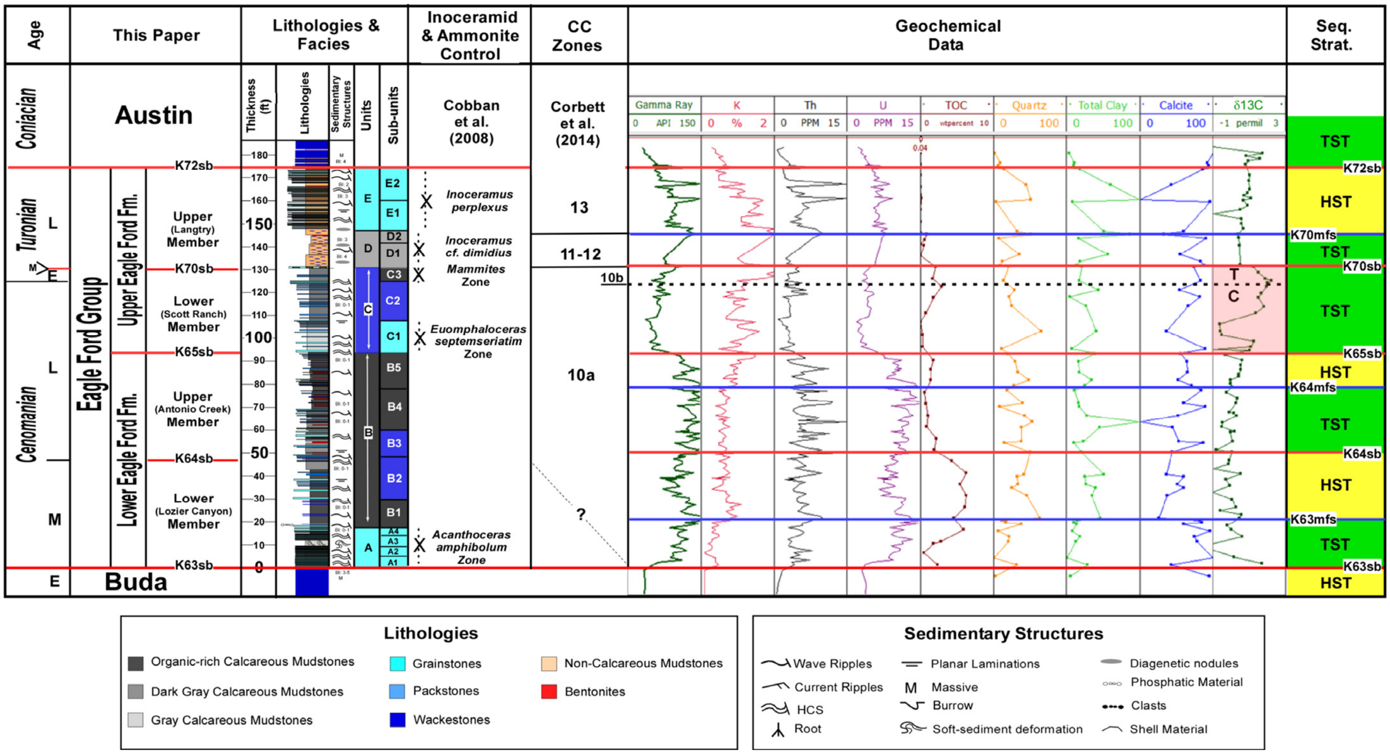


**Figure 5. Summary of the lithostratigraphy, biostratigraphy, and chemostratigraphy data from the Scott Ranch Section in Lozier Canyon. Please note GR and $\delta^{13}$C profile for the section along with molluscan and calcareous nanno-flora age control.**

the basal portions of the Eagle Ford (Boquillas) are reworked; or (2) the basal 18 in of strata overlying the Buda in the Big Bend area are actually age-equivalent to the Woodbine and that the K60sb sits at the base and K63sb sits at the top of this thin unit. These two conclusions differ markedly from the work of Denne et al. (in press), who would include all of unit A of the lower member of the Eagle Ford as an older sequence. Our research suggests that only the basal clay-rich, low-resistivity marker zone at the base of the Lower Member of the Lower Eagle Ford Formation is at play either as a reworked zone or older depositional sequence equivalent to the Woodbine Group. Clearly these biostratigraphic anomalies need to be the focus of future research in West Texas. In summary, based on present micro-flora and the Lower (Lozier Canyon) Member of the Lower Eagle Ford Formation is interpreted to be late middle Cenomanian in age.

## Upper Member of the Lower Eagle Ford Formation

The Upper (Antonio Creek) Member of the Lower Eagle Ford Formation in West Texas is a U-, Th-, and bentonite-rich, high-GR, mudstone-dominated depositional sequence with moderate (1–2%) TOC content (Figs. 6B and 7). The distinctive high-GR signature of this sequence is clearly driven by its high U and bentonite (Th) content. The high abundance of bentonite beds is the most distinctive aspect of this depositional sequence in outcrop and core, and their unique abundance provides a distinct chronostratigraphic aspect to this unit (Fig. 7). Geophysical logs from a research borehole also illustrate that this member is also characterized by an overall resistivity decrease, at least across the basal portions of this sequence, as well as more subtle changes on the neutron, density, and sonic logs (Fig. 7).

The K64sb at the base of this depositional sequence (allomember) is marked by a change from TOC-rich, high-resistivity mudstones with an overall funnel-shaped GR profile (below), to U- and Th- (bentonite) rich mudstones with high GR values and decreasing resistivity values from the base up (Fig. 7). The K65sb at its top is marked by a change from U- and Th- (bentonite) rich, high-GR mudstones below to U- and TOC-poor, low-GR, thickly-interbedded, bioturbated packstones and mudstones (above). An interpreted mfs, labeled the K64mfs (Fig. 7), is placed at the maximum GR inflection that also marks the change from a bell-shaped GR profile (below) to an overall funnel-shaped (decreasing) GR profile (above). Transgressive deposits are interpreted below the mfs and highstand deposits above (Fig. 7). Superposition, as well as work by Corbett et al. (2014) on calcareous microflora, suggests a late Cenomanian age for this sequence (Fig. 3). Presently, there is no molluscan age control for this sequence from Lozier Canyon.

## Lower Member of the Upper Eagle Ford Formation

The Lower (Scott Ranch) Member of the Upper Eagle Ford Formation in West Texas is a uranium-poor (low-GR) depositional sequence made up of thickly inter-bedded bioturbated white packstones and gray mudstones (Figs. 6C). Besides its overall blocky GR profile, one of the most diagnostic aspects of this member is the presence of a positive $\delta^{13}$C isotope excursion, the peak of which is the interpreted proxy for the C–T stage boundary, in the basal (30 ft +/-) of this depositional sequence (Fig. 7). A distinctive thin (10 ft +/-) clay-rich, low-TOC, low-resistivity zone, also marks the base of this sequence on geophysical logs (Fig. 7). The K70sb at its top is marked by a change from thickly- interbedded packstones and carbonate mudstones below to bioturbated mudstones above. A slight increase in U and Th content, as well as a change to more bell-shaped log GR and resistivity patterns, occurs above this surface. At Lozier Canyon, the positive $\delta^{13}$C isotope excursion is restricted to this member, and the excursion also ends at the K70sb (Fig. 7).

In terms of age control in the Lozier Canyon outcrops, Cobban et al. (2008) report middle late Cenomanian *Euomphaloceras septemseriatum* fauna in unit C1 at the base of this member and Early Turonian *Mammites* fauna from unit C3 at the top of this

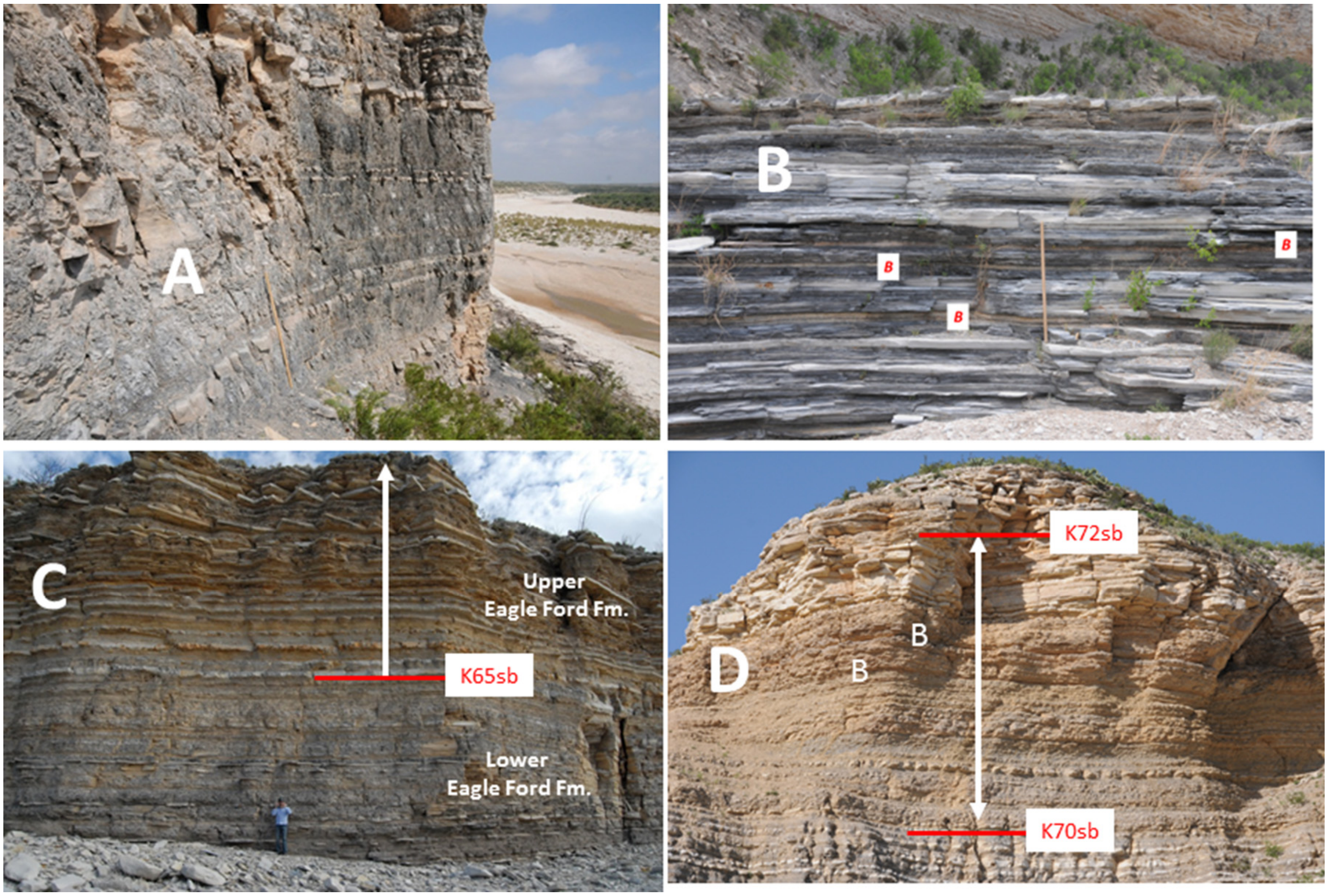


**Figure 6. Lozier Canyon system outcrop images of (A) the organic-rich Lower Member of the Lower Eagle Ford Formation; (B) the bentonite-rich Upper Member of the Lower Eagle Ford Formation; (C) the interbedded, U-poor, Lower Member of the Upper Eagle Ford Formation; and (D) the mudstone-prone, bentonite-bearing Upper Member of the Upper Eagle Ford Formation. B indicates bentonite bed.**

member. Corbett et al. also identified latest Cenomanian calcareous micro-flora from sub-units C1 and C2 and earliest Turonian micro-flora from sub-unit C3 (Fig. 5). This is consistent with the associated positive $\delta^{13}C$ isotope excursion profile in this member representing the OAE2, and the maximum positive excursion of this profile being the geochemical proxy for the base of the Turonian ) (Ogg and Hinnov, 2012).

## Upper Member of the Upper Eagle Ford Formation

The Upper (Langtry) Member of the Upper Eagle Ford Formation is a bentonite-bearing depositional sequence that in West Texas consists of bioturbated mudstones in its lower half and thinly-bedded mudstones and grainstones in its upper half (Fig. 6D). Not surprisingly its GR profile is bell shaped in its lower half and funnel shaped in its upper half (Fig. 7). The interpreted K70 mfs occurs within a clay-rich, low-resistivity, and low-velocity marker zone within this depositional sequence. The micro-flora CC12/13 boundary also occurs at or near the K70mfs. Cobban et al. (2008) report *Inoceramus* cf. *dimidius* in the lower half of this depositional sequence and *Inoceramus perplexus* fauna in the upper half. This is consistent with the micro-flora findings of Corbett et al. (2014) making the interpreted transgressive deposits of this depositional sequence early late Turonian in age and the highstand latest Turonian in age.

In terms of bounding surfaces (Donovan et al., 2013, in press) reported rip-up clast lags of underlying strata above the K70sb at the base of and the K72sb at its top. The K70sb at the base is also marked by a change from thickly-interbedded packstones and carbonate mudstones below to bioturbated mudstones above. A slight increase in U and Th content, as well as a change to more bell-shaped GR and resistivity log patterns, occurs above this surface. The K72sb at the top, which also marks the contact with the overlying Austin Group, is marked by a distinct drop in U and Th content and change to an overall blocky GR and resistivity pattern above the K72sb.

## WEST TEXAS TO SOUTH TEXAS SEQUENCE STRATIGRAPHY

A type well for the Eagle Ford Group in South Texas (Webb County) is presented as Figure 4. Based on the petrophysical and geochemical data provided for this well, the same basic allomembers defined in the outcrops in West Texas can also be readily defined in this well (Fig. 4). A quick look at the sonic and TOC columns on this well plot highlights the TOC-rich Lower Eagle Ford Formation and the carbonate-rich Upper Eagle Ford Formation. Distinct low-resistivity marker zones denote the base of both formations as well (Fig. 4). High-GR (U-enriched) zones at the top of both formations define their upper members. Furthermore, the CC12/13 microflora boundary occurs at or near the interpreted mfs within the Upper Member of the Upper Eagle Ford Formation. In the Lower Eagle Ford Formation, organic-rich, high resistivity carbonate mudstones define the Lower Member of the Lower Eagle Ford Formation, while in the Upper Eagle Ford Formation, an overall blocky (low) GR interval, relat-

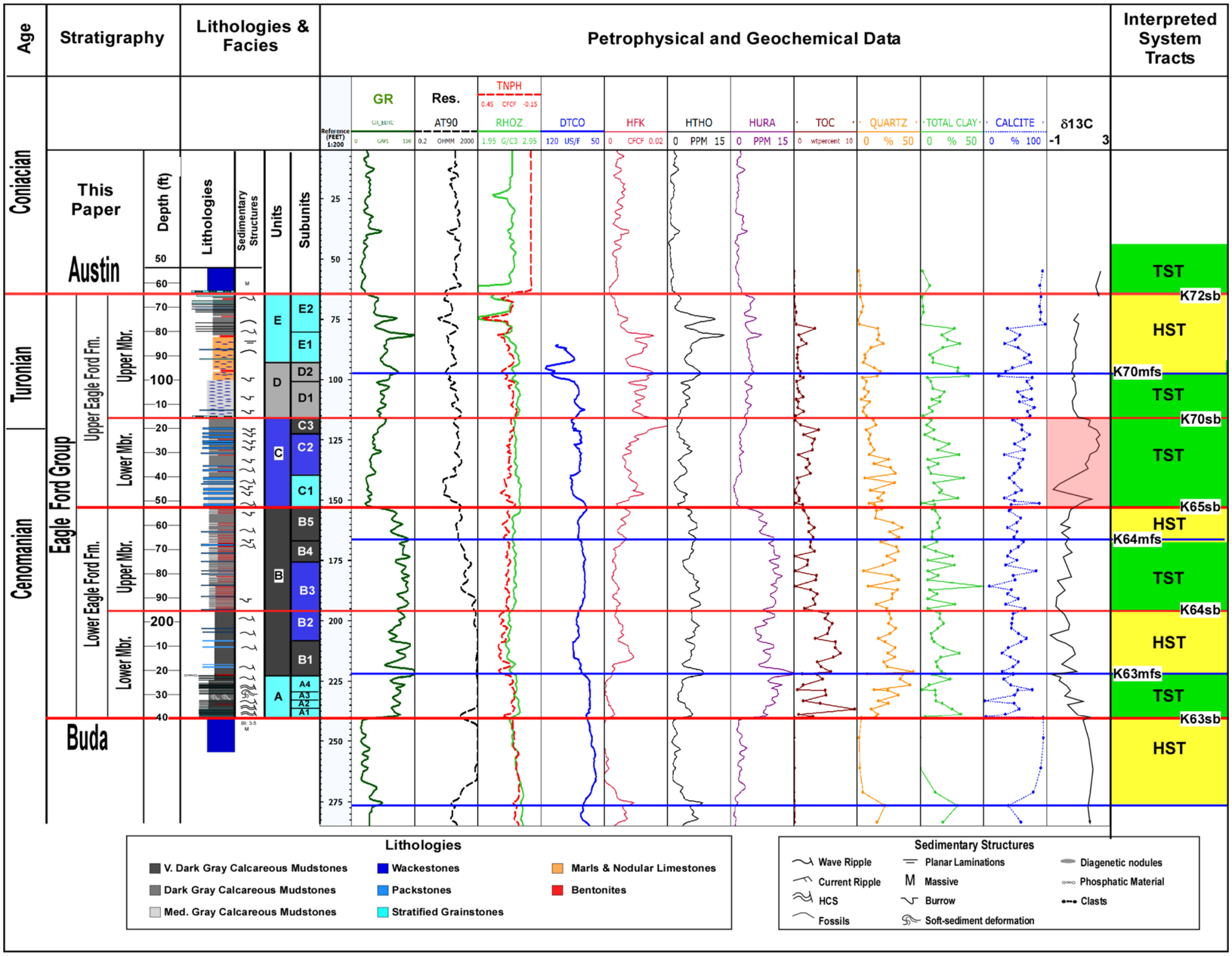


**Figure 7. Summary of the lithologic, petrophysical, and geochemical data, as well as the sequence stratigraphic units and surfaces identified in the BP/SLB Lozier Canyon #1 test well. Well location on Figure 1.**

ed to low U content, marks the Lower Member of the Upper Eagle Ford (Fig. 4). The basal portion of the Lower Member of the Upper Eagle Ford is also marked by the presence of the distinct positive $\delta^{13}C$ isotope excursion, the peak of which is the interpreted proxy for the base of the Turonian (Fig. 4).

Figure 8 is a well-log cross section datumed on the base of the Upper Eagle Ford Formation. Well 2 is the research borehole in Terrell County in West Texas, while Well 1 is the type well in South Texas (Webb County). The locations of the two wells are noted on Figure 1. The sequence boundaries (red lines) and maximum flooding surfaces (blue lines) in all four sequences are correlated between these two wells (Fig. 8). In each depositional sequence, strata between the basal sequence boundary and mfs represent the transgressive deposits, while the strata between the mfs and overlying sequence boundary represent highstand deposits. Between these two wells, the thickness of the Upper Member of the Lower Eagle Ford (colored light gray), as well as the Upper Member of the Upper Eagle Ford (colored light purple), are similar in both wells (Fig. 8). In contrast, the Lower Member of the Lower Eagle Ford (dark gray), as well as the Lower Member of the Upper Eagle Ford (light blue), are both thicker in the South Texas well. For both sequences, it is the thickness of the preserved highstand strata that varies, producing more conformable successions downdip to the southeast and less conformable sections updip to the northwest. Key sequence boundaries to note are the K64sb that separates the Lower and Upper members of the Lower Eagle Ford Formation, and the K70sb that separates the Lower and Upper members of the Upper Eagle Ford Formation.

## SOUTH TEXAS TO CENTRAL TEXAS SEQUENCE STRATIGRAPHY

Figure 9 is a southwest to northeast well-log cross section that traverses the South Texas Submarine Plateau, crosses the downdip extent of the San Marcos Arch, and extends into the southwest corner of the East Texas Basin. The location of this cross section is noted on Figure 1. Well B1 is the same South Texas type well found on Figures 4 and 8. On this cross section, the base of the Upper Eagle Ford Formation was used as the datum for wells B1 through B4, whereas for wells B4 through B5 the K63mfs within the Lower Member of the Lower Eagle Ford Formation is used as the datum.

At least three distinct regional stratigraphic relationships occur across this transect. First, there is a reciprocal thickness relationship between the lower and upper members of the Lower Eagle Ford Formation (Fig. 9). Toward the northeast, the low-GR, high-resistivity, lower member thins, while the higher-GR,

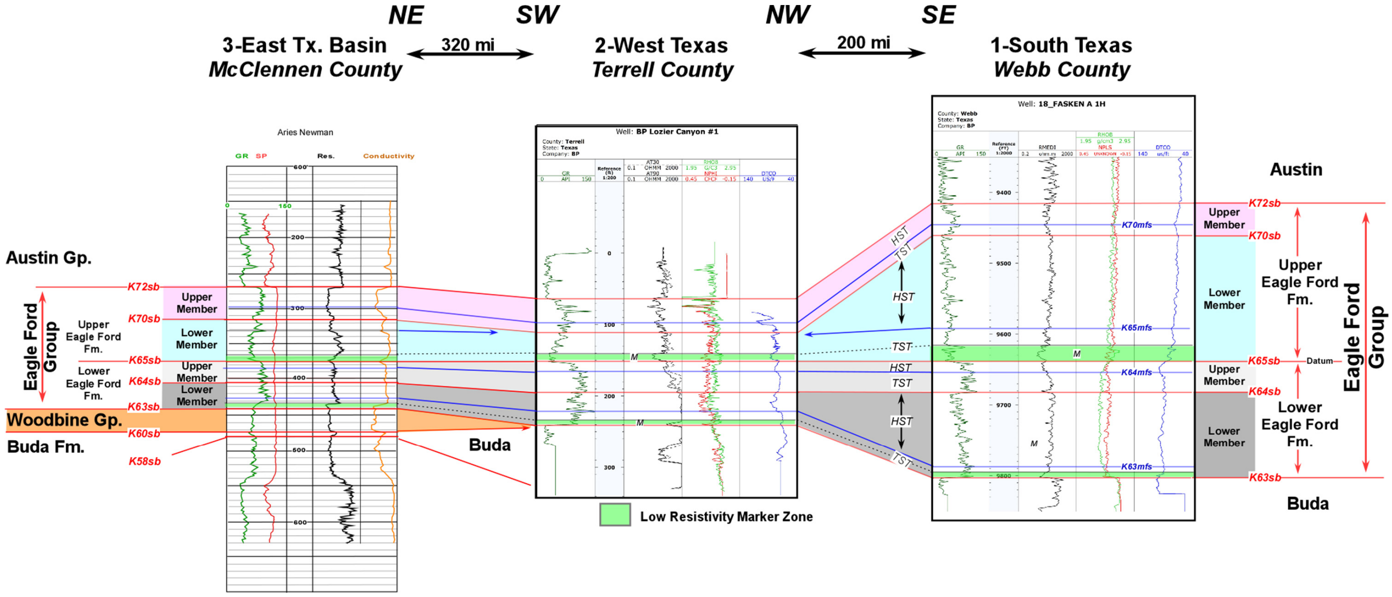


**Figure 8. Type well-log cross section of the sequence surfaces and units correlated from West Texas, to South Texas, and into East Texas Basin. Location of wells on Figure 1.**

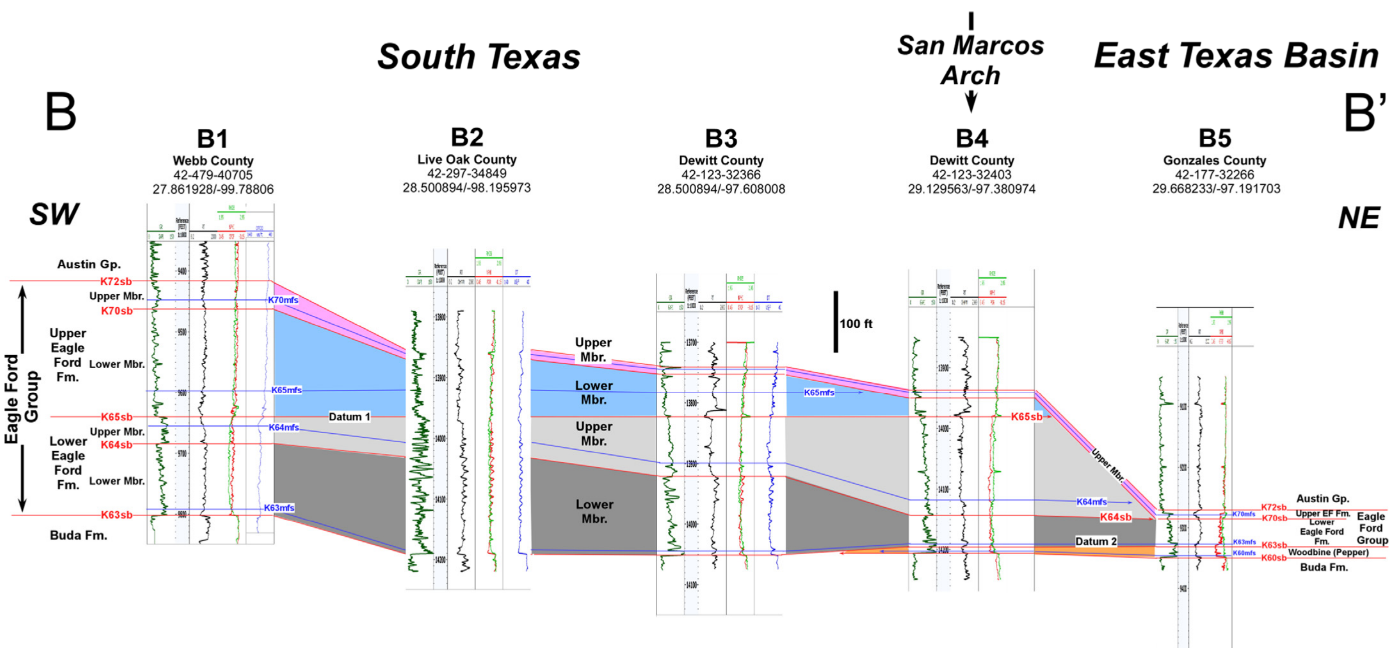


**Figure 9. Well-log cross section illustrating distribution and thickness variations of the depositional sequences units correlated from South Texas to the southwest corner of the East Texas Basin. Location of well-log cross section on Figure 1.**

lower-resistivity, upper member thickens, likely due to an offlapping relationship for the younger sequence. The recognition of this relationship is critical because the organic-rich Lower Member of the Lower Eagle Ford Formation is the primary unconventional source rock reservoir interval within the Eagle Ford Group. The second regional stratigraphic relationship of note is that from the southwest to the northeast the K70sb at the base of the Upper Member of the Upper Eagle Ford sequentially truncates the Lower Member of the Upper Eagle Ford Formation, and once this interval is eroded, begins to truncate into the Lower Eagle Ford Formation (Fig. 9). This truncation has the effect that in well B5 only about 50 ft of Eagle Ford strata remain beneath the K70sb and these remaining strata are the basal portions of the Lower Member of the Lower Eagle Ford Formation. Thus in well B5, the Lower Member of the Upper Eagle Ford Formation, as well as the Upper Member of the Lower Eagle Ford Formation are absent due to erosional truncation by the K70sb located at the base of the Upper Member of the Upper Eagle Ford Formation (Fig. 9). Thus the K70sb appears to have major component of tectonic enhancement. The third and final stratigraphic feature of note is the presence of a distinct additional low- resistivity stratigraphic interval in wells B4 and B5 positioned between the K63sb at the base of the Eagle Ford and the top of the Buda (Fig. 9). This low resistivity zone, which also has more moderate GR values then the overlying basal Eagle Ford, is interpreted as the Pepper Member of the Woodbine Group. In these two wells, the K60sb and the overlying K60mfs are also carried (Fig. 9). This stratigraphic interval appears to be truncated toward the southwest by the overlying K63sb at the base of the Eagle Ford Group.

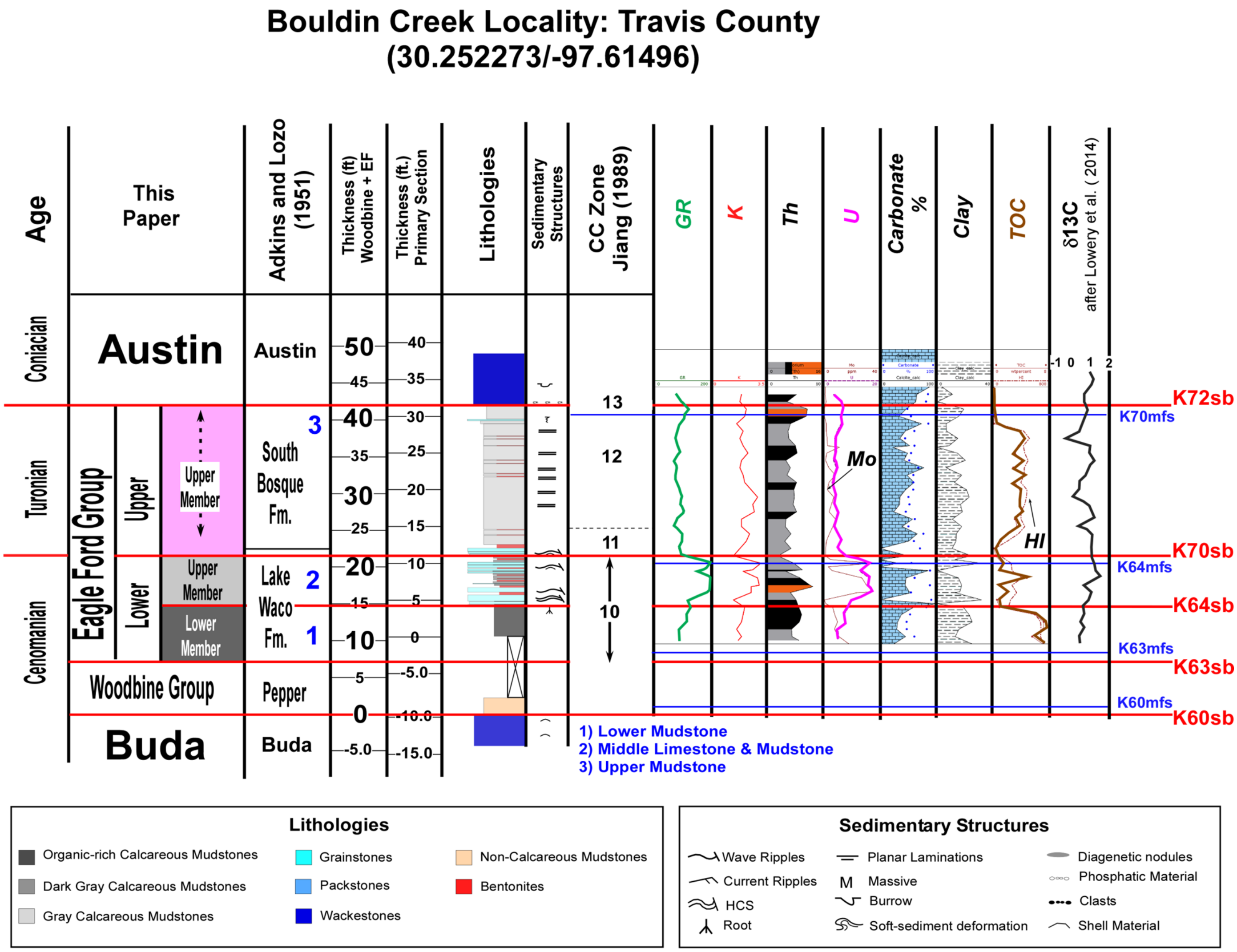


**Figure 10. Summary of the lithologic, petrophysical, and geochemical data, as well as the sequence stratigraphic units and surfaces identified at Bouldin Creek (Travis County).**

## CENTRAL TEXAS (AUSTIN AREA) SEQUENCE STRATIGRAPHY

In order to evaluate the validity of the regional Eagle Ford sequence stratigraphic correlations interpreted from South Texas toward the San Marcos Arch (Fig. 9), research was conducted at Bouldin Creek, a famous Eagle Ford outcrop locality located in Travis County (South Austin) about 50 mi to the northwest of well B5 in Gonzales County (Fig. 1). The basic lithologic, petrophysical, and geochemical data for this locality, along with the classic and updated stratigraphy, are presented as Figure 10. A more detailed base map that illustrates the location of Bouldin Creek along with the location of well B5 in Gonzales County, as well as well C1 in Travis County, can be found on Figure 11. Representative photographs for each of the sequences identified at Bouldin Creek are presented as Figure 12.

Feray (1949) was the first to publish a composite measured section for Bouldin Creek. It was based on two localities about a mile apart that had overlapping stratigraphy. In his composite section, Ferry (1949) recorded 3.4 ft of non-calcareous mudstones, which he interpreted as the Woodbine (Pepper), overlain by 40.5 ft of calcareous mudstones and limestones, which he interpreted as the Eagle Ford. Adkins and Lozo (1951) divided the Eagle Ford succession at Bouldin Creek into three units: (1) a basal (organic-rich) mudstone, (2) middle interbedded zone of limestones, calcareous mudstones, and bentonites, and (3) upper gray mudstone (Fig. 10). Adkins and Lozo (1951) included the lower two units into their Lake Waco Formation (Lower Eagle Ford), and the upper unit into their South Bosque Formation (Upper Eagle Ford).

As illustrated on Figure 10, along the present creek bed, 2 ft of weathered light gray non-calcareous mudstones sit directly overlying the Buda. Following Ferry (1949), these strata are interpreted as the Pepper Formation of the Woodbine Group. At a second locality about one half mile up the drainage a continuous section with 32 ft of Eagle Ford and 7 ft of Austin strata was measured (Fig. 10). Based on Ferry's (1949) original recorded section an approximate 8 ft stratigraphic interval between two outcrops localities is now covered. At the base of the continuous section 4 ft of black mudstones were observed (Fig. 12a). Geochemically, these strata are organic-rich and uranium-poor with a moderate GR signature (Figs. 10). Because these strata are similar in lithologic and geochemical character to sub-unit B1 in Lozier Canyon (Fig. 7) they are assigned to the Lower Member of the Lower Eagle Ford Formation (Fig. 10). Abruptly juxtaposed above the basal organic-rich black mudstones is a 7-ft-thick interval consisting of fossiliferous grainstones interbedded with gray mudstones and abundant bentonite beds (Fig. 12b). Geochemically this interbedded interval is U rich (high GR) and in generally TOC poor. The most diagnostic aspect of this interval, howev-

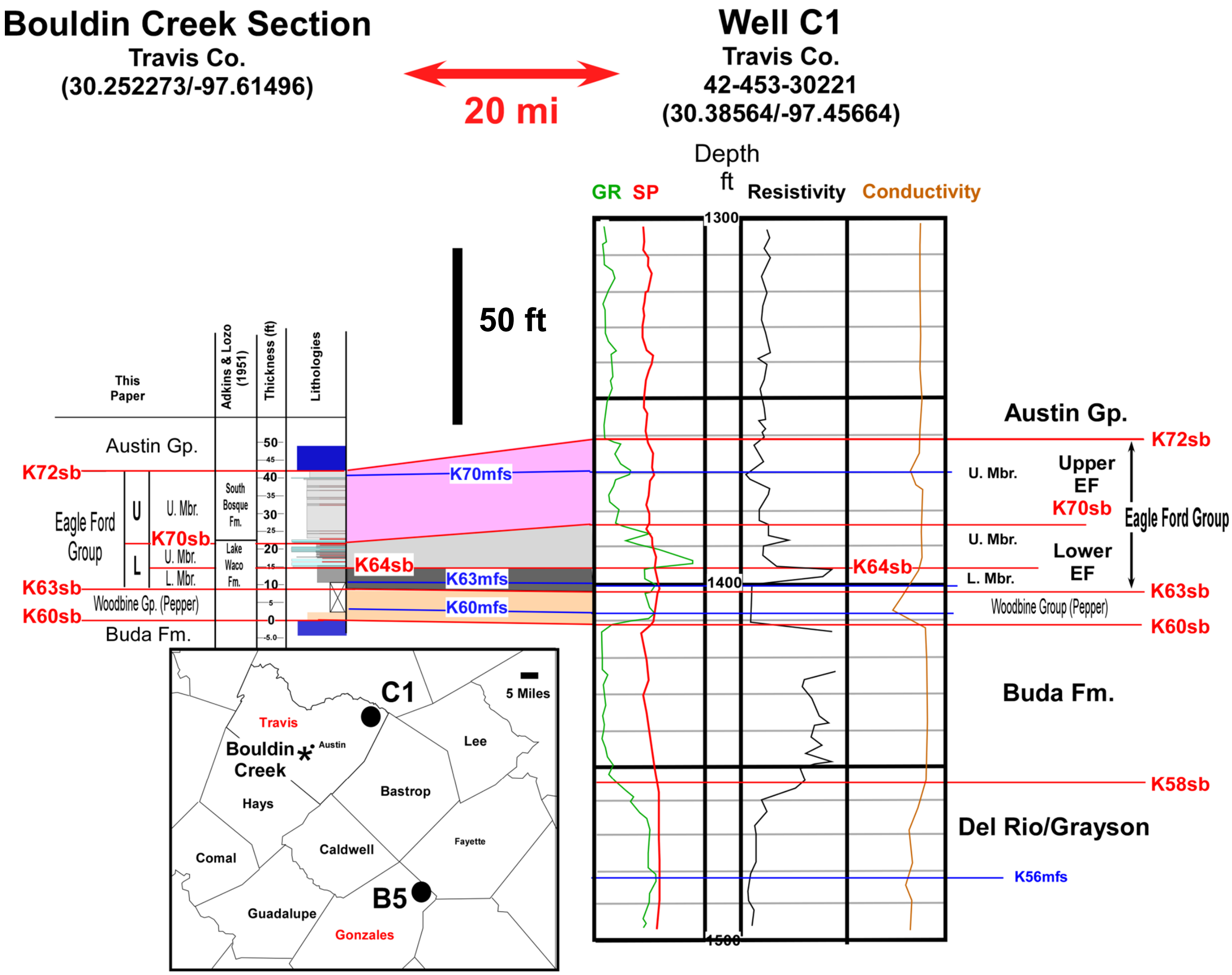


**Figure 11. Outcrop to subsurface tie of the sequence stratigraphic surfaces and units from Bouldin Creek to Well C1 in Travis County, Texas.**

er, is the bentonite abundance. Because these strata are similar in lithologic and geochemical character, as well as bentonite abundance, to sub-unit B3 in Lozier Canyon (Fig. 7), this 7-ft-thick interval in Bouldin Creek is assigned to the Upper Member of the Lower Eagle Ford Formation (Fig. 10). The boundary between these two units marked by the change from TOC-rich and U-poor strata below to TOC-poor and U-rich strata above is interpreted as the K64sb (Fig. 10). This is the identical signature to this boundary in Lozier Canyon in West Texas (Fig. 7), as well as the type well in South Texas (Fig. 4). Above this middle stratigraphic zone in Bouldin Creek, a 21-ft-thick, U-poor interval consisting of gray mudstones, scattered bentonite beds, and interbedded limestones in the basal 1.5 ft (Figs. 10 and 12C). Work by Jiang (1989), as well as our own biostratigraphic analysis, revealed that the bottom of this unit also corresponds to the base of the Turonian. Furthermore, an interpreted condensed interval near the top marks the CC12/13 calcareous micro-flora boundary (Fig. 10). Based on lithologic character, age, and stratigraphic position these strata are correlated to sub-units D1 and D2 in Lozier Canyon (Fig. 7) and this 21-ft-thick interval in Bouldin Creek assigned to the Upper Member of the Upper Eagle Ford Formation (Fig. 10). The K70sb is placed at the base of this interval, while the K72sb is placed at the top. This upper boundary also corresponds to the contact between the Eagle Ford and Austin groups (Fig. 10). Similar to the interpreted well-log correlation into Gonzales County (Fig. 9), strata age-equivalent to Lower Member of the Upper Eagle Ford Formation appear to be absent at Bouldin Creek in Travis County approximately 50 mi to the northwest (Fig. 1). This interpreted sequence stratigraphic hiatus is consistent with the work of Jiang (1989, p. 143) who reported that the upper part of the *Microrhabdulus decorates* Zone (Zone 10) of the latest Cenomanian, as well as the lowermost portions of the overlying *Quadrum gartneri* (Zone 11), is likely missing at Bouldin Creek. Our sequence stratigraphic correlations, as well as Jinag's (1989) biostratigraphic work, would also explain why the distinctive positive isotope $\delta^{13}C$ (OAE2) excursion that bounds the C–T boundary, as well as marks the base of the Lower Member of the Upper Eagle Ford, is not present at this locality (Fig. 10). In terms of comparison with previous work, the Lower Eagle Ford Formation of this study essentially correlates to the Lake Waco Formation (Adkins and Lozo, 1951), while the Upper Eagle Ford Formation essentially correlates to the South Bosque Formation (Fig. 10). The only difference with Adkins and Lozo's (1951) formation stratigraphy is that we include the 1.5 ft of Turonian-age, low-U, low-GR strata at the top of their Lake Waco Formation at Bouldin Creek within the Upper Eagle Ford Formation (Ogg and Hinnov, 2012).

Presently the geographically closest shallow subsurface well to Bouldin Creek with a more complete suite of modern geophysical logs (GR/resistivity) is the one labelled C1 on Figure 11.


**Figure 12. Bouldin Creek outcrop images of (A) Black organic-rich mudstones of the Lower Member of the Lower Eagle Ford Formation; (B) bentonite and uranium-rich mudstones of Upper Member of the Lower Eagle Ford Formation; and (C) gray massive mudstones of the Upper Member of the Upper Eagle Ford Formation.**

This well is located approximately 20 mi to the northeast of Bouldin Creek. In this well, an approximate 50-ft-thick interval is present between the very distinctive top of Buda and base of Austin on the logs (Fig. 11). This thickness is very similar to the 44-ft-thick interval recorded by Feray (1949) between the Buda and Austin at Bouldin Creek. In this well four basic zones between the Buda and Austin are defined and directly correlated to the four depositional sequences defined in the Bouldin Creek section (Fig. 11). The 10-ft-thick, low-resistivity zone at the base is correlated to the Pepper Member of the Woodbine Group. It is bounded by the K60sb at its base and K63sb at its top. Geophysically, this interval is very similar in log signature to stratigraphic interval identified between the Buda and Eagle Ford Group in wells B4 and B5 on cross-section B–B' (Fig. 9). These strata were also provisionally assigned to the Pepper Formation (Woodbine Group). In Well C1, the 5-ft-thick, high-resistivity interval, as well as the 2-ft-thick, higher-GR, low-resistivity interval beneath it, is correlated to the organic-rich, Lower Member of the Lower Eagle Ford in Bouldin Creek (Fig. 11). The K63sb is placed at the base of this depositional sequence and the K64sb at its top. Because the high-resistivity character is a diagnostic feature of this member (depositional sequence) in the outcrops of West Texas (Fig. 7), as well as the subsurface of South Texas (Fig. 4), this criterion was also used in this well. The third zone up from the base, which has an irregular GR and resistivity signature, is correlated to the bentonite-rich Upper Member of the Lower Eagle Ford Formation. The uppermost 21-ft-thick interval, which has a low-GR and low-resistivity signature, is correlated to the Upper Member of the Upper Eagle Ford at Bouldin Creek (Fig. 11). The distinct lower-GR, lowest-resistivity marker in this interval is taken as the K70mfs (Fig. 11).

## CENTRAL TEXAS (WACO AREA) SEQUENCE STRATIGRAPHY

The classic work on the stratigraphy of the Woodbine and Eagle Ford groups in the Waco area was conducted by Adkins and Lozo (1951). In the Waco area they divided the Eagle Ford Group into a Cenomanian-age Lake Waco Formation, which consisted of wavy-bedded limestones interbedded with dark silty shales and bentonites; and a Turonian-age South Bosque Formation, which consisted of dark gray mudstones that contained more abundant thin limestone interbeds in its lower half. A key locality in their work was a composite section recorded near and along the Cloice Branch, a creek flowing into Lake Waco located southwest of the City of Waco (Figs. 1 and 13). A rendering of

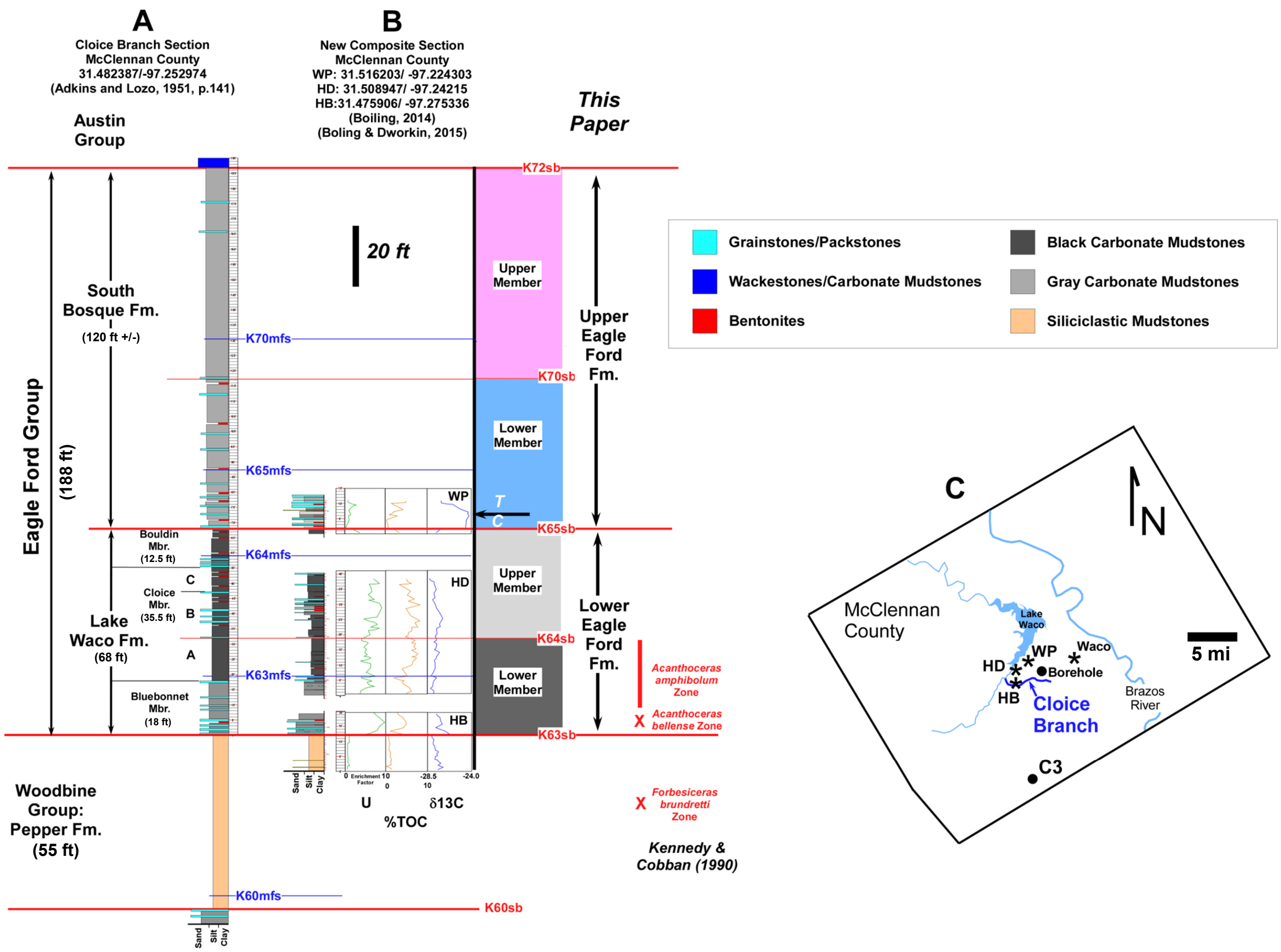


**Figure 13. (A) The Cloice Branch Section described and illustrated by Adkins and Lozo (1951). (B) Correlation of lithologies and geochemical data from sections HB, HD, and WP (Boling, 2014) with the classic Cloice Branch section near Waco. (C) Location map illustrating the key outcrop and subsurface well (C3) in McClennan County, Texas.**

their measured section is provided on Figure 13. At the Cloice Branch locality they recorded: (1) 55 ft of non-calcareous Woodbine (Pepper) strata situated between the Eagle Ford and Del Rio, with the Buda being absent along this portion of the outcrop; and (2) 188 ft of the Eagle Ford strata, 68 ft of the Lake Waco Formation, and approximately 120 ft of the overlying South Bosque Formation (Fig. 13). Within the Lake Waco Formation (Fig. 13), they defined three members: (1) a basal Bluebonnet Member (18 ft), (2) a middle Cloice Member (35.5 ft), and (3) an upper Bouldin Member (13.5 ft). Of these three members the basal Bluebonnet and upper Bouldin members were more limestone-prone, while the middle Cloice Member was more mudstone-prone.

Within the Cloice Member (Fig. 13), Adkins and Lozo (1951) defined three zones: (1) a lower, bentonite-poor mudstone (11 ft), (2) a middle, bentonite-rich, and limestone-rich mudstone (15 ft), and (3) a upper bentonite-rich mudstone (9 ft). Within the South Bosque Formation at Cloice Branch, Adkins and Lozo (1951) outlined that the basal 50 ft contained thin limestone interbeds, while the upper 70 ft was more mudstone prone (Fig. 13). Unfortunately, the original Cloice Branch locality described by Adkins and Lozo (1951) no longer exists, because the drainage was subsequently used by the City of Waco for its municipal landfill. Boling (2014), as well as Boiling and Dworkin (2015), however, were able to recreate much of Adkins and Lozo's Cloice Branch composite section, especially the Lake Waco and basal South Bosque portions, with a series of nearby localities (Fig. 13). Based on the 68-ft-thick Lake Waco section measured by Adkins and Lozo (1951) it appears that Boling's (2014) HB, HD, and WP sections cover most of the Pepper, Lake Waco, and basal South Bosque (Fig. 13). Figure 13 illustrates Boling's (2014) relevant measured sections, their stratigraphic correlation to Adkins and Lozo's (1951) composite Cloice Bank section, as well as U, TOC, and $\delta^{13}C$ data from his study. Boling's HB section captures the upper portions of the Pepper Shale and lower half of the Bluebonnet Member of the Lake Waco Formation. His HD section captured the upper half of the Bluebonnet Member of the Lake Waco Formation, as well as the lower and middle zones of the Cloice Member of the Lake Waco Formation (Fig. 13). Finally, section WP captures the top of the Lake Waco Formation (Cloice Member) and the basal portions of the South Bosque Formation (Fig. 13). Representative photographs of these localities are presented as Figure 14.

The work by Boling (2014), as well as Boling and Dworkin (2015), is significant at many levels. Let us work from the base up. First, the non-calcareous Pepper Formation is geochemically fingerprinted as a low-GR, organic-poor mudstone (Fig. 13). Furthermore, based on ammonites collected by Adkins and Lozo (1951), Kennedy and Cobban (1990) were able to assign the Pepper to the latest early Cenomanian *Forbesiceras brundretti* Zone




**Figure 14. Eagle Ford exposures in the Waco area studied by Boling (2014). (A) Locality HB where the uppermost portions of the Woodbine and basal portions of the Eagle Ford can be examined. (B) Locality WPDS, which is a duplicate of HD, where a large part of the Lower Eagle Ford can be studied. Arrow at K64sb, marks the boundary between the organic-rich Lower Member of the Lower Eagle Ford Formation (below) and the bentonite-rich (red B) Upper Member of the Lower Eagle Ford Formation (above).**

(Fig. 2). Thus the Pepper Formation is older than the Middle Cenomanian Lower Member of the Lower Eagle Ford Formation of West Texas (Fig. 3) reported by Cobban et al. (2008).

The Bluebonnet Member of the Lake Waco Formation, as well as bentonite-poor mudstones in the basal 11 ft of the Cloice Member of the Lake Waco Formation, are organic-rich, especially the bentonite-poor strata in the basal Cloice (Fig. 13). Because this basal 29-ft-thick, organic-rich interval of the Lake Waco Formation is very similar to lithologic and geochemical character to the organic-rich A1 to B2 sub-zones in Lozier Canyon (Fig. 7), this portion of the Lake Waco Formation is assigned to the Lower Member of the Lower Eagle Ford Formation (Fig. 13). The K63sb placed at its base of this unit and K64sb places at its top (Fig. 13). Strong support for this correlation and age assignment comes from the biostratigraphic work of Kennedy and Cobban (1990), which was based on the ammonite collections of Adkins and Lozo (1951) at the Cloice Branch section. Kennedy and Cobban (1990) reported that the lowermost portions of the Bluebonnet Member of the Lake Waco Formation at Bouldin Creek contain ammonites of the mid middle Cenomanian *Acanthoceras bellense* Zone, while upper portions of the Bluebonnet Member, as well as the lower portions of the overlying Cloice Member at Bouldin Creek contain ammonites of the late middle Cenomanian *Acanthoceras amphibolum* Zone. These are the same ammonite zones reported by Cobban et al. (2008) in the interpreted Lower Member of the Lower Eagle Ford Formation in Lozier Canyon and Big Bend (Fig. 3).

In terms of chronostratigraphic significance and depositional sequence character for the Eagle Ford Group few things are as diagnostic as the bentonite-rich Upper Member of the Lower Eagle Ford Formation. The bentonite-rich, upper 39 ft of the Lake Waco Formation are assigned to this unit. As illustrated on Figure 13, at the interpreted K64sb at the base of this unit, Boling and Dworkin (2015) recorded the onset of a more U-rich interval that also displayed an overall drop in TOC content. This bentonite- and U-rich, as well as more moderate TOC content signature is similar to the characteristics of the Upper Member of the Lower Eagle Ford Formation in Lozier Canyon (Fig. 7). However, what cements the stratigraphic positioning of this interval, as well as the placement of contact of the Lower and Upper Eagle Ford formations is Boling and Dworkin's (2015) section WP (Fig. 13). At section WP, the contact between the Lake Waco and South Bosque formations, as well as the basal 15 ft of the South Bosque Formation can be examined (Fig. 13). The contact between the Lake Waco and South Bosque is marked by a distinct drop in U and TOC content similar to the Lower/Upper Eagle Ford contact in West Texas (Fig. 7) and South Texas (Fig. 4). Most importantly, however, was the identification of the distinctive positive isotope $\delta^{13}C$ (OAE2) excursion that bounds the C–T boundary and marks the base of the Upper Eagle Ford Formation, as well as the Lower Member of the Upper Eagle Ford, in West Texas (Fig. 7) and South Texas (Fig. 4). The efforts of Boling and Dworkin (2015), when combined with the data of Adkins and Lozo (1951), as well as Kennedy and Cobban (1990), clearly document that the Lake Waco Formation of the Eagle Ford Group in the Waco area is stratigraphically, geochemically, and chronostratigraphically, equivalent to the Lower Eagle Ford Formation in South and West Texas. Furthermore, both the organic-rich Lower Member of the Lower Eagle Ford Formation and the bentonite-rich Upper Member of the Lower Eagle Ford Formation are present within the Eagle Ford outcrops along the west flank of the East Texas Basin in the vicinity of Waco.

In order to tie the defined outcrop stratigraphy in the vicinity of Waco to the shallow subsurface a nearby well with a modern

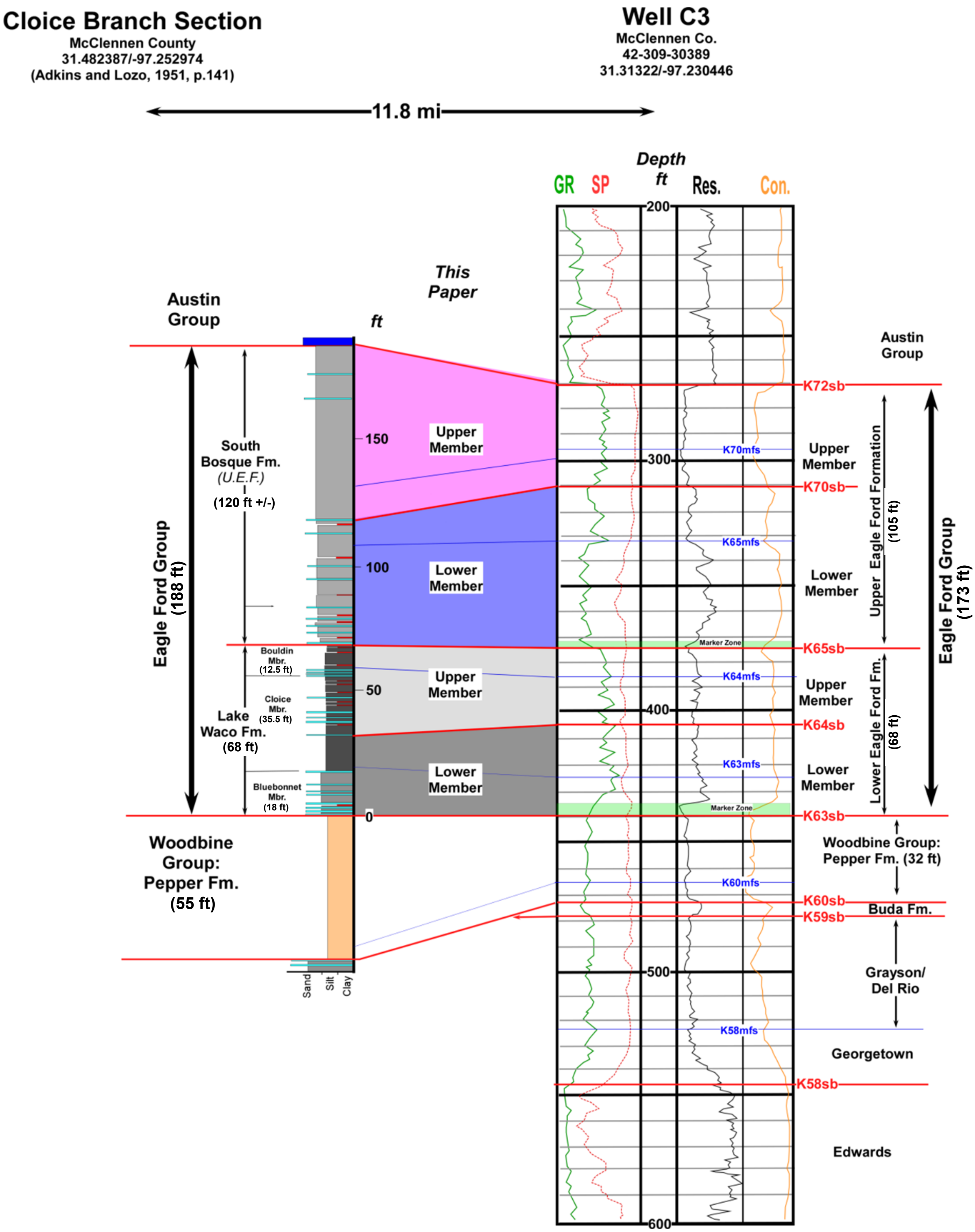


**Figure 15.** Outcrop to subsurface tie of the sequence stratigraphic surfaces and units from the Cloice Branch area near Waco to Well C3 in McClennen County, Texas. Legend for lithologies is shown on Figure 13.

suite of geophysical logs (GR and resistivity) was required. Well C3 located about 12 mi from the Cloice Branch measured section was identified (Fig. 15). In this well a 32-ft-thick interval defined as the Pepper Formation (Woodbine Group) was defined based on moderate-GR and low-resistivity values, and a stratigraphic position between the Buda and Eagle Ford. This compares to a 55-ft-thick, Pepper section defined Adkins and Lozo (1951) in their composite section at Cloice Branch (Fig. 15). A 173-ft-thick, Eagle Ford section was also identified bounded by the K63sb at the base and the K72sb at the top. This is fairly similar to the 185-ft-thick, Eagle Ford section recorded by Adkins and Lozo (1951) at their Cloice Branch composite section (Fig. 15). 68 ft above the base of the Eagle Ford in Well C3, an abrupt GR drop occurs, along with a resistivity low; this boundary is interpreted as the K65sb that marks the base of the Upper Eagle Ford Formation (Fig. 15). This is exactly the same level where the Lower/Upper Eagle Ford contact occurs in the Cloice Branch section (Fig. 15). The basal 35 ft of the Lower Eagle Ford Formation in this well, with slightly higher resistivity is correlated to the Lower Member of the Lower Eagle Ford Formation while the lower-resistivity, upper 33 ft of the Lower Eagle Ford Formation is correlated to the Upper Member of the Lower Eagle Ford (Fig. 15). Within the Upper Eagle Ford Formation, the upper, 40-ft-thick interval with higher-GR and lower-resistivity character is interpreted as the Upper Member of the Upper Eagle Ford, while the underlying 133 ft that has a lower-GR and higher-resistivity signature is interpreted as the Lower Member of the Upper Eagle Ford (Fig. 15). In summary, the Lower and Upper Eagle Ford formations, as well as the two allomembers in each can be defined in the outcrops and shallow subsurface of the Waco area. Figure 8 is a summary diagram that illustrates the similar well log characteristics among wells in West Texas, South Texas, and East Texas. The main difference among these 3 areas is the presence of Pepper (Woodbine) strata in the subsurface in the East Texas Basin.

## NORTH TEXAS (DALLAS AREA) SEQUENCE STRATIGRAPHY

For the Dallas area, the best published work to date on the internal stratigraphy of the Eagle Ford Group is the work by Brown and Pierce (1962) in their report on Mobil's Eagle Ford research borehole, which was located about 5.2 mi south of the old town of Eagle Ford in Dallas County (Fig. 16). Excluding the Tarrent strata, which we include with the Woodbine, Brown and Pierce (1962) reported a 454-ft-thick, Eagle Ford interval section in the borehole (Fig. 16). From there written description and core illustration the following zones from the top down can be defined: (1) a 120-ft-thick interval of dark gray calcareous mudstones with thin scattered sandstones beds; (2) 239 ft of grayish brown calcareous mudstones containing thin limestone interbeds; (3) a 70-ft-thick shale interval containing 34 bentonite beds; and (4) a 25-ft-thick, bentonite-free, calcareous mudstone whose basal 11 ft is sandy. Following the Eagle Ford stratigraphy of the Dallas area outlined by Adkins (1932), Brown and Pierce (1962) assigned the uppermost 120 ft interval to the Arcadia Park Formation, and the underlying 334 ft to the Britton Formation. In this paper, we assign the upper two zones to the Upper Eagle Ford Formation, and the lower two zones to the Lower Eagle Ford Formation. Clearly the most diagnostic interval in this succession is the 70-ft-thick, bentonite-rich zone in the lower Britton, which we interpret as the Upper Member of the Lower Eagle Ford Formation (Fig. 16). The underlying, bentonite-free mudstones within the lower Britton are assigned to the Lower Member of the Lower Eagle Ford (Fig. 16). In terms of the interpreted Upper Eagle Ford Formation, the Arcadia Park Formation at the top is correlated to the Upper Member of the Upper Eagle Ford, while the strata marked as Upper Britton are interpreted as the Lower Member of the Upper Eagle Ford (Fig. 16). In terms of outcrop biostratigraphic control in the Dallas area (Stephenson, 1952), ammonites of the late middle Cenomanian *Acanthoceras amphibolum* Zone were recovered from the basal portions of the Britton Formation. In contrast, the underlying Lewisville Formation, the uppermost formation of the Woodbine Group, contains ammonites of the earliest middle Cenomanian *Conlinoceras tarrantense* ammonite zone, while the Dexter Formation, the middle formation of the Woodbine Group, contains ammonites of the latest early Cenomanian *Forbesiceras brundretti* Zone (Fig. 3).

To date, no geophysical logs have been found for the Mobil Eagle Ford borehole in Dallas. Presently, the closest well to the borehole, that contains both GR and resistivity logs, is located about 19 mi to the southwest (Fig. 16). In this well, labeled C6, the Austin Chalk and Buda Limestone are fairly-distinct, blocky, low-GR intervals with elevated resistivity values. The Austin/Eagle Ford and Woodbine/Buda contacts are abrupt lithologic and petrophysical breaks, and are respectively labeled the K72sb and the K60sb (Fig. 16). Between the Austin and Buda, the basal 320 ft can be characterized as having an overall moderate-GR baseline, as well as spiky/irregular resistivity pattern; while the upper 445 ft can be characterized as having a lower-GR baseline, as well as overall lower-resistivity values (Fig. 15). Based on these two very different sets of geophysical log characteristics, the lower 320 ft is assigned to the Woodbine Group, while the upper, 445-ft-thick interval is assigned to the Eagle Ford Group (Fig. 16). This 445-ft thickness assigned to the Eagle Ford Group is very similar to the 454-ft thickness defined in the research borehole (Fig. 16). Within the Eagle Ford Group in this well, the GR drop the base of the green highlighted zone at approximately 1135 ft is interpreted as the K65sb, the boundary between the Lower Eagle Ford and Upper Eagle Ford formations (Fig. 16). Thus, in this well, 70 ft of the Lower Eagle Ford Formation and 375 ft of the Upper Eagle Ford Formation are interpreted (Fig. 16). This compares to the 95 ft and 359 ft interpreted, respectively, for these formation in the borehole (Fig. 16). Within the interpreted Lower Eagle Ford Formation in the borehole, the basal (40 ft) portion, characterized by overall higher resistivity, is correlated to the Lower Member of the Lower Eagle Ford Formation (Fig. 16). The overlying 30-ft-thick zone within the Lower Eagle Ford Formation in the borehole, which is characterized by overall lower resistivity, is correlated to the bentonite-rich Upper Member of the Lower Eagle Ford Formation (Fig. 16). Within the Upper Eagle Ford in well C6, the 120-ft-thick, higher-GR zone at the top is correlated to the Arcadia Park Formation in the borehole. This interval in both the borehole, and nearby well, is interpreted as the Upper Member of the Upper Eagle Ford Formation (Fig. 16). The K70sb is placed at its base. The underlying 255 ft of the Upper Eagle Ford Formation, which has moderate and somewhat blocky GR signature, is correlated to the Upper Britton Formation in the borehole, and interpreted as the Lower Member of the Upper Eagle Ford Formation (Fig. 16).

## REGIONAL CORRELATIONS— WEST FLANK OF THE EAST TEXAS BASIN

Based on the outcrop to subsurface ties in Dallas, Waco, and Austin (wells C6, C3, and C1) a regional north to south well-log cross section for the Woodbine and Eagle Ford groups is offered as Figure 17. This cross section is based on using as a datum the K63sb at the base of the Eagle Ford Group. In terms of the Eagle Ford Group, the distinctive high-resistivity Lower Member of the Lower Eagle Ford Group can be correlated from Dallas County to Travis County (Fig. 17). However, this member (depositional sequence) gets much thinner in Bell and Travis counties due to truncation by the overlying K64sb at the base of the Upper Member of the Lower Eagle Ford Formation (Fig. 17). The Upper Member of the Upper Eagle Ford Formation can also be correlated from Dallas to Austin on this well-log cross section (Fig. 17).

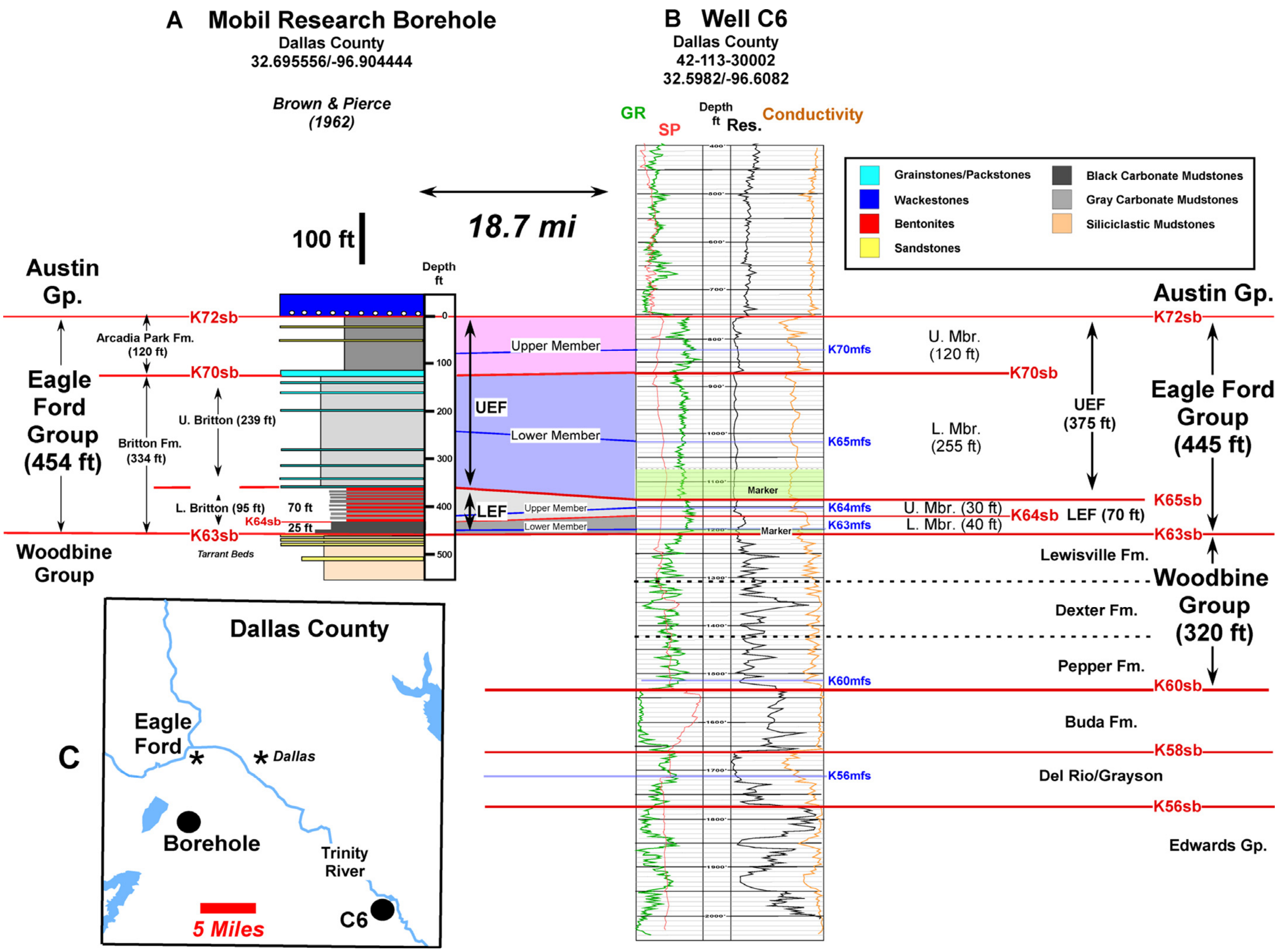


**Figure 16. (A) Lithostratigraphic units in the Mobil's Dallas Area Eagle Ford borehole defined by Brown and Pierce (1962) and in this paper. (B) Borehole to well-log tie of the sequence stratigraphic surfaces and units from the Eagle Ford Borehole to Well C6 in Dallas County, Texas. (C) Location map illustrating the location of: (1) Eagle Ford, Texas, (2) the Mobil Research Borehole, and (3) Well C6.**

However, within this depositional sequence thinning of the interpreted highstand systems tract (K70mfs to K72sb) can also be observed to the southwest toward Austin (Fig. 17). However, the most interesting surface within the Eagle Ford Group, however, is the K70sb at the base of the Upper Member of the Upper Eagle Ford Group (Fig. 17). From Dallas County to Bell counties (wells C6 to C2), this unconformity sequentially truncates most of the underlying Lower Member of the Upper Eagle Ford Formation; and between Bell and Travis counties (wells C2 and C1), this unconformity bevels the remaining portions of this depositional sequence, as well as truncates the upper portions of the underlying Upper Member of the Lower Eagle Ford Formation (Fig. 17). The interpreted regional truncation by the K70sb between Dallas and Travis counties is also consistent with the Eagle Ford section observed at Bouldin Creek outcrop in Austin, where the Lower Member of the Upper Eagle Ford Formation is absent (Fig. 10). As illustrated on Figure 9, the K70sb follows a similar truncation pattern of underlying strata from Webb County in South Texas toward Gonzales County in Central Texas.

Similar to the Eagle Ford Group, the underlying Woodbine Group displays the same north-to-south thinning along the west flank of the East Texas Basin (Fig. 17). The Woodbine Group systematically changes in thickness from over 300 ft in the Dallas area to less than 10 ft in the Austin area (Fig. 17). While internal correlations within the Woodbine were beyond the scope of this study Woodbine thickness variations appear to be due to the systematic truncation from the top down of the Lewisville, Dexter, and then Pepper formations by the K63sb located at the base of the Eagle Ford Group. The regional truncation by the K63sb at the base of the Eagle Ford continues into South Texas (Fig. 9), where the Pepper Formation was identified in wells B5 and B4 in Gonzales and eastern Dewitt counties but absent in the three wells (B1 to B3) to the southwest.

## SUMMARY

In order to evaluate how the Eagle Ford Group of West and South Texas correlates into the Eagle Ford and Woodbine groups of the East Texas Basin, a study of the Eagle Ford outcrops and shallow subsurface along the western flank of the East Basin was conducted. The goal was to see if the chronostratigraphic units defined in the Eagle Ford in South and West Texas could be defined in this area. Work to date suggests that the Lower and Upper Eagle Ford formations, as well as their two associated members defined within outcrops of West Texas, as well as subsurface of West and South Texas, can also be defined within the outcrops and shallow subsurface of the Eagle Ford Group in Central and North Texas along the western flank of the East Texas

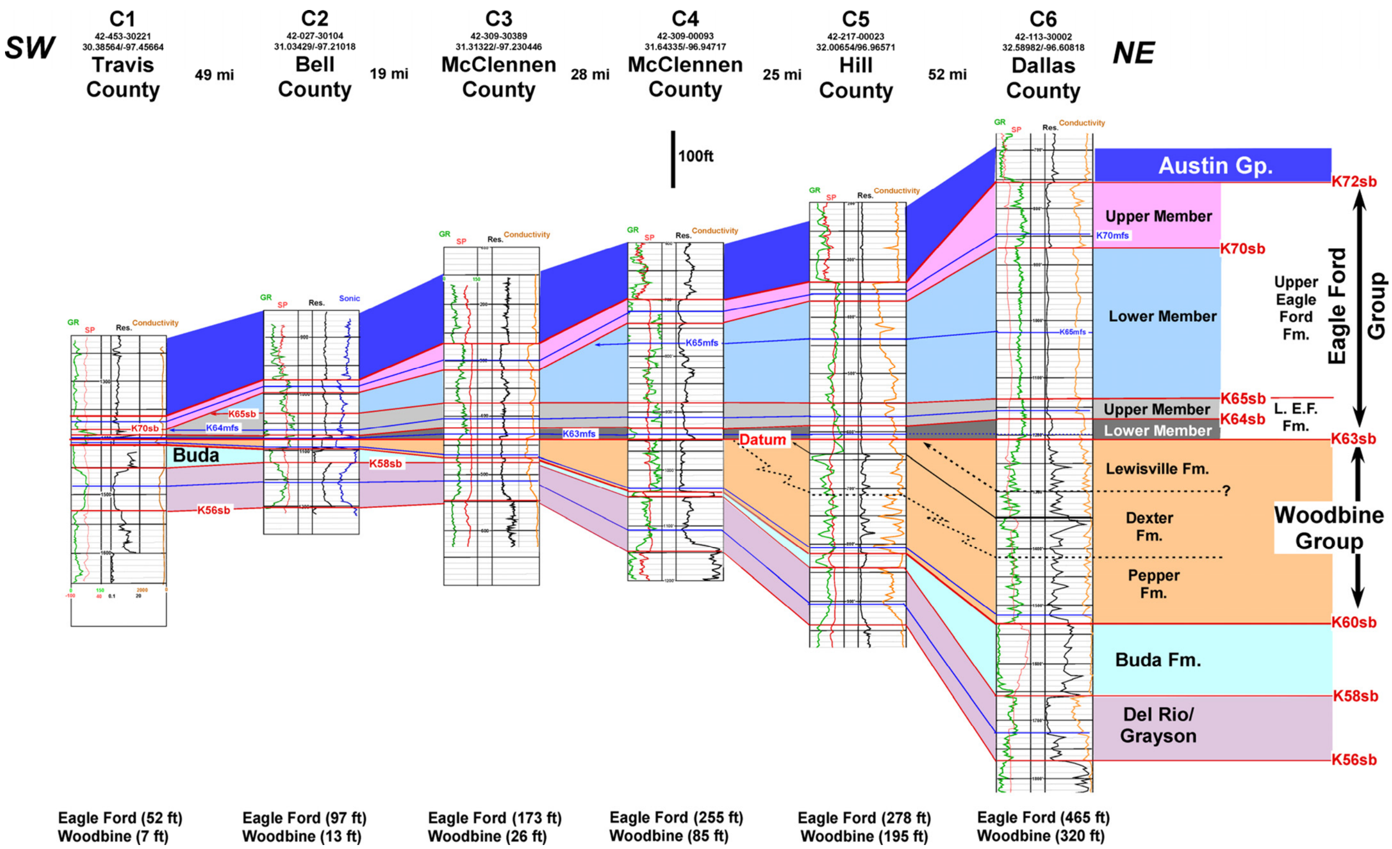


**Figure 17. Well-log cross section illustrating distribution and thickness variations of the depositional sequences (allostratigraphic) units correlated from Dallas County to Travis County in the shallow subsurface along the western flank of the East Texas Basin. Location of well-log cross section on Figure 1 .**

Basin. Key to this analysis, was the identification of: (1) the low-resistivity marker zones at the base of the Lower and Upper Eagle Ford formations; (2) the organic-rich Lower Member of the Lower Eagle Ford Formation along with its distinctive high-GR and high-resistivity, maximum flooding surface; (3) the bentonite-, Th-, and U-rich, Upper Member of the Lower Eagle Ford Formation; (4) the U- and TOC-poor basal portions of the Lower Member of the Upper Eagle Ford Formation with its characteristic positive $\delta^{13}C$ isotope excursion at its base; and (5) the high-GR, low-resistivity mudstone associated with the Upper Member of the Upper Eagle Ford Formation.

With these distinctive chronostratigraphic units of the Eagle Group in place, the organic-poor, moderate-GR, low-resistivity mudstones within the underlying Woodbine Group, as well as its basal Pepper Shale, can also be readily identified and defined as an older chemostratigraphically-distinct chronostratigraphic unit. Thus our work supports the classic biostratigraphic interpretation that (1) the Eagle Ford Group is a coeval (mid-middle Cenomanian to latest Turonian) unconformity-bounded chronostratigraphic unit mappable across Texas and (2) the Woodbine Group as an older (mid early Cenomanian to earliest middle Cenomanian) unconformity-bounded chronostratigraphic unit that stratigraphically underlies the Eagle Ford Group (Fig. 3). Correlations of the Woodbine Group along the western flank of the East Texas Basin suggest that the present distribution, thickness, and facies patterns of the Woodbine were modified by the angular unconformity (K63sb) at the base of the overlying Eagle Ford Group. From the Dallas to Austin area of the East Texas Basin, this unconformity sequentially truncates the Woodbine Group from the top down to the point that only thin portions of the basal Pepper Formation are present in the Austin area. Furthermore, once the distinctive moderate-GR/low-resistivity character of the mudstones within the Pepper Formation (Woodbine Group) are recognized, local erosional remnants of Woodbine Group can now be identified and mapped in the subsurface of South Texas and separated from overlying younger Eagle Ford strata.

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