GCAGS JOURNAL
A Publication of the
Gulf Coast Association of
Geological Societies
www.gcags.org

Regional Stratigraphy of the Edwards Group and Associated Formations of Texas (Lower Cretaceous, Comanchean): In Defense of the Classic View

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ABSTRACT

Bound between regional unconformities, carbonate rocks of the Middle Albian–Lower Cenomanian Fredericksburg-Washita Division are ubiquitous across the Comanche Shelf of Texas, at the surface and in the subsurface. They represent the gradual but fluctuating marine inundation of the Comanche Shelf as Comanchean times came to an end. They were deposited in four adjoining depositional provinces: (A) the Central Texas Platform (peritidal shelf interior and shallow-marine shelf, represented by the Edwards Group); (B) the pelagic open-marine shelf of North and Trans-Pecos Texas; (C) the Maverick Basin (closed, partly restricted shelf-basin); and (D) Stuart City and Devils River shelf-edge trends (narrow belts of bioclastic and constructional marine "reef" sediments).

Utilizing a regional network of five interlocking stratigraphic cross-sections compiling the work of many geologists throughout North, Central, and southwestern Texas, this paper examines, documents, evaluates, and integrates all stratigraphic aspects of the "classic view" of the Edwards Group and adjacent formations: (a) physical stratigraphy; (b) distribution of formations, members, and key beds; (c) discontinuity surfaces (= hardgrounds); (d) distribution of paleoenvironments; (e) long-established ammonite zones; (f) limited benthic fossil occurrence; and (g) correlations based upon sequence stratigraphy.

Five published papers over the 2007–2016 decade have challenged aspects of some long-held Edwards Group stratigraphic relationships, based mostly on still-emerging paleontology and distribution of benthic molluscs, primarily rudists (the "revisionist view").

Six second- and third-order sub-cycles are identified within the undivided Fredericksburg-Washita Division of the Central Texas Platform, Maverick Basin, and North and West Texas, and provide compelling confirmatory evidence for earlier stratigraphic conclusions contributed to by eleven different published authorities, from 1958 to 2016:

1. **The Burt Ranch Member (basal Segovia Formation), the Regional Dense Member (basal Person Formation), and the Kiamichi Member (basal Georgetown Formation) are stratigraphic equivalents representing a regional flooding event, all three being in the *Adkinsites bravoensis* Ammonite Zone (lowermost Washita).**
2. **The peritidal Person Formation is the shelf-interior equivalent of the pelagic-shelf Georgetown Formation (except for its uppermost member, the Main Street, which forms the thin remnant Georgetown Formation of the distal Central Texas Platform); the Person Formation is also equivalent to the combined middle and upper McKnight plus lower Salmon Peak formations of the Maverick Basin.**
3. **The Dolomitic and Kirschberg members (lower members of the Kainer Formation) are laterally equivalent to all of the Fort Terrett Formation of the Edwards Plateau; and the combined Grainstone Member of the Kainer Formation, all of the Person Formation, plus the Main Street Member are laterally equivalent to the Segovia and Fort Lancaster formations of the Edwards Plateau.**
4. **Thus the Person Formation, comprising the second and third sub-cycles, is properly assigned to the lower Washita, not the Fredericksburg.**

Comparison of the resulting comprehensive (i.e., integrated) regional stratigraphic framework (the "classic view") with the conclusions of the "revisionist view" demonstrates the fallibility of regional stratigraphic interpretations based upon limited criteria, and now encourages investigation of ancillary stratigraphic issues, such as: (i) changes in regional discontinuity surfaces passing from one depositional province to another; (ii) correlation patterns in shelf-to-basin settings; (iii) relative influence of regional versus local stratigraphic observations; and (iv) can a well-defined, physically derived stratigraphic architecture provide a framework by which lithofacies-controlled benthic fossil distribution may be detected?

Manuscript received March 6, 2017; revised manuscript received May 14, 2017; manuscript accepted June 6, 2017.

GCAGS Journal, v. 6 (2017), p. 111–134.

INTRODUCTION

Background

For purposes of this summary, employing the commonly used division concept of Hill (1887, 1901), resurrected by Lozo and Stricklin (1956), and Lozo (1959a, 1959b) serves to simplify and facilitate discussion by dealing with two cycles of the Comanche Series as regional time-rock units—early examples of what is now called "sequence stratigraphy." The lower cycle is wholly Fredericksburg (approximately middle Albian), whereas the upper cycle actually consists of two sub-cycles, lower Washita (upper Albian), and upper Washita (lower Cenomanian), which comprises the Del Rio and Buda formations. The Del Rio and Buda represent the final flooding of the Comanche Shelf at the end of the Comanchean Epoch (end of Washita as well as end of early Cenomanian).

Figure 1, adapted from Smith et al. (2000) and Rose (1972), is a comprehensive graphic summary of Fredericksburg and Washita stratigraphy of Central and southwestern Texas, in relation to the North Texas standard section, with ammonite zones. Columns are numbered for ease of reference throughout the text.

Rose (1972) recognized that the Lower Cretaceous Edwards Group of Central Texas comprised two regional depositional cycles, Fredericksburg and lower Washita. In the subsurface of the Central Texas Platform, and in outcrops along the Balcones Fault Zone, they were the Kainer and overlying Person formations (Fig. 1, column 4). In outcrops of the eastern Edwards Plateau, their close—but not exact—stratigraphic equivalents were the Fort Terrett and overlying Segovia formations (Fig. 1, col. 3).

Thin, shallow-marine, marly members separate both successions, the Regional Dense Member (RDM = basal Person), and the Burt Ranch Member (basal Segovia). Following van Siclen (1958) and Tucker (1962), Rose (1972) showed that (1) the RDM is laterally continuous with the Kiamichi Shale, the basal member of the lower Washita Georgetown Formation of north-central Texas and the East Texas Basin (Fig. 1, col. 1a); (2) the RDM is equivalent to the upper part of the Burt Ranch Member (Fig. 1, cols 4 and 3), and (3) the Person Formation is thus the peritidal lateral-equivalent of the pelagic-shelf Georgetown Formation (Fig. 1, cols. 4 and 1a). This basic understanding of Fredericksburg-Washita stratigraphic relationships has been subsequently embraced by at least seven additional published authorities (Abbott, 1973; Young, 1974, 1979a, 1979b, 1986; Bay, 1977; Cook, 1979, Maclay and Small, 1986; Moore, 1996; Hovorka et al., 1996), and is here represented as the "classic view."

Recent publications (Waite et al., 2007; Phelps et al., 2014, 2016; Scott et al., 2016a, 2016b), here represented as the "revisionist view," have challenged the long-held assignment of the Person Formation (Edwards Group) to the lower Washita sub-cycle, claiming instead that it should be assigned to the upper part of the Fredericksburg cycle. All five publications accept, however, that the Segovia Formation is lower Washita. There is little stratigraphic dispute where Fredericksburg and lower Washita strata contain ammonites; the problem is that ammonites are extremely rare in shelf-interior settings, represented by the Edwards Group. Here, stratigraphic relationships depend upon

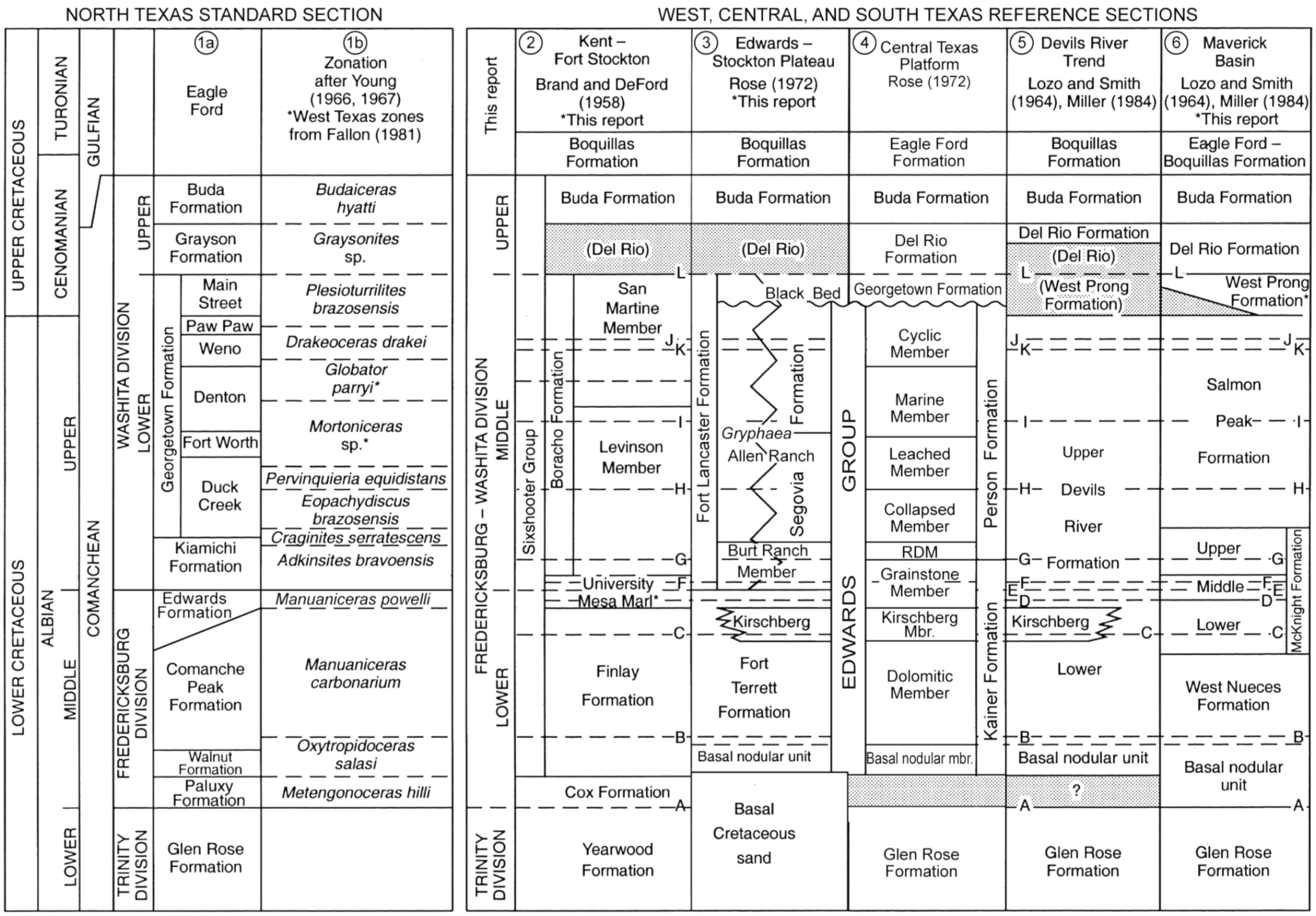


Figure 1. Correlation of Fredericksburg-Washita formations in different regions of Central and southwestern Texas, in relation to North Texas reference section and ammonite zonation (modified after Smith et al., 2000; Rose, 1972). Columns numbered for reference in text.

physical stratigraphy and correlation of depositional cycles, inasmuch as benthic invertebrate fossils are largely facies-controlled, their bio-zones are still evolving, and their chronostratigraphic significance is speculative.

The basic stratigraphic disagreement addressed by this paper concerns the stratigraphic assignment of the Person Formation of the Edwards Group: is it part of the Fredericksburg sub-cycle, per the "revisionist view," or is it the lower part of the lower Washita sub-cycle, per the "classic view"? At a more fundamental level, however, three conceptual disputes underlie the dispute:

(1) The first dispute concerns the identification and definition of regional depositional sequences. Should sequence-successions established in one province be expected to be present unchanged in an adjacent province having a very different depositional setting? Should not a region's demonstrated regional stratigraphy determine the interpretive placement of sequence-stratigraphic cycles? Or should the provincial (or global) sequence-stratigraphic tail be allowed to wag the regional geologic dog?

(2) The second dispute concerns the relative influence of different lines of stratigraphic evidence in resolving stratigraphic disputes, specifically the admissibility of physical stratigraphic correlations derived from detailed stratigraphic sections, passing laterally from ammonite-bearing formations through non-ammonite-bearing formations and back again: is such evidence conceptually legitimate in establishing correlations across the peritidal parts of the Central Texas Platform? The writer maintains that (a) the very substantial body of congruent, extensively mapped geologic evidence; (b) the concordance and continuity of internal and bounding physical correlations; (c) the regular isopachous and facies trends of the Fredericksburg and lower Washita subcycles; (d) the consistent agreement of lithologic correlations with the ammonite zonations; (e) the remarkable coincidence of newly recognized third-order lower Washita subsequences with projected ammonite zones; and (f) the implausibility of physical correlations required by the "revisionist view" that the Person Formation is Fredericksburg, collectively compel an affirmative answer to this question.

(3) The third dispute concerns the widespread discontinuity surface at the base of the terrigenous Kiamichi Shale in North Texas and Oklahoma (WA–1 of Scott et al. [2003]), where deposition was relatively slow: what happens to this surface passing southward onto the Central Texas Platform carbonate region, where sediment accumulation rates were higher? Obviously, such surfaces cannot extend endlessly, but how do they disperse in areas of more rapid accumulation, especially very shallow-shelf realms? Should we be surprised if the lithology of an overlying spreading sequence changes, passing from one depositional region to another?

Purposes

The purposes of this paper are:

(1) To review the abundant and diverse evidence mandating the re-establishment of the correct stratigraphic relationships of the Edwards Group of Texas, especially as they relate to the Person, Georgetown, and Segovia formations (the "classic view").

(2) To identify the several lines of evidence that render the "revisionist view" irreconcilable with acknowledged stratigraphic relationships, and to replace previous derived (and thus flawed) sequence-stratigraphic interpretations with a sequence-stratigraphic classification that is consistent with the "classic view."

(3) To discuss and illustrate: (a) the regional use and misuse of discontinuity surfaces (hardgrounds) in carbonate stratigraphy; (b) stratigraphic principles involved in establishing plausible shelf-to-basin correlations; (c) the power of comprehensive, regional, multi-evidential stratigraphic analysis, compared with evidence based on a single, facies-sensitive, benthic faunal criterion; (d) the possible use of a well-documented physical stratigraphic framework to detect paleoenvironmental influences on the distribution of benthic invertebrate fossils.

Documentation and Stratigraphic Conclusions

The foundation of this paper is a well-documented, physically mapped, interlocking regional network of five stratigraphic cross-sections in the Edwards Plateau, Maverick Basin, Balcones Fault Zone, subsurface of the Central Texas Platform, and north-central Texas (Fig. 2). The five large-scale cross-sections are described in the Appendix and are included in the digital version of this paper (Figs. A1–A5), and are also included within a companion paper in the 2017 *GCAGS Transactions* (Rose, 2017).

Based upon 75 measured outcrop sections, 44 shallow and deep cores, and more than 100 wireline logs (most supported by sample logs), the cross-sections demonstrate and document the true stratigraphic relationships among Fredericksburg and lower Washita formations (surface and subsurface). Compiled from detailed published work by more than 25 geologists since 1960[1] and supported by a long-established ammonite zonation and numerous ammonite collections at or near the constituent measured sections, these regional cross-sections underpin the following stratigraphic conclusions (reference to Figure 1 is recommended):

(1) The Kiamichi Member (basal Georgetown Formation) thins southward from North Texas, and grades laterally into the upper part of the RDM of the Person Formation. The RDM grades northwestward into the upper Burt Ranch Member of the Segovia Formation in the Edwards Plateau. All three lithologic units (including the lower Burt Ranch) lie in the zone of *Adkinsites bravoensis*, the definitive Kiamichi ammonite.

(2) Wireline-log correlations purporting to show that the RDM correlates with the Walnut or Comanche Peak formations (Phelps, 2011; Phelps et al., 2016) do not employ logs from five additional intervening wells which would otherwise show that the RDM is, in fact, continuous with the Kiamichi Formation as demonstrated by Rose (2016c). Furthermore, such suggested correlations conflict with well-established stratigraphic relationships of Moore (1964, 1967), and are irreconcilable with published geologic mapping in southwest Austin (Garner and Young, 1976).

(3) Passing southward onto the axis of the San Marcos Arch, successive members of the pelagic-shelf Georgetown Formation onlap gentle clinoform slopes of the southward-thickening peritidal Person Formation; discontinuity surfaces separate the two formations at all outcrops. Only the thin uppermost Main Street Member of the Georgetown Formation, resting unconformably on the Person Formation, is present throughout the Central Texas Platform. Thus all of the Person Formation is geometrically equivalent to most of the Georgetown Forma-

[1]Lozo (1959a); Nelson (1959, 1973); Shelburne (1959); Winter (1961); Tucker (1962); Wilbert (1963); Lozo and Smith (1964); Moore (1964, 1967, 1996); Young (1966, 1974, 1979a, 1986); Bishop (1967); Dixon (1967); Smith (1970); Rose (1966, 1970, 1972, 1986a, 1986b, 2016b, 2016c); Abbot, (1973); Amsbury et al. (1973); Bay (1977); Bolland and Geffert (1979); Smith and Brown (1983); Humphreys (1984); Miller (1984); Maclay and Small (1986); Lemons (1987); Hovorka et al. (1996); Smith et al. (2000); Scott et al. (2003).

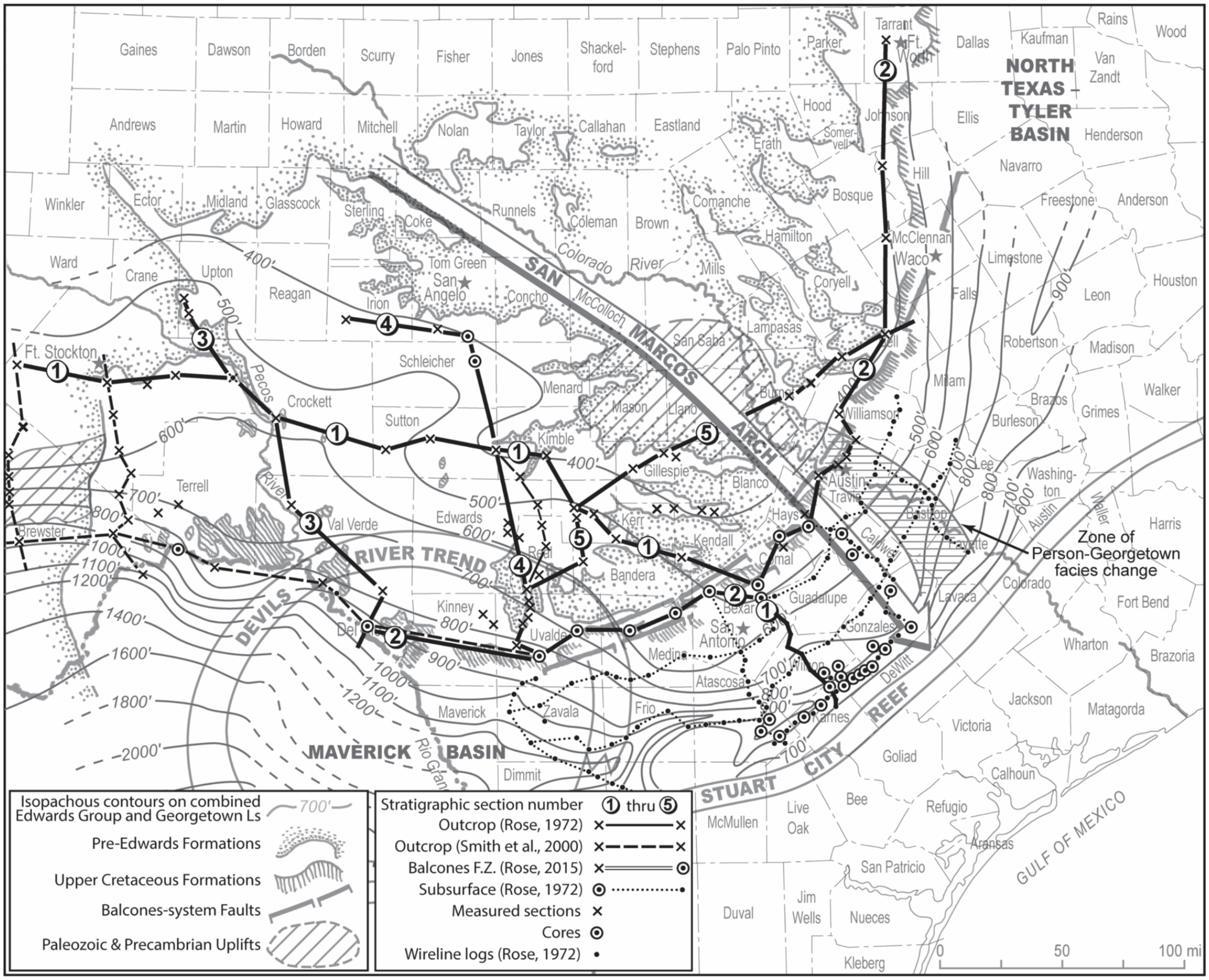


Figure 2. Fredericksburg-Washita correlation network, Central Texas, in relation to main depositional elements and regional isopachs of Edwards Group and equivalent formations. Trends of regional stratigraphic cross-sections #1 through #5 are shown in bold solid lines. Derived from Lozo and Smith (1964), Smith et al. (2000), Tucker (1962), Moore (1964, 1967, 1996), Rose (1972), Miller (1984), Humphreys (1984), Maclay and Small (1986), and Hovorka et al. (1996).

tion. Regional lithostratigraphic and biostratigraphic (am monite) relationships mandate that they are also stratigraphic equivalents, and that discontinuity surfaces at different outcrops do not represent a single disconformity.

(4) In the Edwards Plateau, shallow-shelf limestones above a widespread regional disconformity near the top of the Segovia Formation (the "Black Bed") are probably equivalent to the pelagic-shelf Main Street Member.

(5) The Fort Terrett Formation is laterally equivalent to the Basal Nodular, Dolomitic, and Kirschberg members of the Kainer Formation.

(6) The Segovia Formation is laterally equivalent to the highest member of the Kainer Formation (the Grainstone Member) plus all of the Person Formation, and the Main Street Member of the Georgetown Formation.

(7) Paleontologic evidence cited to date (Phelps et al., 2014, 2016, Scott et al., 2016a, 2016b) in support of assigning the Person Formation to the Fredericksburg sub-cycle is almost entirely based on facies-sensitive benthic faunas, and disregards documented physical stratigraphic relationships as well as a long-established ammonite zonation that fully supports assignment of the Person Formation to the lower Washita subcycle.

REGIONAL SETTING

Lower Cretaceous (middle and upper Albian) carbonate sediments were deposited in peritidal to shallow marine environments on the vast, flat Comanche Shelf, which covered much of what is now Central and western Texas (Fig. 3). Beneath a sheltered inland sea to the north, carbonate deposition changed to terrigenous clastic sedimentation in central Oklahoma. The Albian Gulf of Mexico Basin bordered the southeastern margins of the Comanche Shelf, marked by a long, narrow belt of skeletal carbonate sediments, the Stuart City Reef (Winter, 1961). Seaward of the Stuart City, water depth increased abruptly and steadily, so that open-marine pelagic carbonate sediments accumulated in oceanic water hundreds of feet deep. On the Comanche Shelf, however, water was generally quite shallow, although there were broad, structurally-controlled depressions and swells in the interi-

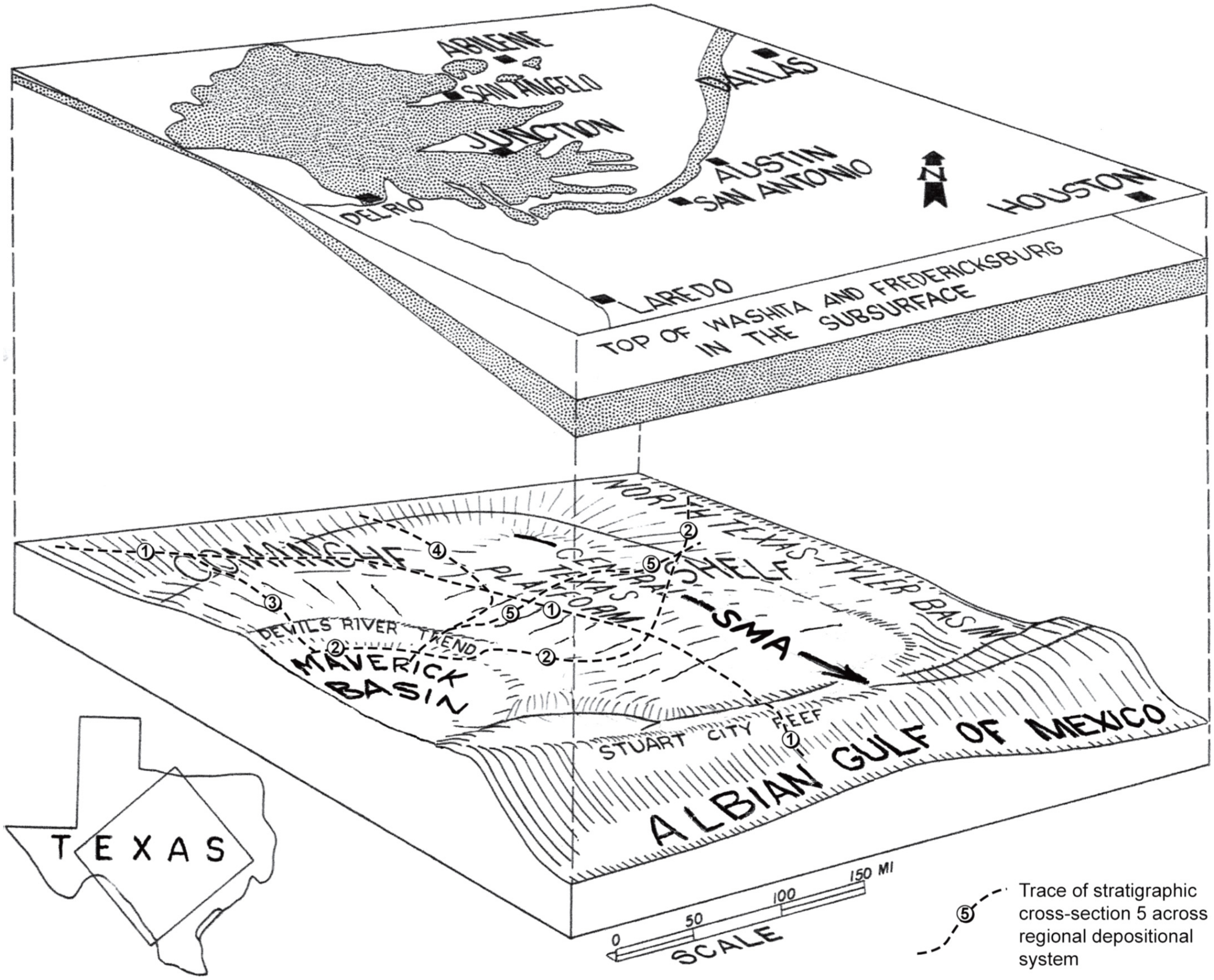


Figure 3. Regional depositional and structural elements, Central Texas, during early Washita time, showing traces of regional stratigraphic cross-sections #1 through #5 (modified after Rose, 1972). SMA = San Marcos Arch. The four adjoining depositional provinces include (A) Central Texas Platform (peritidal shelf-interior and shallow-marine shelf, represented by the Edwards Group); (B) pelagic open-marine shelf of North and Trans-Pecos Texas; (C) Maverick Basin (closed, partly restricted shelf-basin; and (D) Stuart City and Devils River shelf-edge trends (narrow belts of bioclastic and constructional marine "reef" sediments).

or of the shelf that exerted great influence on formation thickness and lithology (Rose, 1972, 2016a). The two dominant depressions were the Maverick Basin on the southwest, and the East Texas Basin (North Texas–Tyler Basin of Fisher and Rodda [1969]) on the north and northeast. Separating these two depressions was a broad, elongate swell, the Central Texas Platform, the structural and depositional axis of which was the southeast-trending San Marcos Arch, asymmetrically located near the northeast margin of the platform, and the dominant influence on facies and thickness of all Cretaceous formations in Central Texas.

The broad area of sheltered deposition between: (1) the San Marcos Arch on the northeast; (2) the lee side of the Stuart City Reef to the southeast; and (3) the Devils River Trend to the southwest formed a vast offshore platformal sediment trap where peritidal carbonate sediments could accumulate, mostly free of terrigenous sedimentation. All the carbonate rocks now included in the Edwards Group accumulated as two depositional cycles of very shallow marine and peritidal strata on the Central Texas Platform. To say that "an Albian geologist could have snorkeled, waded, or walked all the way from San Angelo to DeWitt County" (more than 200 miles) would be no exaggeration (apocryphal epigram attributed to the late Frank Lozo).

REGIONAL STRUCTURE

Restored structure on top of the Edwards Group and associated limestones (top Georgetown in the subsurface and Balcones Fault Zone) allows integration of surface and subsurface mapping throughout the region (Fig. 4). Where post-Paleogene erosion in the eastern Edwards Plateau and Hill Country has removed part or all of the upper Edwards (Segovia Formation), the original total Edwards thickness has been restored by adding Edwards isopachous values (derived from the subsurface and from the central and western parts of the Edwards Plateau, where the complete Edwards section is present) to the base Edwards of Rose (1972, 1986a, 2004, 2016a).

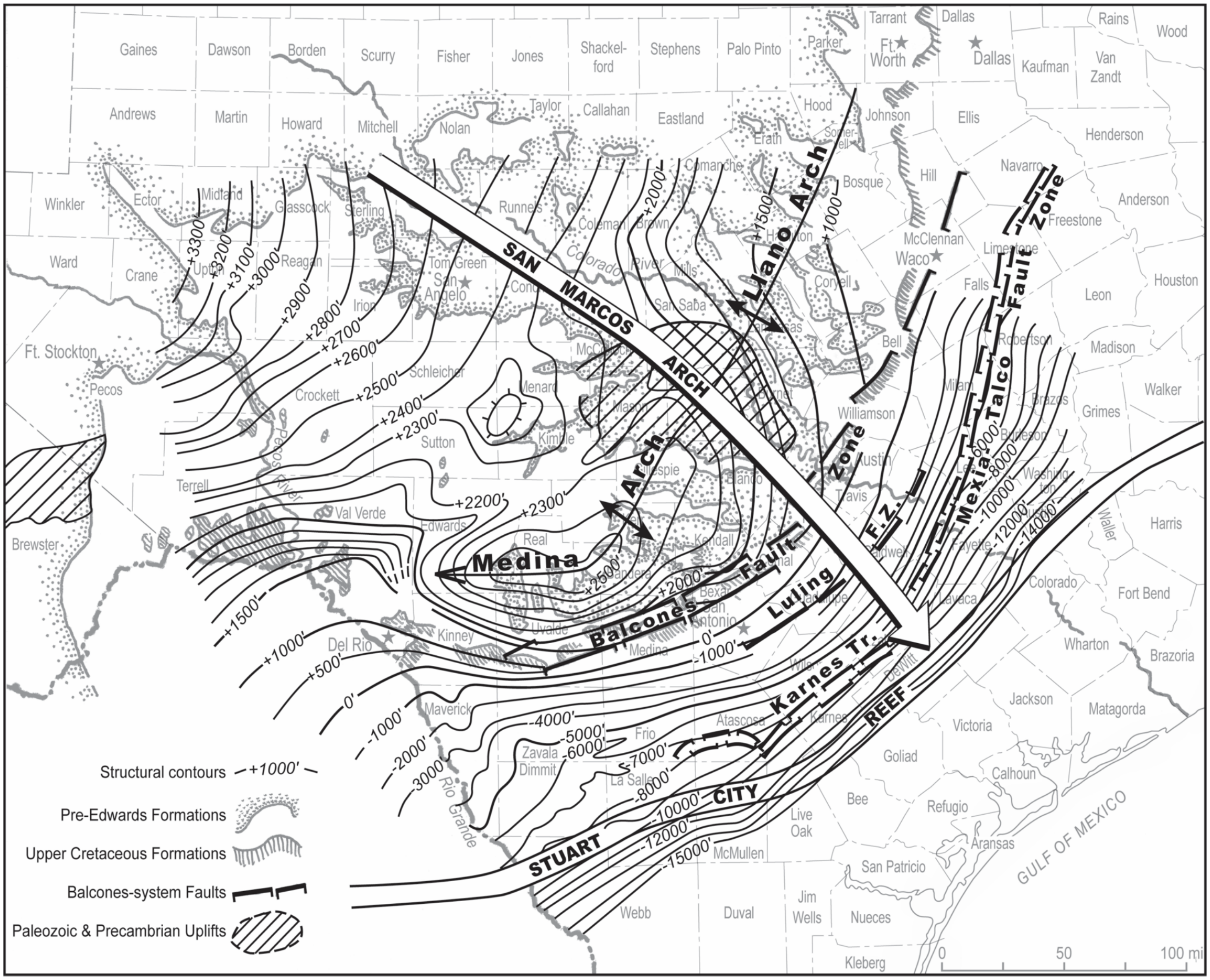


Figure 4. Regional structure map on top of Edwards Group and associated formations (Top Georgetown in subsurface) (modified after Rose, 2016a).

Northwest of the Llano Uplift, the base of the Edwards rises gently (~10 feet per mile) but steadily toward the northwest, reflecting regional Miocene/Pliocene uplift of the Colorado Plateau. The Llano Uplift itself has a long geologic history as a domal uplift; it lies beneath the apex of the San Marcos Arch. Adjacent to the Llano Uplift on the south is the Medina-Llano Arch (Rose, 1972; Ewing, 2005), a late Tertiary structure related to Balcones faulting and uplift (Rose, 2016a). The Llano Uplift represents a structural buttress around which Edwards strata dip steeply eastward and southward, across the Balcones Fault Zone, then gulfward beneath the Gulf Coastal Plain.

The Balcones Fault Zone lies consistently above the Ouachita structural belt, midway between the leading overthrusted and folded zone and the trailing metamorphic thrust front (Rose, 2016a). Faulting is en echelon and mostly extensional, down to the southeast. The Balcones Fault Zone extends about 350 miles, from near Del Rio to near Hillsboro, and reaches maximum displacement (about 2000 feet) around San Antonio. Time of faulting (and concurrent uplift of the eastern Edwards Plateau) is widely accepted as late Oligocene and early Miocene (Weeks, 1945a, 1945b; Galloway et al., 2000, 2011; Rose, 2016a); there is no evidence of movement during the Early Cretaceous. Today, the Balcones Fault Zone is widely considered to be dormant (Ewing, 2005).

Centered across the San Marcos Arch, and about 30 miles downdip (southeast) of the Balcones Fault Zone is the en echelon Luling Fault Zone. Its lateral extent is much smaller—about 100 miles—and cumulative displacement is somewhat less, perhaps 1200–1500 feet. Its antithetic relationship with the Balcones Fault Zone indicates that it is also of late Oligocene to middle Miocene age.

However, there are two other dominant fault systems in the subsurface of south-central Texas that were active during Edwards deposition (and afterward). Both lie downdip from, and broadly parallel to, the Balcones-Luling system:

(1) The Mexia-Talco Fault Zone of the East Texas Basin, a narrow synthetic-antithetic graben, extends southward across Milam, Lee, Bastrop and Gonzales counties, about 20 miles downdip of the Luling Fault Zone (Weeks, 1945b); and

(2) The Karnes and Atascosa troughs (Rose, 1972), similar antithetic-synthetic graben systems that stretch northeast-southwest across southeastern Gonzales, northwestern Karnes and northern Atascosa counties.

Ewing (1991) assigned these fault systems to the Peripheral Graben System of the northern Gulf Coast Basin, correctly noting the coincidence of these narrow extensional features with the pinchout edge of the underlying Louann Salt (Jurassic), and ascribing their origin to gulfward gliding on the salt, beginning in the Late Jurassic and probably continuing even to the present day. Dramatic fault-related thickness variations are especially apparent in the Karnes Trough, beginning with the Kainer Formation.

REGIONAL DEPOSITIONAL REALMS OF THE LOWER WASHITA SUBCYCLE

Shallow-shelf sedimentation was widespread during the lower (Fredericksburg) sub-cycle, whereas regional transgression during the early Washita caused shelf-interior facies to retreat back onto the Central Texas Platform, and the San Marcos Arch became the dominant influence on thickness and distribution of carbonate facies (Fig. 5). Peripheral to the inner Central Texas Platform, peritidal Person and Segovia carbonates grade laterally into shallow-marine sediments of the Fort Lancaster Formation, then into pelagic marls (Boracho Formation). Southwestward, an arcuate belt of coarse bioclastic carbonates (the Devils River Trend) formed around the northern rim of the Maverick Basin, declining basinward (Humphreys, 1984; Miller, 1984) into pelagic mudstones (Salmon Peak). Northeastward from the San Marcos Arch, Person peritidal sediments grade into shallow-marine wackestones and fine skeletal packstones, then into pelagic lime mudstones (Georgetown), and farther northward into marls with subsidiary lime mudstones, assigned to the lower Washita Group or subcycle (Scott et al., 2003). Gentle clinoform slopes (Rose, 1972, 2016b, 2016c) coincide with the transition from shallow shelf to pelagic-marine shelf environments. Discontinuity surfaces are common where transgressive marly sediments rest upon shallow-shelf particulate limestones. With this perspective, it is easy to understand why ammonites are extremely rare in the Person and Segovia formations (Young, 1974), but common in the adjacent Fort Lancaster, Boracho, Salmon Peak, and Georgetown formations.

AMMONITE BIOSTRATIGRAPHY

Pioneering work by Adkins (1927, 1933) established that thick sections of Cretaceous marls and limestones in the vicinity

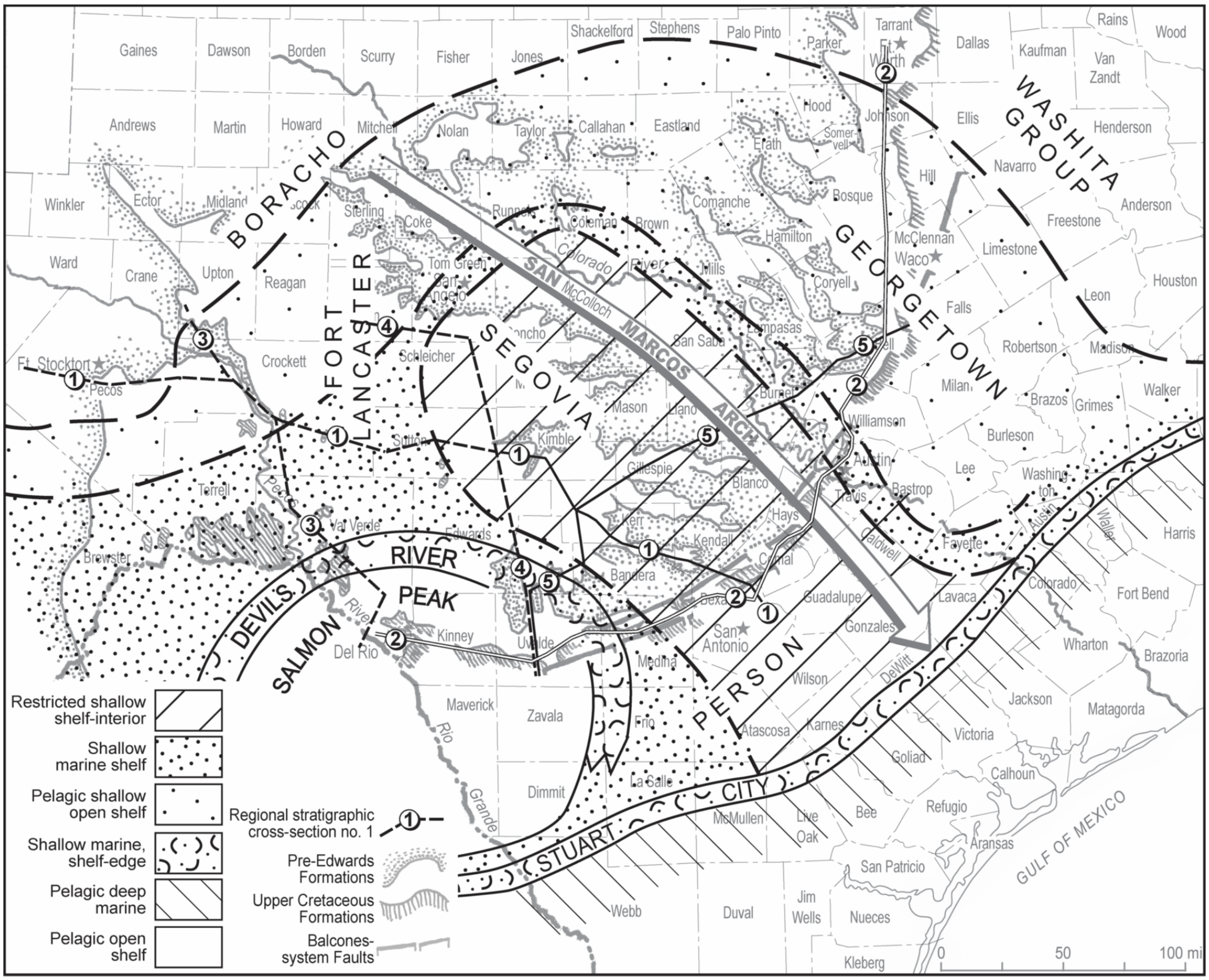


Figure 5. Lower Washita depositional environments (provinces) and formation names (modified after Rose, 1972, 2016a; Smith et al., 2000). Shallow-shelf sedimentation was widespread during the lower (Fredericksburg) sub-cycle, whereas regional transgression during the upper (early Washita) sub-cycle caused shelf-interior facies to retreat back onto the Central Texas Platform, and the San Marcos Arch became the dominant influence on thickness and distribution of carbonate facies.

of Fort Stockton, West Texas, contained the same sequence of ammonites that were known to exist in the Kiamichi Formation and Washita Group of North Texas. Later refinements, such as Young (1966, 1967), Smith et al. (2000), and Scott et al. (2003), affirm the excellent correspondence of the two successions. The ammonite succession (Fig. 1, columns 1a and 1b) is derived primarily from Young.

Ammonites are common in the Boracho Formation, but less so eastward and southward in the Fort Lancaster Formation (Fig. 1, cols. 2 and 3). However, tongues of marly, nodular ammonite-bearing strata in the Fort Lancaster represent shallow flooding episodes reaching a few tens of miles into the interior of the Edwards carbonate bank, even into the Segovia Formation. Lower Washita ammonites in such zones provide the basis for establishing the correlatives with the classic ammonite succession of North Texas, and provide robust and independent support for correlations based upon physical stratigraphy.

Smith et al. (2000) projected correlation surfaces (A–L) through all six of their regional stratigraphic cross-sections, reflecting the North Texas stratigraphic sequence of formations, which is a proxy for the North Texas Fredericksburg-Washita ammonite succession (Fig. 1). Rose (2016c) extended those correlation surfaces through the non-ammonite bearing peritidal carbonate facies, based on physical stratigraphy, and reconciled all correlation surfaces among his five regional stratigraphic cross-sections. Ammonite collections, many provided by Smith et al. (2000) and Young (1966, 1974, 1979a, 1979b) are noted on all stratigraphic cross-section.

In general, the writer ascribes more confidence to correlations based upon ammonites (because of their proven reliability and pelagic habits) than to benthic pelecypods and foraminifera (because of their greater susceptibility, as bottom-dwellers, to environmental influences, as well as to the infant status of Fredericksburg–lower Washita benthic biostratigraphy in the Edwards Group).

PERSON FORMATION IS LOWER WASHITA, NOT FREDERICKSBURG

What follows is a systematic review of evidence indicating that the Person Formation should be assigned to the lower Washita subdivision. The five regional stratigraphic cross-sections (see Appendix) provide the fundamental evidence; however, excerpted shorter segments of these sections are shown in the main body of this paper to illustrate main arguments advanced.

Regional Perspective on Main Depositional Cycles and Major Lithofacies Distribution

In seeking to grasp basic regional stratigraphic relationships, it is helpful to start by examining regional stratigraphic cross-sections at reduced scales—to look at the "big picture." Figure 6 shows three of the five regional stratigraphic cross-sections (#2, #3, and #4) greatly reduced, without formation names or subcycle boundaries—see full-scale versions in digital version as Figures A2–A4. All three cross-sections are similarly oriented, from near the axis of the Central Texas Platform (the San Marcos Arch) into the Maverick Basin. All three cross-sections show the Fredericksburg-Washita Division to be bounded below and above by regional disconformities, and to consist clearly of three subcycles. Lateral continuity of lithologic units is remarkably regular and extensive, and thicknesses of the subcycles are mutually compatible. The middle and upper sub-cycles thicken southward and westward from the Central Texas Platform into the Maverick Basin. In all three cross-sections, dolomite and widespread evaporite collapse breccias are concentrated in the lower and middle sub-cycles over the San Marcos Arch and interior of the Central Texas Platform; they are absent around the peripheral margins of the Central Texas Platform. Anhydrite (probably subaqueous) and correlative peripheral collapse breccias are present, however, in the Maverick Basin. In the middle sub-cycle of cross-sections #3 and #4, marine and shallow-marine tongues project laterally from the shallow-marine periphery into the peritidal platform interior, clearly indicating the presence of additional lower-order depositional subsequences. On cross-section #2, the marine middle cycle at left (north) appears to change southward by facies change and depositional topography into peritidal shelf interior sediments.

Conclusion: Throughout the map area, the Fredericksburg-Washita Division consists of three stratigraphic sub-cycles; the middle sub-cycle itself also contains lower-order subsequences of wide extent.

Thickness Trends, Lower Washita Successions, Edwards Plateau to Subsurface

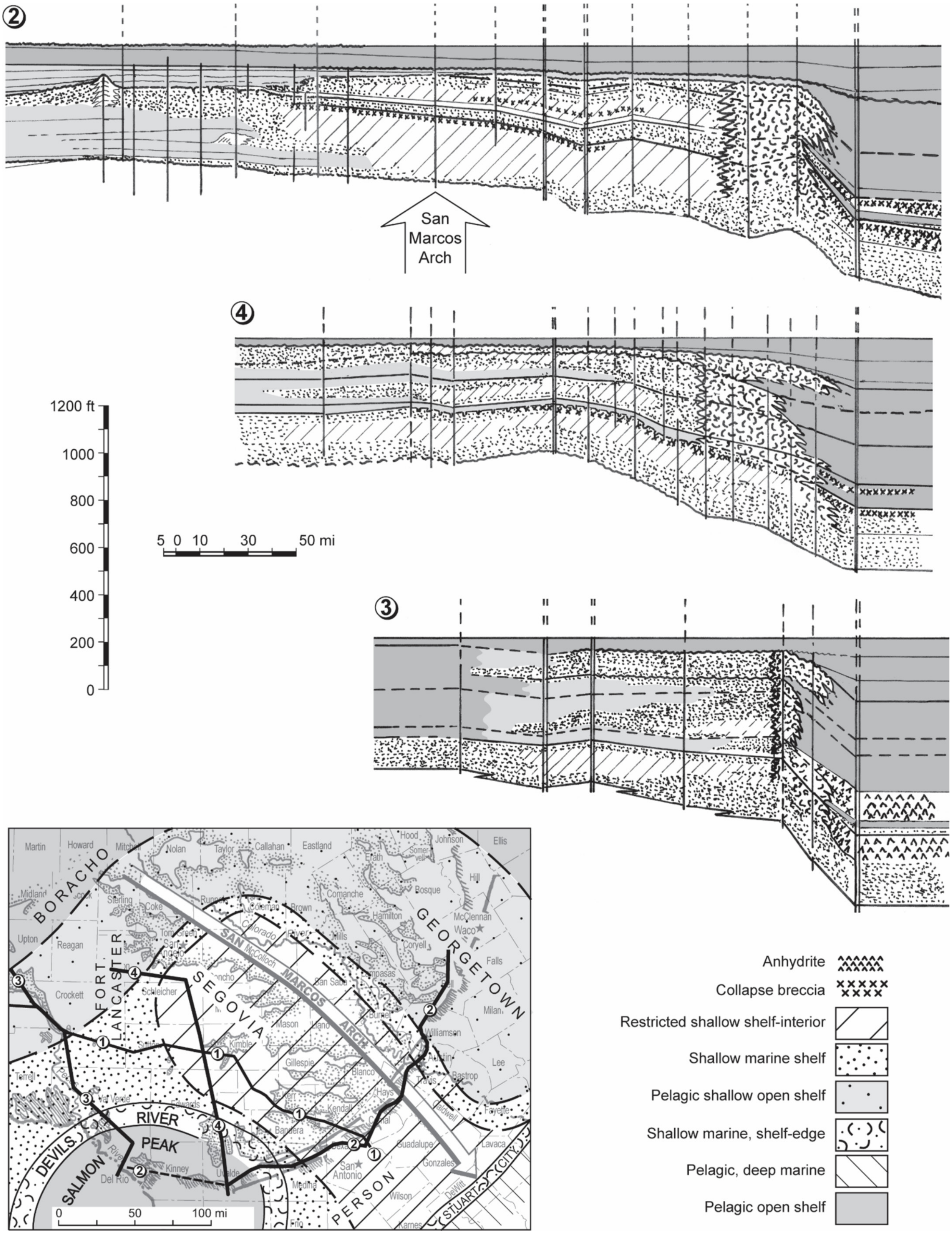
The mapped sequence (Fig. 7) corresponds to the middle sub-cycle referred to above (lower Washita time-rock unit [Fig. 1, cols. 2–6]). Southwesterly, the Segovia Formation thickens gradually across the Edwards Plateau, from the San Marcos Arch to the Devils River Trend. The Segovia's southeastern stratigraphic counterpart, comprising the combined lower Washita part of the upper Kainer (Grainstone Member), the overlying Person Formation plus the thin overlying Main Street Member (uppermost Georgetown Formation) shows similar thickness trends and comparable lithofacies gradations, indicating they are geographic representatives of the same depositional cycle. There are no indications of westward thinning adjacent to the Balcones Fault Zone, as the "revisionist theory" would require. Besides, the age of Balcones faulting is known to be Oligocene-Miocene (not Albian), as discussed herein under Regional Structure.

Conclusion: The Segovia and Person Formations are geographic counterparts of the same depositional cycle.

Regional Correlations, Edwards Plateau to Subsurface, San Marcos Platform

Stratigraphic cross-section V–V' (Fig. 8) is excerpted and modified from regional stratigraphic cross-section #1 (Fig. A1). It shows Edwards lithostratigraphic relationships from the shallow subsurface of the San Marcos Arch westward into outcrops of the Edwards Plateau (Fig. 1, cols. 3 and 4). Note again that underlying and overlying regional disconformities confine the entire Georgetown/Edwards succession: above the underlying Glen Rose Formation of the Trinity Division, and below the overlying Del Rio or Buda Formations (upper Washita). Successions within the Fort Terrett and Segovia formations correlate closely with their Kainer and Person counterparts of the Balcones Fault Zone and adjacent subsurface, notably, two evaporite collapse-intervals, the Kirschberg and Allen Ranch breccias, and the Burt Ranch Member with the Grainstone Member and RDM. The widespread *Gryphaea* biostrome of the eastern and central Edwards Plateau is probably represented by *Gryphaea* specimens in the Selma core, as noted. The widespread Caprinid bed in the upper Segovia correlates with the Marine Member of the upper Person. The thin, pelagic-marine uppermost Georgetown interval

(FACING PAGE) Figure 6. Comparison of three small-scale shelf-to-basin stratigraphic cross-sections, Fredericksburg-Washita Division, Central and West Texas. Datum = top Buda Limestone. All three cross-sections show the Fredericksburg-Washita Division to be bounded above and below by regional disconformities, and to consist of three sub-cycles.


②
San
Marcos
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1200 ft
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③
BORACHO
FORT LANCASTER
SEGOVIA
SAN MARCOS ARCH
GEORGETOWN
DEVILS RIVER
SALMON PEAK
PERSON
STUART CITY
0 50 100 mi
Anhydrite
Collapse breccia
Restricted shallow shelf-interior
Shallow marine shelf
Pelagic shallow open shelf
Shallow marine, shelf-edge
Pelagic, deep marine
Pelagic open shelf

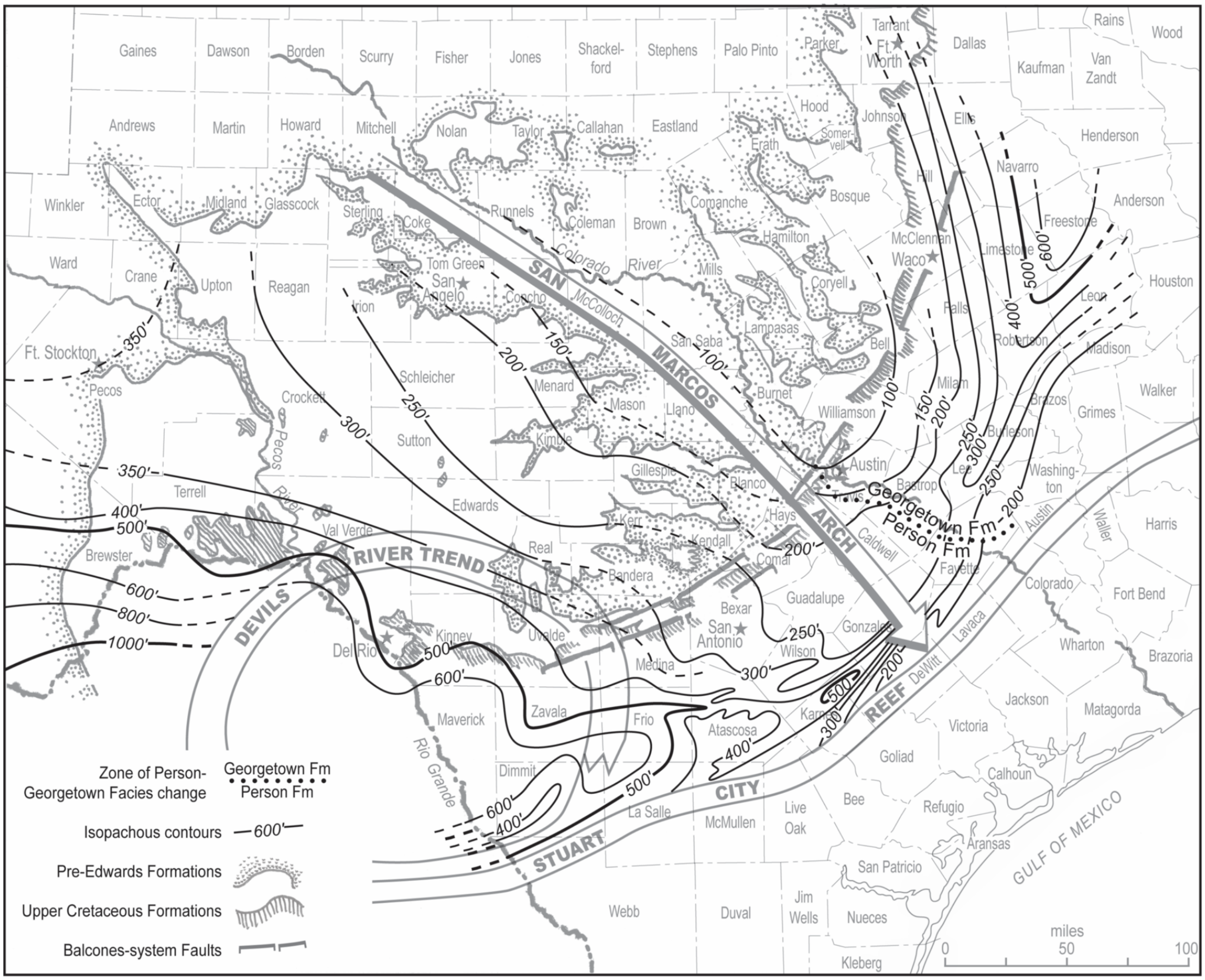

Figure 7. Isopachous contours, lower Washita depositional cycle (in Edwards Plateau = Segovia Formation; in Balcones Fault Zone and adjacent subsurface = Grainstone Member of Kainer Formation plus all of Person Formation plus thin overlying Georgetown Formation) (from Rose, 2016a, reproduced with permission).

that rests unconformably on the Person Formation of the Central Texas Platform (Main Street Member) changes facies westward to skeletal limestones indistinguishable from underlying Segovia carbonates, and correlates with the thin interval of Segovia above the regional Black Bed unconformity on the Edwards Plateau (Halley and Rose, 1977; Smith and Brown, 1983; Moore, 1996). All proponents of the "revisionist view" accept that the Segovia is coeval with the Georgetown, based on shared classic ammonite zones (Fig. 1, cols. 1a, 1b, and 3), established by Adkins (1927, 1933) and Smith et al. (2000). The basal member of the Segovia Formation (the Burt Ranch Member) is equivalent to the Kiamichi Formation of North Texas, both being in the *Adkinsites bravoensis* zone (R. Scott, 2015, personal communication).

Cross-section V–V' (Fig. 8) demonstrates by inspection the fundamental problem with the "revisionist hypothesis": it shows the Person Formation (claimed by "revisionists" to be Fredericksburg) laterally equivalent to the Segovia Formation, acknowledged by "revisionists" to be lower Washita, thus equivalent to the Georgetown Formation of North Texas. In order to satisfy the "revisionist" hypothesis, the Person Formation would have to thin abruptly to zero west of the Balcones Fault Zone; correspondingly, the Segovia Formation would be required to thin reciprocally eastward to zero. Such drastic thinning of otherwise consistent shelf successions would be unprecedented in the region. This represents a stratigraphic correlation which, lacking any physical evidence whatsoever, is simply not credible. Confronted with this evidence, Prof. Robert Scott has invoked (2015, personal communication) possible Albian-age Balcones faulting; however, such faulting is incompatible with the known presence of thick lower Washita formations on the upthrown block of the Balcones system. Also, there is no structural or stratigraphic evidence of such hypothesized faulting, and multiple authorities have shown that Balcones faulting took place in the late Oligocene and Miocene, not the Early Cretaceous. This evidence is devastating to the "revisionist" argument, and none of its adherents has been unable to offer a credible alternative explanation to date.

Conclusion: The Person Formation is laterally equivalent to almost all of the Segovia Formation of the Edwards Plateau, except for the lower Burt Ranch Member (which is equivalent to the Grainstone Member of the Kainer Formation). Inasmuch as the Segovia is accepted as being coeval with the Georgetown, the Person Formation must be coeval with the Georgetown Formation, thus lower Washita.

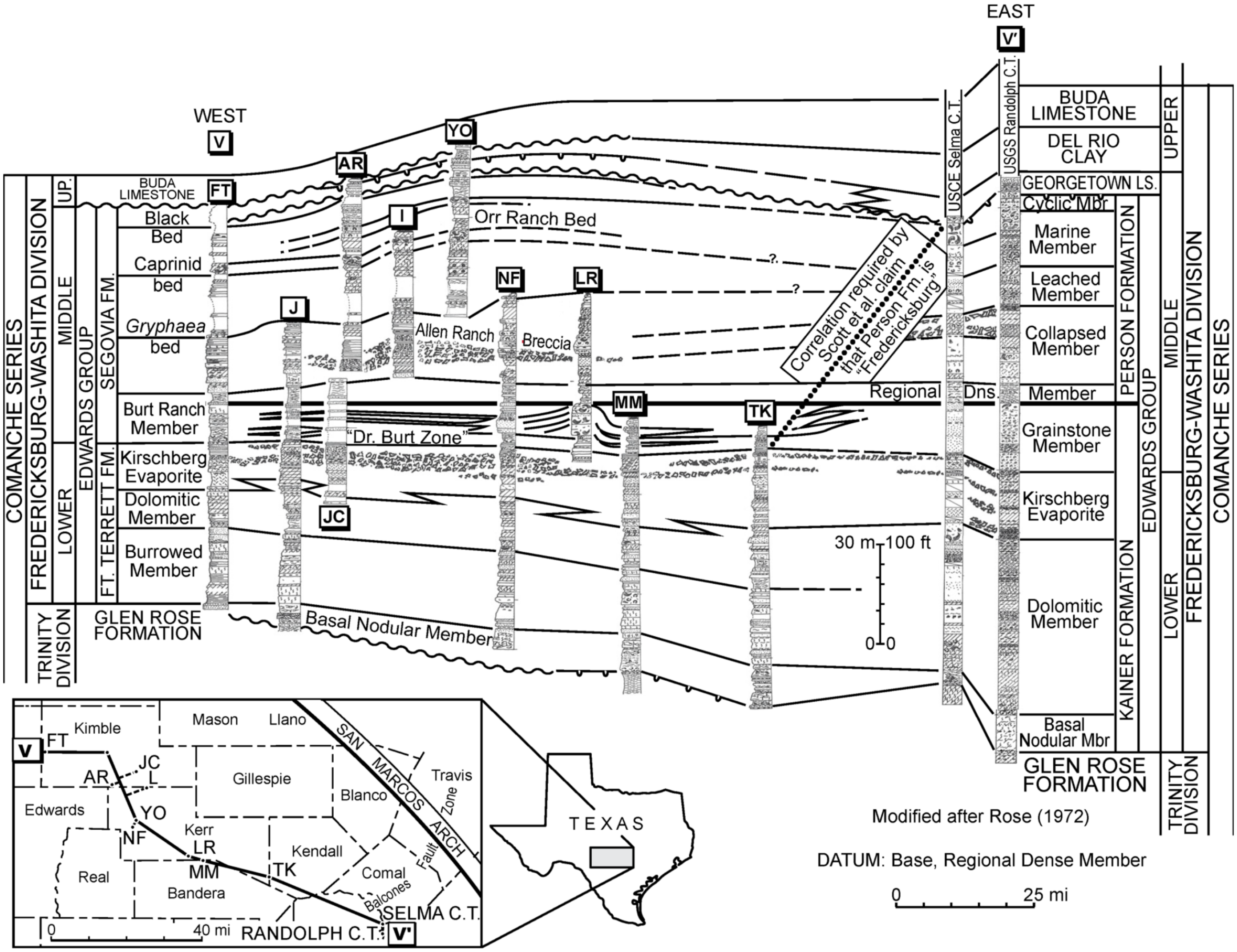

Figure 8. Northwest-southeast stratigraphic cross-section V–V' showing Fredericksburg-Washita stratigraphy from Edwards Plateau across Balcones Fault Zone into shallow subsurface, Central Texas Platform (modified after Rose, 1972, 2016c). Datum = base Regional Dense Member (RDM). Dotted line represents implausible correlation required for Person Formation to be assigned to Fredericksburg sub-cycle, as advocated by Phelps et al. (2014) and Scott et al. (2016a, 2016b), and criticized by Rose (this paper).

Regional Correlations, Central Texas Platform to Devils River Trend to Maverick Basin

Cross-section W–W' (Fig. 9) is excerpted and modified from regional stratigraphic cross-section #2 (Fig. A2), based upon shallow core-tests as well as measured outcrop sections. It passes southwesterly and westerly from near the San Marcos Arch, across the Central Texas Platform and the Devils River Trend, into and across the north side of the Maverick Basin (Fig. 1, cols. 3–6). The two cores on the left end of Fig. 9 (Selma and Randolph core tests) are the same two cores on the right end of cross-section V–V' (Fig. 8; note scale change). Physical correlation from the Kainer and Person formations into and across the Devils River Trend is poor (as it is from Fort Terrett and Segovia measured sections in the Edwards Plateau across the Devils River). However, Hovorka et al. (1996) were able to trace stratigraphic intervals from the Kainer and Person formations through the Devils River Formation, and Miller (1984) demonstrated by closely spaced detailed measured sections that the Fort Terrett succession could be discerned in the lower Devils River and southward into the West Nueces Formation of the Maverick Basin. Even though the Segovia, upper Devils River, and Salmon Peak formations are positioned as geometric equivalents, individual strata cannot be traced continuously from either the Person or Segovia formations through the upper Devils River and into the Pryor Member of the (lower) Salmon Peak Formation (Winter, 1961). Nevertheless, it is clear, from both lateral juxtaposition as well as ammonite zones in the adjacent Maverick Basin that the upper Devils River must be assigned to the lower Washita time-rock unit.

Geometric clinoform relationships from the upper Devils River into the Salmon Peak have been repeatedly invoked (Winter, 1961; Rose, 1972; Bloxsom, 1972; Humphreys, 1984; Miller, 1984; Hovorka et al., 1996), citing the following evidence:

(1) Isopach mapping of overlying Del Rio, Buda, and Eagle Ford formations demonstrate obvious closed-basin contours that are concordant with the areal extent and thickness of the underlying Salmon Peak Formation, suggesting water depths of several hundred feet.
(2) Thick lower Washita Salmon Peak pelagic lime mudstones are stratigraphically juxtaposed against thick, shallow shelf-margin upper Devils River bioclastic limestones, strongly implying that the Salmon Peak was de-

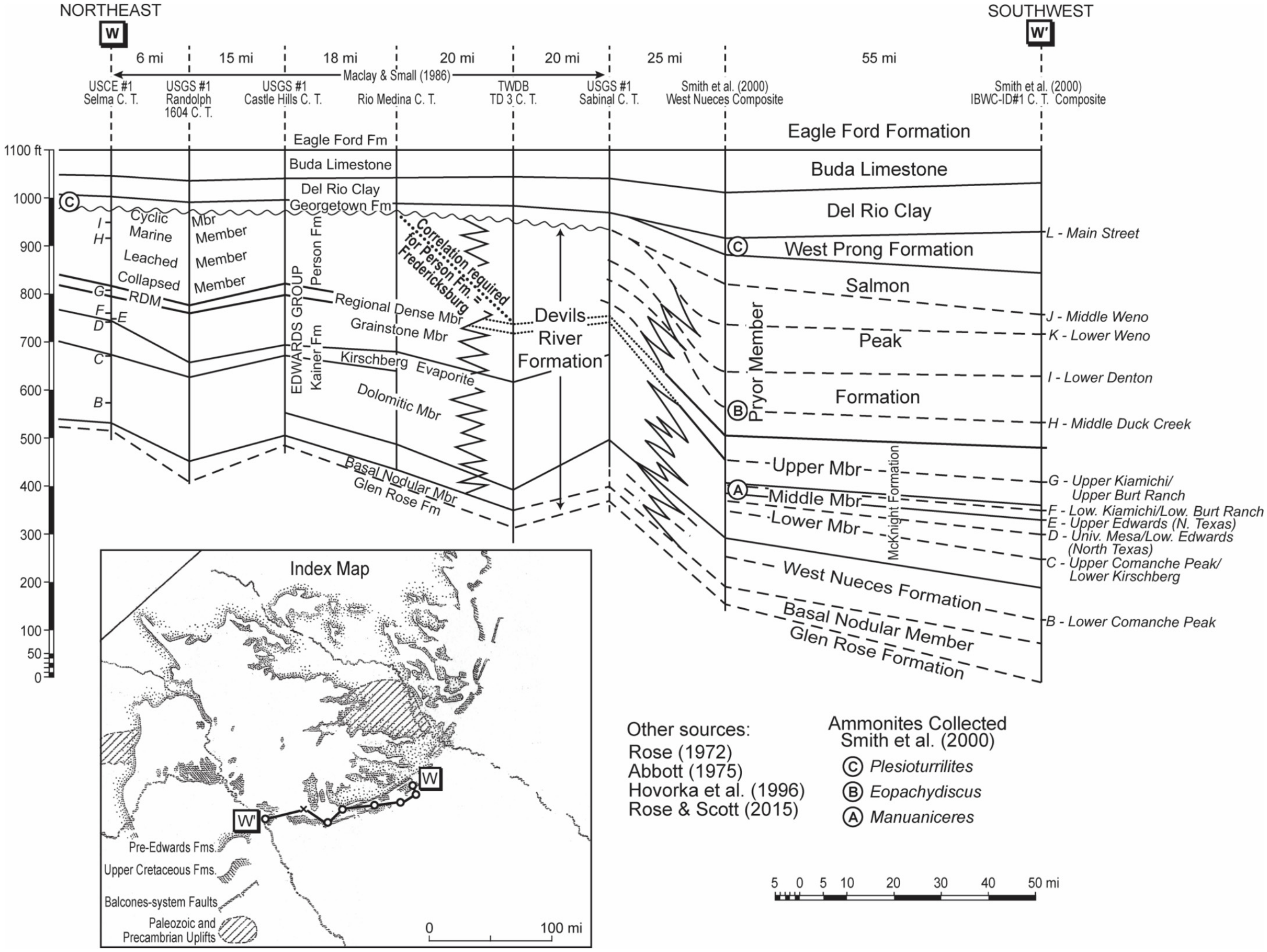

Figure 9. Northeast-southwest stratigraphic cross-section W–W' showing Fredericksburg-Washita stratigraphy from axis of San Marcos Arch, Central Texas Platform across Devils River Trend into Maverick Basin. Datum = top Buda Limestone. Dotted line represents implausible correlation required for Person Formation to be assigned to Fredericksburg sub-cycle, as advocated by Phelps et al. (2014, 2016) and Scott et al. (2016a, 2016b). This figure and counterpart Figure 8 constitute evidence that is fatal to the "revisionist" hypothesis. Derived from Lozo and Smith (1964), Rose (1972), Maclay and Small (1986), Hovorka et al. (1996), Smith et al. (2000), and Rose (2016c).

posited in deeper water, as clinoform slopes between the two formations.

(3) The subsurface Pryor Member of the Salmon Peak Formation (Winter, 1961; Rose, 1972; Humphreys, 1984) is a southward-thinning wedge interpreted as the starved-basin equivalent of the shallow-shelf Person Formation.

(4) Lower Washita ammonite zones in the Salmon Peak (Smith et al., 2000) appear to rise stratigraphically where projected toward and into the upper Devils River Formation (Miller, 1984; see also regional stratigraphic cross-sections #2–#4 (Figs A2–A4).

As with preceding Figure 8, Figure 9 also shows the implausible physical correlation required to satisfy the "revisionist" claim that the Person Formation should be assigned to the Fredericksburg sub-cycle—the Person Formation would be required to thin abruptly to zero approaching the lee side of the upper Devils River bank, and the upper Devils River Formation would have to thin eastwardly and reciprocally to zero. There is neither precedence nor physical evidence for such drastic and conveniently offsetting stratigraphic thickness changes – in fact, the physical evidence itself argues strongly against such a correlation. Taken together, Figures 8 and 9 constitute evidence that is fatal to the "revisionist" hypothesis, and no credible alternative explanation has been advanced to explain this long-apparent and logically irreconcilable conundrum.

Conclusions: The Person Formation is laterally equivalent to the upper Devils River Formation, which on the Edwards Plateau is equivalent to the Segovia Formation, accepted as lower Washita. Moreover, the Person Formation is probably equivalent to the Pryor Member of the Salmon Peak Formation of the Maverick Basin.

Georgetown-Person Ammonite Biostratigraphy of K. Young

A series of papers published by Keith Young records his evolving understanding of the true nature of the Georgetown-Person stratigraphic relationship, passing southward along the Balcones Fault Zone onto the San Marcos Arch (Young, 1959, 1967, 1974, 1979a, 1979b, 1986). Incorporating the findings of his students, especially Martin (1961), Winter (1961), Tucker (1962), Wilbert (1963), Rose (1972), and Abbott (1973), he recognized by 1974 that the Kiamichi Formation thins southward, and merges with the upper RDM, which extends across the San

Marcos Arch at least as far south as New Braunfels (Fig. 1, cols 1a, 1b, and 4) This demonstrated that the Person and Georgetown formations are lateral equivalents, and that the age of the Person Formation must therefore be early Washita, not Fredericksburg (Fig. 10). Although he showed them as having a facies relationship (i.e., interbedded), Young (1974, 1979a) acknowledged that no examples of interbedded Georgetown and Person rock types had been found, but pointed out that the Duck Creek Member thickened and contained progressively more particulates ("sparites") passing southward into the Person Formation, implying a laterally transitional relationship.

The key ammonite associated with the Kiamichi Formation and its equivalents is *Adkinsites bravoensis*. Young (1974, 1979a) stated that *Adkinsites bravoensis* is present at the McNeil Quarry locality "in the Regional Dense Marker at the top of the Kainer," which Prof. Scott ignored. Moreover, *Adkinsites bravoensis* was also identified and collected at the nearby Round Rock locality from the Kiamichi Member of the Georgetown Formation by W. S. Adkins, R. T. Hazzard, and K. P. Young (Feray, 1949). Young also recognized that the Kiamichi/Edwards hardground on the flank of the San Marcos Arch was not the same hardground that is present between the Person and Georgetown on the crest of the arch.

According to Young's (1979b) schematic stratigraphic cross-section (Fig. 10), successive Georgetown ammonite zones, beginning with *Eopachydiscus brazoensis*, followed by the *Pervinquieria equidistans*, *Drakeoceras lasswitzi*, *Mortoniceras wintoni*, and *D. drakei* zones, pinch out southwardly onto (or grade laterally into) increasingly thick shallow-shelf carbonates of the Person Formation (reference to the North Texas Reference Section [Fig. 1, col. 1a and b] is recommended here). Only the highest Georgetown ammonite zone, *Plesioturrilites brazoensis* (coincident with most of the Main Street Formation), makes it onto and across the crest of the San Marcos Arch. This distribution of ammonites therefore supports the interpretation of Tucker (1962), that the Georgetown was a deeper-water equivalent of the peritidal Edwards A–zone (= Person Formation). Rose (1972, 2016a, 2016b, 2016c) modified this interpretation by including the effects of shelfward depositional thickening and clinoform surfaces, especially in the Duck Creek Member.

Thus the physical stratigraphic relationships between the Georgetown and Person formations on the northeast flank of the Central Texas Platform are analogous to those on the southwest flank, across the Person/upper Devils River/Salmon Peak transition into the Maverick Basin. It is puzzling that adherents of the "revisionist hypothesis" appear to accept one example, but not its counterpart on the northeast side of the San Marcos Arch.

<u>Conclusions</u>: Except for the *Plesioturrilites* zone (Main Street equivalent), the Georgetown Limestone is laterally equivalent to the Person Formation, and the RDM is laterally continuous with the Kiamichi Member.

Stratigraphic Cross-Section X–X' Shows that the Kiamichi Grades Laterally into the Upper RDM

Stratigraphic cross-section X–X' (Fig. 11), a transect from the northeastern flank of the San Marcos Arch northward toward the East Texas Basin, shows Georgetown-Edwards stratigraphic relationships in outcrops along the Balcones Fault Zone, across the belt of facies change in Travis County, Texas (Fig. 1, cols. 1a, 1b and 4). The writer carried out field work at all five Georgetown/Edwards localities in September and October 2015.

As shown by Rose (2016c), the trace of stratigraphic cross-section X–X' lies updip from and parallel to the line of the subsurface section shown by Phelps (2011), Phelps et al. (2014, 2016), and Scott et al., 2016b), which they claim demonstrates that the RDM correlates northward into the Walnut–Comanche Peak interval.

Over a distance of 20 miles, the Person Formation (including the marly RDM at the base), thins northward regularly from 81 feet to 12 feet). The basal contact of the RDM on the Grainstone Member at the two northern localities is an iron-stained, bored discontinuity surface; to the south this contact lacks borings.

Over the same 20 miles, the overlying Georgetown Formation thickens reciprocally northward from 35 feet to 100 feet. The Georgetown-Person contact is everywhere an iron-stained, bored, discontinuity surface, but almost certainly not the same surface (Rose, 1972, 2016b, 2016c; Young, 1974, 1979a); i.e., such exposure surfaces are intrinsic to the successive onlap of pelagic open-shelf marly limestones onto and across shallow-shelf particulate limestones (Rose, 1970, 1972). Accordingly, the common presence of iron-stained and/or bored hardgrounds at the top of the Person should not be taken as evidence for a single, common disconformity between the Person and overlying Georgetown formations.

The Kiamichi Member is present at the northern two localities (Brushy Creek and McNeil Quarry) in the upper part of the RDM. *Adkinsites bravoensis*, diagnostic of the Kiamichi, has been collected at both localities (Feray, 1949; Young, 1974, 1979). Ammonites collected at or near all five measured sections demonstrate the progressive southward onlap of Georgetown beds onto (or grade laterally into) the shallow-shelf strata of the southward-thickening Person Formation, precisely as Young had first indicated in 1974, and re-affirmed in 1986.

Figure 11 also demonstrates the implausibility of the claim by Phelps (2011), Phelps et al. (2016), and Scott et al. (2016a, 2016b), that the RDM correlates with the Walnut or Comanche Peak formations, contrary to well-documented work by Moore (1964, 1967, 1996). In fact, the RDM lies about 100–150 feet above the Comanche Peak–Walnut interval in the Austin area. The extraordinary hypothesis advanced by Phelps and Scott ignores the well-known and consistent ~400 foot thickness of the Edwards Group (including the Walnut Formation) in the Austin area, well-established by detailed surface mapping (Garner and Young, 1976) and adjacent subsurface studies (Tucker, 1962; Rose, 1972; Abbott, 1973). Further, for this hypothesis to be correct would require a ±100–150 foot contemporaneous, northeast-striking, antithetic normal fault to lift the "Walnut or Comanche Peak" strata up so as to be truncated by the overlying Georgetown Formation in the Barton Creek vicinity. Other incontrovertible evidence nullifies the Phelps/Scott claims:

(1) Almost all Balcones faulting is synthetic ("down-to-the-coast"), ala Collins and Woodruff (2001);
(2) There is a well-studied normal fault on the north side of Barton Creek immediately southwest of the Loop 1/Loop 360 measured section (right side of Figure 11) but it is synthetic, not antithetic (Garner and Young, 1976; Collins and Laubach, 1990);
(3) The Loop 1/Loop 360 measured section lies on the downthrown side of this fault; and
(4) Balcones faulting is Oligocene/Miocene, not Albian.

<u>Conclusions</u>: The Kiamichi Member of the lower Washita Georgetown Formation merges southward with the upper part of the RDM, thus the overlying Person Formation must be stratigraphically (and geometrically) equivalent to the Georgetown, except for its thin uppermost Main Street Member. Also, the RDM is not correlative with the Walnut or Comanche Peak.

REGIONAL FREDERICKSBURG-LOWER WASHITA DEPOSITIONAL CYCLES

History of Depositional-Cycle Classification

Moore (1996) recognized three cycles of deposition within the Fredericksburg–lower Washita succession on the Central Texas Platform, equivalent to: (1) the Fort Terrett Formation, (2) the Segovia Formation, and (3) the Main Street Member of

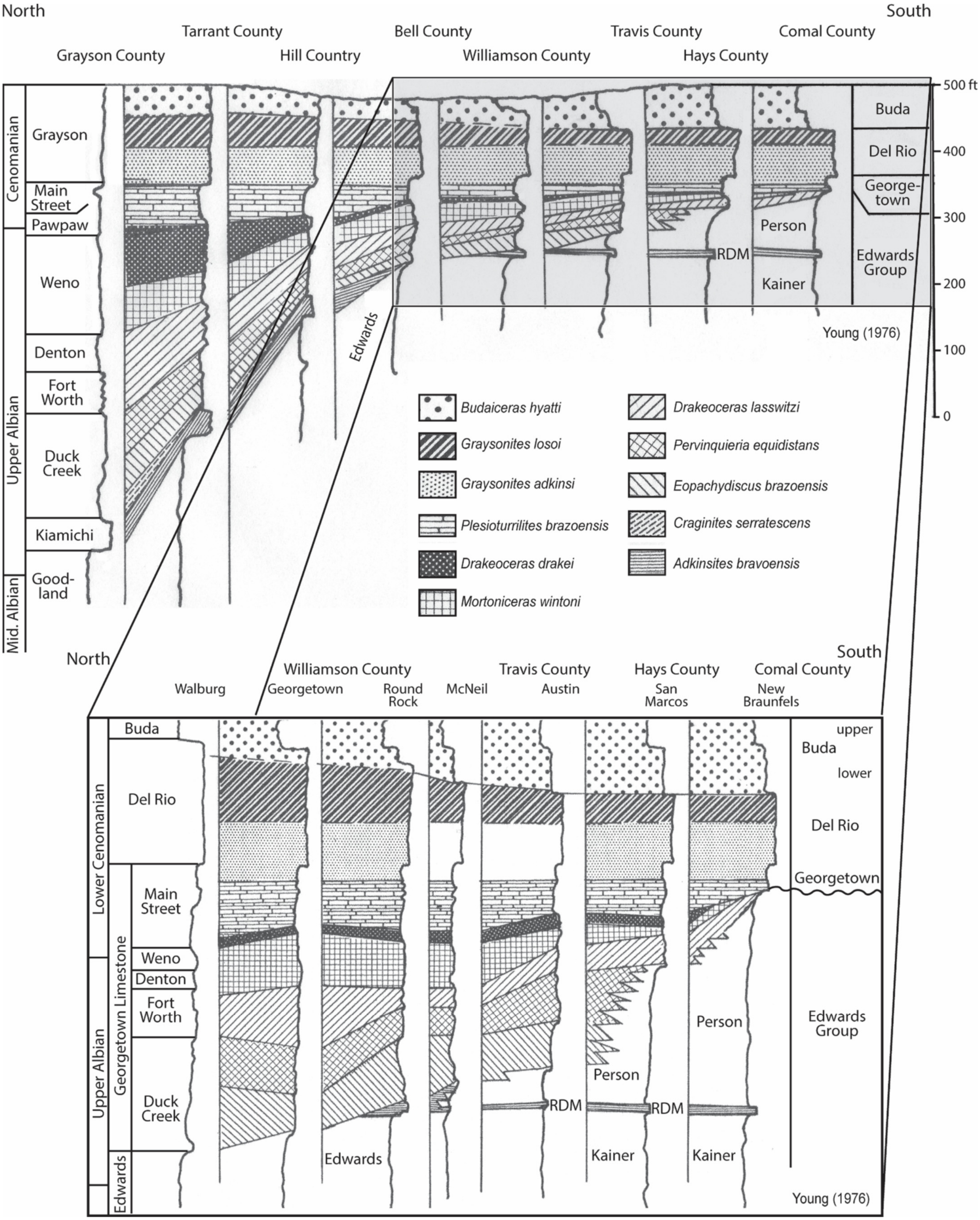

Figure 10. Schematic cross-sections of regional and local stratigraphic relations of upper Albian and lower Cenomanian ammonite zones and equivalent formations, Texas, demonstrating lateral equivalency of (1) Georgetown and Person formations, and (2) Kiamichi and Regional Dense members (RDM) (modified after Young, 1979b, with permission). Datum: top Buda Limestone.

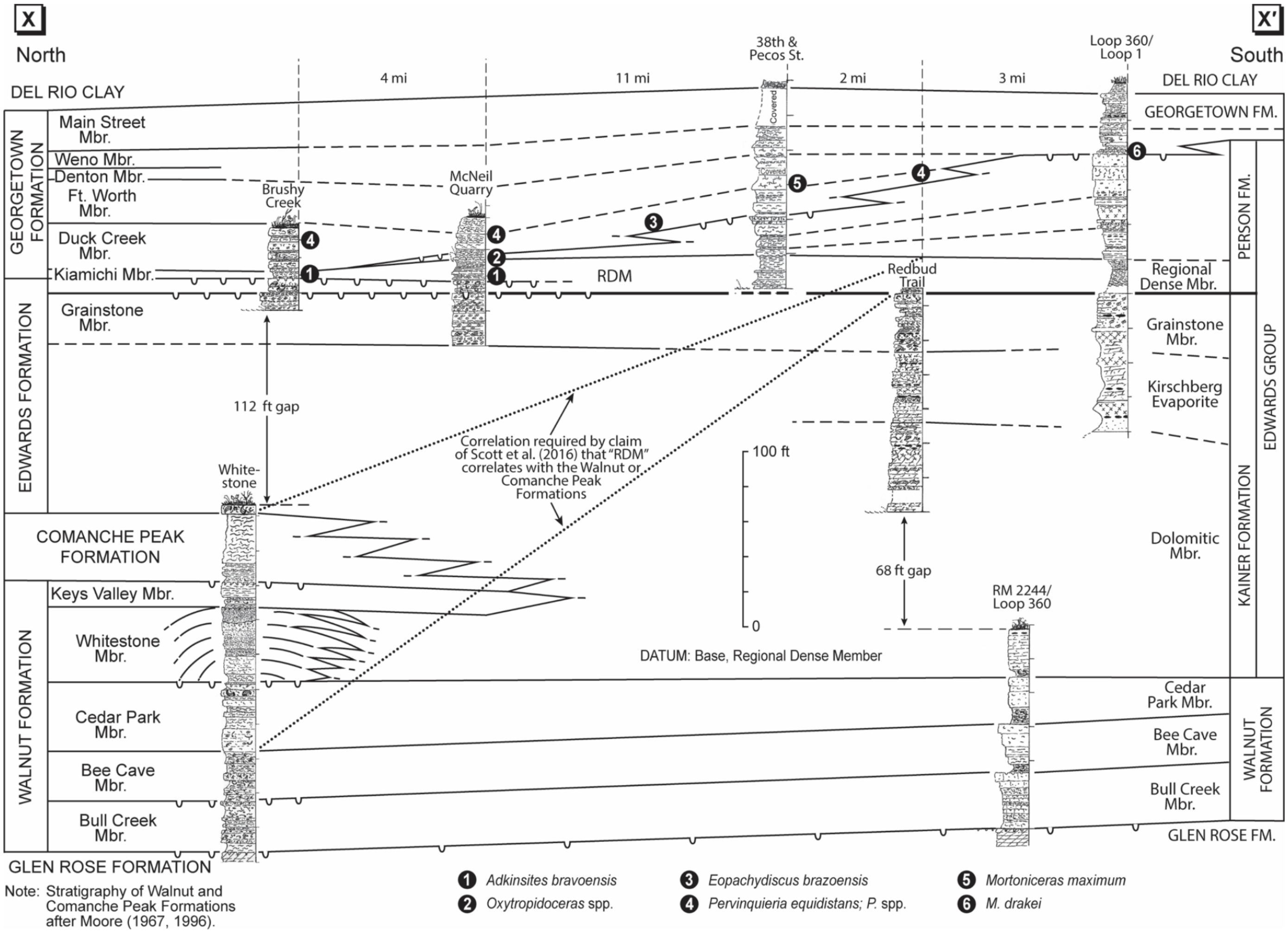

Figure 11. North-south stratigraphic cross-section X–X', Travis Co., Texas, showing (1) Kiamichi Member of Georgetown Formation passes laterally into upper part of Regional Dense Member (RDM); and (2) Georgetown and Person formations are lateral equivalents. Dotted line shows implausible correlation required to satisfy claim of Phelps et al. (2016) and Scott et al. (2016b) that Person Formation is equivalent to Comanche Peak–Walnut formations. Numbered symbols represent ammonite collections. Section derived from Moore (1967, 1996) and Rose (2016b, 2016c). Datum = top Buda Limestone. Section excerpted from regional stratigraphic cross-section #2 (Fig. A2).

the Georgetown Formation and its Edwards Plateau counterpart above the Black Bed (Fig. 12).

Smith et al. (2000) separated this same succession into two depositional cycles. Their lower subdivision corresponds closely to the Fort Terrett Formation of the Edwards Plateau, lower Devils River Formation of southwestern Texas, and in the Maverick Basin, the West Nueces Formation plus the Lower Member of the McKnight Formation. Their upper subdivision includes the Fort Lancaster and Segovia formations of the western and eastern Edwards Plateau, respectively, the Boracho Formation of the Boracho (= Fort Stockton) Basin, the upper Devils River Formation of southwest Texas, and the middle and upper members of the McKnight Formation plus the Salmon Peak Formation in the Maverick Basin (the overlying Del Rio and Buda formations constitute the uppermost [upper Washita] of Smith et al.'s [2000] three Fredericksburg-Washita cycles),

Phelps (2011) and Phelps et al. (2014) perceived the entire Edwards and Georgetown succession to represent only one transgressive-regressive cycle. Focused on the Gulf Coast part of the Comanche Series, however, they did not consider the implications of the correlative Fort Terrett–Segovia succession of the Edwards Plateau (the northwestern two-thirds of the Central Texas Platform), thus mistakenly placed the Person Formation in the Fredericksburg cycle.

Rose (2016b) pointed out the above errors, and showed that the Fredericksburg–lower Washita (F–lW) succession on the Central Texas Platform) consisted of three transgressive-regressive cycles, in upward order:

(1) Cycle F–lW1: Fort Terrett–lower Kainer—thin basal transgression (= Basal Nodular Member) overlain by thick regression (= gradually shallowing peritidal deposits of the Dolomitic Member, culminating in the widespread Kirschberg Evaporite).
(2) Cycle F–lW2: Segovia Formation below the Black Bed unconformity—Grainstone Member of the Kainer Formation plus all of the Person Formation—transgressive ammonite-bearing marly sequence grading southeasterly to miliolid grainstone, capped by upper Burt Ranch marl/RDM (= Kiamichi Member), overlain by regressive thick peritidal dolomites and collapse breccias, succeeded upward by a transgressive-regressive couplet (shallow-marine, coarse-bioclastic limestones [Marine and Cyclic members of Person Formation and *Gryphaea* Bed and Orr Ranch Bed of the Segovia Formation]).
(3) Cycle F–lW3: Upper Georgetown—Paw-paw and Main Street members of Georgetown Formation in the Balcones Fault Zone and subsurface represent the concluding lower Washita transgression that covered the Central Texas Plat-

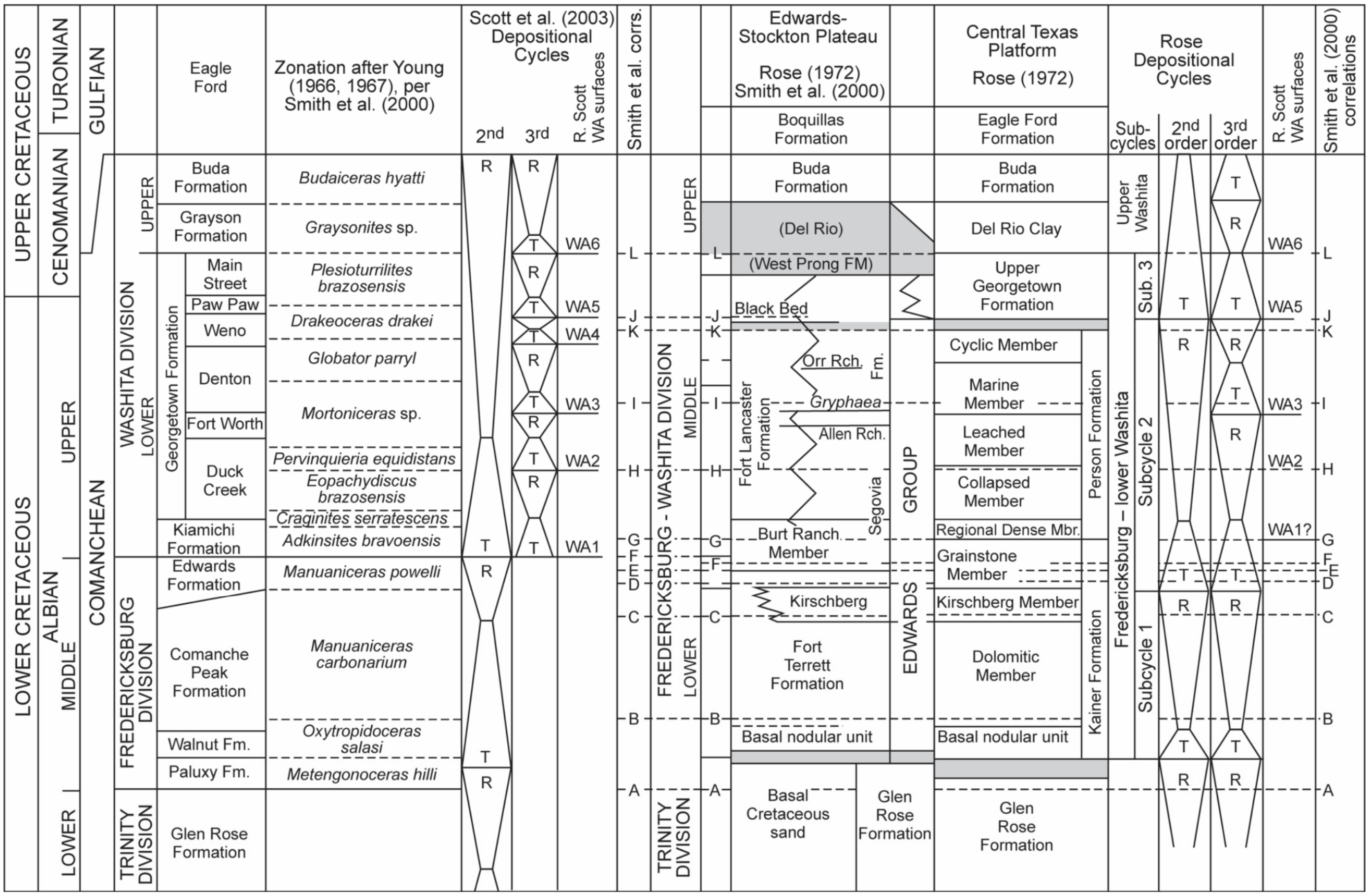

Figure 12. Comparison of sequence-stratigraphic cycles between North Texas standard reference section (Scott et al., 2003) and Rose (this paper). Note second-order Fredericksburg-Washita sub-cycles and lower Washita third-order subsequences. Dotted lines are correlation surfaces from Smith et al. (2000). Derived from Smith et al. (2000), Scott et al. (2003), and Rose (2016b, 2016c).

form; the uppermost Segovia Formation above the Black Bed is probably a shallow-shelf facies of the upper Georgetown.

As a final consequence, Rose (2016b) recommended elevating the upper boundary of Phelps et al.'s (2014) Aptian-Albian Supersequence from 101 to 99.6 Ma, coinciding with the Georgetown–Del Rio boundary, a suggestion which Phelps et al. (2016) rejected.

The present paper further amplifies and augments Rose's (2016b) recommendation, emphasizing that, over most of the Central Texas Platform, the entire Fredericksburg–lower Washita succession (Albian) is in shallow-shelf carbonate facies (= Edwards Group), and the obvious regional sequence boundary is the disconformity at the base of the Buda or Del Rio formations (Fig. 12). This very widespread disconformity marks the beginning of the final flooding of the Central Texas Platform near the end of Comanchean time. That is where the upper boundary of the Aptian-Albian naturally occurs (reinforced by the fact that the overlying Del Rio and Buda formations are early Cenomanian).

The Fredericksburg (sub-cycle 1) represents a single, long, very widespread transgressive-regressive cycle of deposition characterized by shallow-shelf subtidal and supratidal dolomitic and evaporitic environments in the interior of the Central Texas Platform, and subtidal to shallow-shelf limestones far to the west and north, around and beyond the margins of the Central Texas Platform.

In contrast, the lower Washita (sub-cycle 2) records a regional retreat of peritidal carbonate deposition onto the Central Texas Platform, and shallow-marine shelf carbonates are seen to grade southward, westward and northward (peripheral to the platform interior) into marly, marine, ammonite-bearing carbonate facies. An analogous facies change also occurs eastwardly, where the thin, shallow-marine uppermost Segovia Formation above the Black Bed disconformity is interpreted to grade laterally into the thin, pelagic-marine Main Street Member (uppermost Georgetown), which rests disconformably on the Person Formation (Rose, 1972, 2016c; Halley and Rose, 1977). This lateral gradation is postulated to lie in the 60 mile gap between the Balcones Fault Zone and west-central Kerr County. Lacking this regional perspective, Phelps et al. (2014, 2016) mistakenly identified this disconformity as the significant stratigraphic boundary at the natural top of the Aptian-Albian Supersequence.

Recommended Classification of Fredericksburg–Lower Washita Depositional Cycles

The present paper deals with the two sub-cycles that constitute the Albian Fredericksburg–lower Washita Division (the overlying Cenomanian Del Rio and Buda formations [Upper Washita] represent the third sub-cycle of the Fredericksburg-Washita Division of Smith et al. [2000]). Figure 12 summarizes the relationships described below. Figures 13 and 14 are small-scale regional stratigraphic cross-sections showing the boundaries of sub-cycles and subsequences, and boundaries of formations and members, respectively. Reference to all three figures is recommended.

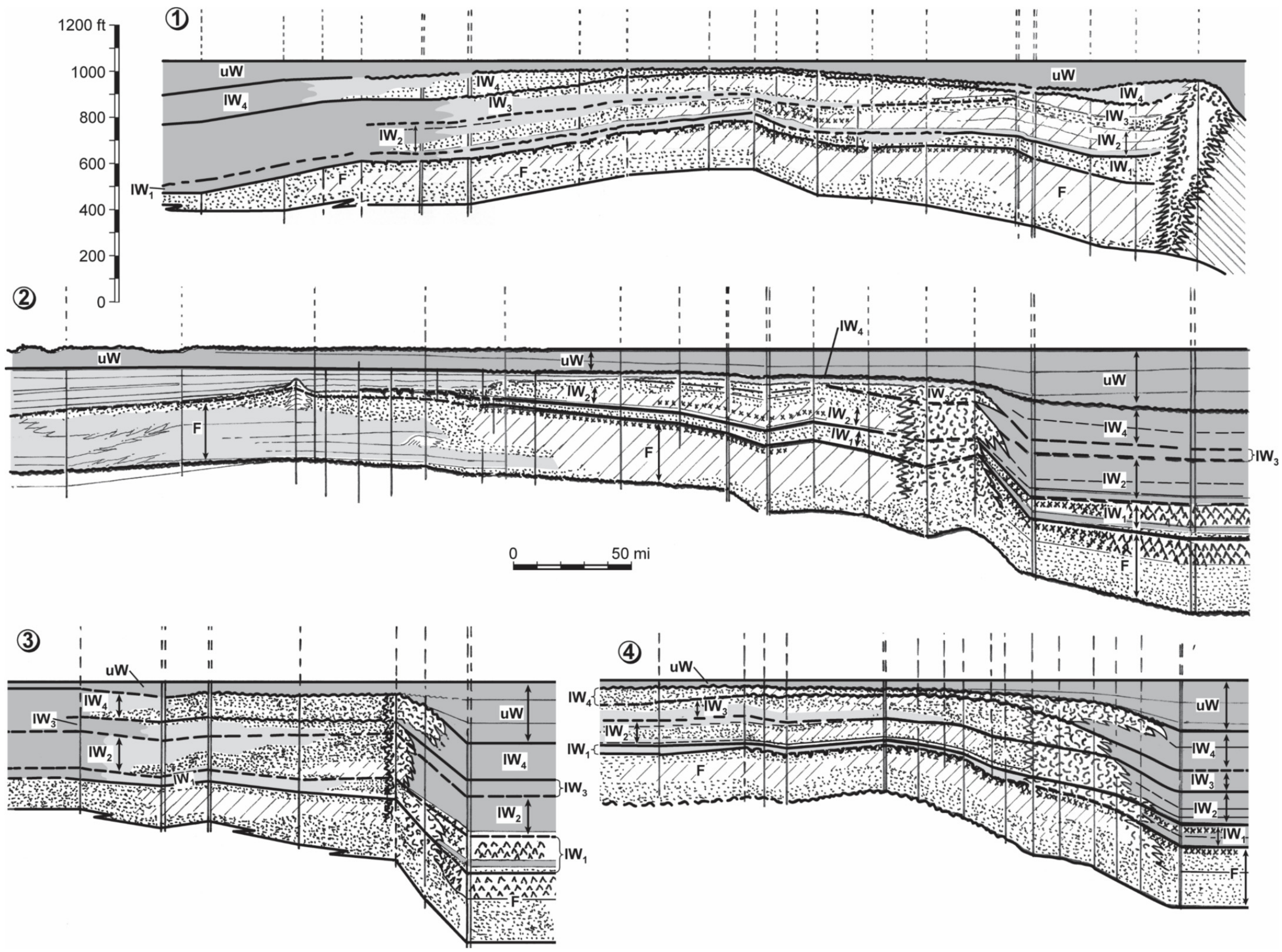

Figure 13. Small-scale regional stratigraphic cross-sections #1, #2, #3, and #4, showing boundaries of Washita-Fredericksburg sub-cycles and lower Washita subsequences (modified after Rose, 2016c). Datum = top Buda Limestone. For location of sections, see Figures 2, 3, and 5.

Fredericksburg Sub-Cycle (F–lW1)

The Fredericksburg sub-cycle is best defined in and around the type locality, in the eastern Edwards Plateau. As previously noted, it is represented by the Fort Terrett Formation, consisting of a thin basal transgressive leg overlain by a single thick gradually shoaling-upward limestone and dolomite succession that culminates in a widespread evaporitic collapse breccia, the Kirschberg Evaporite (remnant in-situ gypsum deposits are present in northern Gillespie and eastern Menard counties). The Fort Terrett is present throughout the Edwards Plateau region, and extends westward into Trans-Pecos Texas, and northward, beyond the Callahan Divide area of North Texas. Southward from the type area, the Fort Terrett Formation grades laterally into the lower Devils River Formation and the West Nueces–lower McKnight formations of the Maverick Basin (Figs. 13 and 14). The eastward equivalent in the Balcones Fault Zone and subsurface of the Central Texas Platform is the lower part of the Kainer Formation (the Dolomitic Member, in the upper part of which are evaporite collapse breccias assigned to the Kirschberg Evaporite).

Lower Washita Sub-Cycle (F–lW2)

The lower Washita sub-cycle of the Central Texas Platform is best defined in the eastern Edwards Plateau, as represented by the Segovia Formation. Its westward equivalent is the Fort Lancaster Formation; its Maverick Basin counterparts are the upper Devils River, middle and upper McKnight, and Salmon Peak formations. All parties to this stratigraphic dispute agree that these formations belong in the lower Washita sub-cycle (Fig. 12).

As shown in Figures 12–14, the eastward equivalent of the Segovia Formation is the interval (Grainstone Member of the Kainer Formation + all of the Person Formation + the thin Main Street Member of the Georgetown Formation), contrary to the claim of Phelps (2011) and Phelps et al. (2014, 2016), that the Grainstone Member and Person Formation belong in the Fredericksburg sub-cycle. A regional disconformity separates the peritidal Person Formation from the overlying thin pelagic-marine Main Street Member (uppermost Georgetown), thought to be the same as the Black Bed disconformity in the upper Segovia Formation.

The lower Washita sub-cycle comprises four third-order subsequences, in upward order:

Subsequence 1 (lW–1): The lower part of the Burt Ranch Member of the Segovia Formation consists of marly lime mudstone with thin interbeds of miliolid grainstone/packstones in the central and western Edwards Plateau. Easterly (toward the Stuart City Reef) and southerly (toward the Devils River Trend), the miliolid grainstone facies increases at the expense of the marly facies, finally leaving only a thin (15–20 feet) marl at the top of

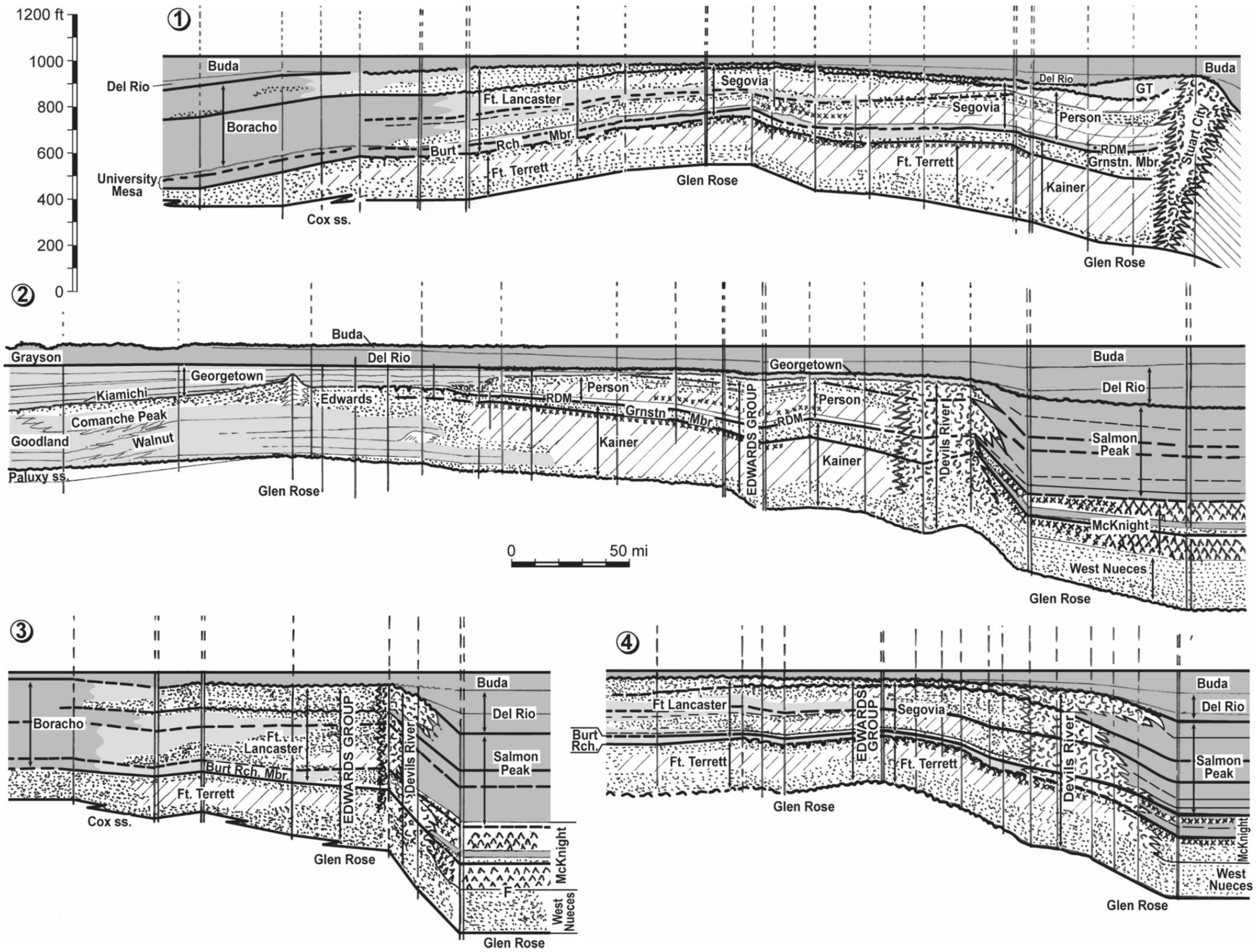

Figure 14. Small-scale regional stratigraphic cross-sections #1, #2. #3, and #4, showing names and boundaries of Fredericksburg-Washita formations and members (modified after Rose, 2016c). Datum = top Buda Limestone. For location of sections, see Figures 2, 3, and 5.

the Burt Ranch interval, which is the Regional Dense Member (RDM) of the Person Formation, as well as the basal transgression of overlying lower Washita subsequence lW–2. Thus the Grainstone Member of the (upper) Kainer Formation is the easterly equivalent of the lower Burt Ranch Member of the Segovia Formation. Based on published ammonite collections, the Burt Ranch Member, the RDM, and the Kiamichi Shale of North Texas are all in the ammonite zone *Adkinsites bravoensis*, acknowledged by all disputants to be basal Washita. In the Maverick Basin, the middle and upper members of the McKnight Formation are Burt Ranch equivalents (Smith et al., 2000). A discontinuity surface (hardground) is present at the base of the Burt Ranch Member throughout the Edwards Plateau. Eastward and southward, however, additional hardgrounds are present higher in the Burt Ranch, at contacts of marl beds upon miliolid grainstones (Rose, 1970, 1972, 2016c).

Subsequence 2 (lW–2): In the central Edwards Plateau, this subsequence begins with a thin (20–30 feet) marine marl interval in the upper Burt Ranch Member; farther south and east, as discussed above, the thin upper marl of the Burt Ranch Member is interpreted to be the same as the RDM of the Balcones Fault Zone and adjacent subsurface. Above the RDM/upper Burt Ranch Marl, subsequence lW–2 contains mostly peritidal dolomitic strata assigned to the Leached and Collapsed members of the Person Formation and lower-middle Segovia and Fort Lancaster formations. In the Edwards Plateau, the top of subsequence lW–2 lies below the shallow-marine invasion marked by the widespread *Gryphaea* Bed, interpreted to be equivalent to the Denton Formation of North and Central Texas, and characterized by Young (1974, 1979a) as a *Gryphaea* lumachelle. In the Fort Lancaster Formation of the western Edwards Plateau, this marine invasion is represented by ammonite-bearing marine marls above shallow-shelf carbonates of Smith et al.'s (2000) "Middle Caprock." In the Balcones Fault Zone, Martin (1961) noted outcropping *Gryphaea* lumachelles in the Denton Member just north of the axis of the San Marcos Arch. The same marine invasion is represented by the Marine Member of the Person Formation, so the underlying Leached and Collapsed members are assigned to subsequence lW–2. In the Maverick Basin, subsequence lW–2 cannot be clearly identified, but the subsurface Pryor Member of the Salmon Peak Formation (Winter, 1961; Rose, 1972; Humphreys, 1984) is likely to be its starved-basin equivalent.

Subsequence 3 (lW–3): In the upper Segovia Formation of the eastern Edwards Plateau, this subsequence consists mostly of higher-energy shallow-marine bioclastic limestone strata, from the *Gryphaea* Bed invasion upward to the Black Bed disconformity. Farther west, in the Fort Lancaster Formation, subsequence 3 consists of alternating intervals of ammonite-bearing marl and shallow-marine shelf limestones, becoming more marine to the west and north. To the south, subsequence 3 is present, though ill-defined, in the upper Devils River Formation, and in the Maverick Basin, in the middle part of the Salmon Peak Formation. Eastward from the Balcones Fault Zone, subsequence 3 comprises the Marine and Cyclic members of the Person Formation.

Subsequence 4 (lW–4): The uppermost subsequence of the lower Washita subcycle comprises all strata between the Black Bed/Green Bed/Red Bed/Yellow Bed disconformity (Rose, 1972; Halley and Rose, 1977; Smith and Brown, 1983; Smith et al., 2000) and the regional disconformity at the base of the overlying Del Rio or Buda formations, as discussed above. In the eastern Edwards Plateau, this is a shallow marine, mostly bioclastic limestone succession that thickens southward from zero to more than 50 feet thick. In the western Edwards Plateau it is the "Upper Caprock" of Smith et al. (2000), which thickens southward and westward from 50 feet to more than 150 feet In the Maverick Basin it is undefined, but probably comprises the upper 150–200 feet of the pelagic Salmon Peak Formation. In the Balcones Fault Zone (as previously discussed), it is the thin (0–25 feet) Main Street Limestone, uppermost member of the Georgetown Formation, containing the diagnostic ammonite *Plesioturrilites*, which is also found at the top of the Salmon Peak Formation in the Maverick Basin, and in the top of the Fort Lancaster Formation in Trans-Pecos Texas. In the subsurface downdip from the Balcones Fault Zone, the Georgetown Formation thickens gulfward across the shelf to more than 200 feet in the contemporaneous Karnes Trough (Rose, 1972). However, it is not known whether such thick Georgetown intervals are only Main Street equivalents or perhaps successively older Georgetown members may intervene in the lower measures.

As shown by Figure 13, stratigraphic distribution of the four lower Washita subsequences (lW–1, lW–2, lW–3, and lW–4) provides independent support for the stratigraphic correlations otherwise derived using more traditional stratigraphic methods. Counterpart Figure 14 (facing) repeats the same four regional cross-sections, in which main formation and member names are shown.

Recognition of these sub-cycles and subsequences of the Fredericksburg-lower Washita succession applies only to the Central Texas Platform. Whether they are recognizable to the north and northeast, in the East Texas Basin, or elsewhere, is conjectural. The obvious fact that there is disagreement about these cycles constitutes tacit validation of the principle that such cycles should be first recognizable in a given depositional region, rather than projecting their presence in from outside provinces.

The Edwards Group of the Central Texas Platform constituted a vast offshore sediment trap for prolific manufacture and accumulation of a diverse suite of very shallow carbonate and evaporitic facies, far removed from any contemporary supply of production-impeding terrigenous muds and clays. Rates of carbonate sediment accumulation were substantially greater than in more terrigenous-rich stratigraphic equivalents in open marine shelf settings of north Texas and southern Oklahoma, as exemplified by clinoform surfaces extending outward and downward from the shelf interior. Contrary to claims of Phelps et al. (2014, 2016) and Scott et al. (2016a, 2016b), it should be no surprise that the clay-rich Kiamichi Shale of North Texas changes facies to the slightly argillaceous micrite of the RDM passing southward into the carbonate province of the Central Texas Platform.

INTERPRETATION OF HARDGROUNDS IN CARBONATE STRATIGRAPHY

As shown here, the Kiamichi Shale, an important regional spreading (i.e., transgressive) sequence in North Texas and Oklahoma, thins steadily southward and passes into the upper RDM on the Central Texas Platform, where it also represents a regional flooding surface, located well above the beginning of the transgressive leg of subsequence lW–1 (previous Figures 12–14). Moreover, while the base of the RDM is almost everywhere abrupt and iron-stained, there is (with a few notable exceptions) commonly little evidence for subaerial (or even submarine) exposure or erosion in most outcrops and cores. This may be explained by the known higher rates of sediment accumulation on the Central Texas Platform, compared with the starved basin to the north. If so, this suggests that the prominent regional hardground at the base of the Kiamichi in North Texas (Scott et al.'s WA–1) probably begins to separate as it impinges southward onto the Central Texas Platform, splaying out into less prominent hardgrounds or simple bedding surfaces, such as those noted by Rose (1970, 1972) in the correlative Burt Ranch Member of the Segovia. By analogy, Young (1974, 1979a) recognized that the base-Kiamichi disconformity at Round Rock was not the same disconformity as that at the base of the Georgetown farther southward, toward the axis of the San Marcos Arch.

The Kiamichi thickens northward to more than 50 feet in North Texas. Scott et al. (2003) estimated that the duration of the hiatus below regional disconformity WA–1 to be 1.00 to 1.28 million years in North Texas, which may represent the time required for deposition of all the lower part of the Burt Ranch Member in the Edwards Plateau, as well as the Grainstone Member of the Kainer Formation on the distal Central Texas Platform (Figs. 1, 8, and 12–14). This implies that Disconformity WA–1 occurs as the culmination of transgressive subsequence lW–1, not the initiation. If that supposition is correct, then the regional discontinuity surface at the base of the Burt Ranch Member represents the true base of the first transgressive pulse above Fredericksburg strata, and the base of the RDM represents the next such pulse.

This dispute exemplifies the understandable tendency for stratigraphers to project widespread discontinuity surfaces (and sequence boundaries) from one depositional province into another. Ordinarily, however, there are no features uniquely diagnostic of one particular hardground over another, and identification of subaerial vs submarine discontinuity surfaces in shallow shelf carbonate sequences is neither reliable nor significant. Rose (1970, 1972) documented repetitive hardgrounds wherever marine marls rested upon miliolid grainstone strata—that is, exposure surfaces (either subaerial or submarine) are intrinsic features associated with small-scale marine transgressions over particulate carbonate sediments, and may not be widely traceable, especially where clinoform slopes are involved. In any case, even regionally significant surfaces must end somewhere; the most likely ending-places should be expected to lie at the boundaries between different depositional provinces.

Another interesting aspect of this stratigraphic problem concerns the influence of depositional topography and discontinuity surfaces on facies changes. Wherever marine-shelf carbonate sediments encroach gradually on gentle clinoform slopes of shallow-shelf origin, we see a series of transgressions, of varying scales. The upper surface of each clinoform represents a period of nondeposition and exposure, submarine or subaerial, of long or transitory duration. Here it is useful to distinguish between "formation-scale" facies changes and "member or bed-scale" facies changes. For example, the writer would freely acknowledge that a discontinuity surface where the Duck Creek Member rests on a Person clinoform surface mandates that the Duck Creek (at that locality) is younger than the Person. However, a succession of counterpart contacts, all involving serially younger Georgetown members (and multiple repetitive discontinuity surfaces) on Person clinoforms indicates that the Person Formation is a shelf-interior facies of the pelagic-shelf Georgetown Formation. This conclusion is mandated by the regional Person-Segovia equivalency (Segovia and Georgetown both being accepted as lower Washita).

Yet another aspect of this fascinating topic has to do with graphics—on stratigraphic cross-sections we represent interbedded facies changes with zig-zag lines (*"give it the old light-*

ning!"), but we do not have a comparable symbol to represent simple lithologic gradations, especially in carbonate rocks, which appears to characterize the Duck Creek–Person facies change in Central Texas.

This stratigraphic example demonstrates a pregnant topic for future research: the genesis, interpretation, and utilization of hardgrounds in physical stratigraphy.

SHELF-TO-BASIN CORRELATION ISSUES

Most authorities seem to agree that clinoformal settings characterize the peripheral margins of the Central Texas Platform. The gulfward front of the Stuart City Reef, which forms the southeastern margin of the Central Texas Platform, declines into dark contemporaneous lime mudstones; paleo-topographic relief may be as much as 1000 feet or more. By analogy, Devils River clinoforms slope eastwardly, southwardly and westwardly into the subsiding Maverick Basin, suggesting paleotopographic relief of 150–200 feet. The Devils River Trend forms the southwestern margin of the Central Texas Platform. The western, northwestern, and northern margins of the Central Texas Platform lie in West Texas, on the stable Comanche Shelf, where clinoform slopes were present, but more gentle and gradual, as shown by the east-west stratigraphic cross-sections of Smith et al. (2000). Most of the long (~250 miles) northeastern margin of the Central Texas Platform has been removed by Tertiary erosion; only a 50 mile segment remains, southeastward from a narrow belt of intermittent outcrops along the Balcones Fault Zone into the subsurface beneath Travis, Bastrop, and Fayette counties.

A typical lateral succession would feature peritidal muddy dolomite and limestone of the platform interior grading to shallow marine muddy limestones, passing (often abruptly) into a narrow band of coarse-grain, high wave-energy bioclastic and/or bioconstructional limestones, sloping downward into mud-rich marine limestones. That model is reasonably characteristic of the southeastern (Stuart City) and southwestern (Devils River) margins of the Central Texas Platform. Implicit in this stratigraphic model is that the shelf sediments are coeval with the juxtaposed "off-shelf" sediments.

It is not characteristic of the northeastern and northwestern margins of the Central Texas Platform, however, where subsidence rates were lower, depositional slopes were much more gentle, and lateral facies changes were more gradual. Protected by the wide, shallow inland sea between the cratonic terrigenous Albian shoreline in central Oklahoma (as well as the constructional barrier of the Stuart City Reef); the north and northeastern margins of the Central Texas Platform were much more sheltered from high energy currents and waves than its southeastern and southwestern margins. As a direct result, such facies progressions feature lower-energy carbonate successions, and muddy, shallow-shelf subtidal deposits that grade laterally into shallow pelagic-marine muds and marls. Even so, evidence of low clinoforms, and subtle basinward thinning is apparent in stratigraphic cross-sections of both outcrops as well as wireline logs of wells, as shown by Tucker (1962) and Rose (1972, 2016c). This is the site of the lateral Person-to-Georgetown facies change, which is also mandated by the demonstrated fact that the Person, Georgetown and Segovia formations are lateral equivalents (Figs. 8 and 9).

RECONCILING BENTHIC BIOSTRATIGRAPHY AND INTEGRATED STRATIGRAPHY

Stratigraphic conclusions discussed to this point have resulted from the integration of: (1) widespread surface and subsurface mapping; (2) physical stratigraphy; (3) distribution of formations, members, and key beds, (4) discontinuity surfaces (hardgrounds); (5) distributions of paleoenvironments; (6) long-established ammonite zones; and (7) correlations based on sequence stratigraphy. The writer has taken pains to reconcile and "close" all correlations among the five regional stratigraphic cross-sections, as well as on Figures 6, 13, and 14, paying particular attention to correlation surfaces based on ammonite zones.

Prof. Scott (in Phelps et al., 2014; Scott et al., 2016a, 2016b) disputed the stratigraphic conclusions presented here, primarily based on distribution of benthic organisms (mostly rudists). The writer points out that experience with benthonic foraminifera in Recent carbonate sediments of South Florida and the Bahamas (Rose and Lidz, 1977), shows the acute sensitivity of benthic faunas to even minor differences in bottom sediment, water depth, water circulation patterns, and depositional environments. Albian rudists, as quasi-colonial benthos, were at least as sensitive to analogous environmental influences, rendering variations in rudist morphology equivocal with regard to their chronological significance..

The writer notes the two omnipresent alternatives concerning interpreted changes in morphology of benthic organisms: *chronologic or environmental?* Yet Scott ascribes all morphologic changes defining rudist genera and species without question to chronologic significance. In addition, sampling of rudists from the Edwards Group has been notably sparse and scattered, without accompanying detailed descriptions of host lithologies for comparative purposes. Moreover, the stratigraphic definition of rudist biozones in the Edwards Group is still in its infancy, and here the writer points out the other omnipresent alternative in such zonations: *such boundaries are based only on what has been discovered and identified to date, and are always subject to revision as new studies indicate.* This is especially concerning in the early phases of establishing zonations. Finally, Prof. Scott has clearly relied almost entirely on benthic fossil evidence in challenging the long-held stratigraphic conclusions concerning the Edwards Group and associated formations, to the exclusion of comprehensive (= integrated) stratigraphy.

Given the existing detailed and comprehensive stratigraphic framework that documents and interrelates the Fredericksburg and lower Washita strata of Central Texas (Figs. 2, 13, 14, and A1–A5), the writer respectfully suggests that it may constitute an unusually reliable opportunity for paleontologists to conduct future discriminating studies of the distribution of rudist and other benthic faunas by lithofacies as well as by evolution and geologic time.

DISCUSSION

This extended stratigraphic dispute arose from an unexpected and very interesting discovery by Waite et al. (2007) in a long core from the Pioneer #1 Schroeder well through the Stuart City Reef at Pawnee Field, Bee County, Texas. The entire progradational succession in the Schroeder core consists of apparent Fredericksburg-age rudist-bearing shelf-margin deposits, so that reef facies equivalent to the peritidal Person Formation (lower Washita) appear to be absent. However, extensive, mostly vertical fractures in the top ~300 feet of the Schroeder core are filled with pelagic lime mud containing Georgetown-age planktic foraminifera. Additionally, Waite et al. (2007) found a thin (12 feet) dark, *Lithocodium* boundstone interval at 12,390–12,402 feet, which they chose to correlate with the RDM of the shelf interior to the northwest. As a result, Waite et al. (2007) concluded that the Person Formation was entirely Fredericksburg. Phelps (2011) accepted this revision without question and Phelps et al. (2014) utilized it without comment.

The author disputes the "Waite hypothesis," based on multiple lines of evidence:

(1) Weight of evidence: the conclusion that the Person Formation is entirely Fredericksburg ignores a very substantial, documented and tested regional stratigraphic literature, accepting instead a dubious interpretation supported by a very limited dataset.

(2) The correlation of Waite's thin *Lithocodium* boundstone from the heart of the Stuart City Reef back into the peritidal shelf setting of the RDM obviously represents correlation from one major depositional realm into a very different one. By analogy, Miller (1984) and Smith et al. (2000) were not able to trace the Burt Ranch Member through the Devils River Trend. Further, Waite et al. (2007, their figures 6 and 8) showed that the RDM could not be traced southeastward into the Stuart City Reef in the Texas Eastern #1 Garbe well, nor could it be traced from the Mobil #1 Ford, Jr. well southeastward into the Schroeder #1 well at Pawnee Field. The inferred presence in a highly variable (thickness, lithology, and depositional topography) reef tract, of a thin marker known to be consistent across an adjacent flat shelf-interior is inherently questionable.

(3) The lithology of Waite et al.'s (2007) dark *Lithocodium* boundstone is incompatible with the very consistent, widely extensive, slightly argillaceous lime mudstone lithology of the RDM. Moreover, this rock unit is identified in the Schroeder core only, not widely present in multiple wells across and along the Stuart City Reef.

(4) Phelps et al. (2014, their figure 12) stratigraphic cross-section A–A' demonstrates that the Stuart City Reef is substantially thicker than equivalent formations on the adjacent Central Texas Platform. Moreover, overlying formations such as the Del Rio and Eagle Ford thin over the crest, demonstrating that the crest of the reef was higher than the lee-side flank. Yet the RDM of Phelps is shown to decline approaching the lee side of the Stuart City Reef.

(5) The Waite et al. (2007) study apparently rests on examination of one core. Its startling results beg for supporting evidence from other cores along the Stuart City trend.

However, the main conclusion of Waite et al. (2007) is important and intriguing—that in at least one place (Pawnee Field) the Stuart City Reef apparently consists entirely of Fredericksburg-age reef rocks. Shell chose the original Pawnee location recognizing that it was on a regional structural high, being located above the underlying Sligo reef crest. Even so, based on the general recognition that the lower Washita represents a regional transgression over and across the underlying Fredericksburg facies tracts, conventional stratigraphic thinking would have predicted the presence of a substantial thickness of lower Washita (Person-equivalent) reef facies at Pawnee, situated above the Fredericksburg-age reef, or on its gulfward flank. But the presence of lower Washita pelagic muds suggests (but does no prove) that any equivalent lower Washita reef facies must lie shelfward, not gulfward. The Schroeder well instead indicates lower Washita fore-reef (pelagic) carbonate mud lying on and filtering into fractured Fredericksburg-age reef rock. Where is the Person-equivalent reef facies?

One possible explanation is that the Schroeder core represents a large talus-block of Fredericksburg reef that slid a short distance gulfward beyond the lower Washita reef front, so that pelagic lower Washita muds seeped into fractured Fredericksburg reef-front rocks. A second hypothesis is that the pelagic lower Washita muds occurred in a narrow trough between the Fredericksburg-age reef and its lower Washita counterpart a short distance farther seaward. A third possible interpretation is that lower Washita reef sediments were never deposited around the Pawnee topographic and structural high, but were deposited to the northeast, along the front of the Stuart City Reef. Ancillary to that hypothesis is that, southwest of Pawnee, the lower Washita reef facies shifted northwestward, to the Devils River Bank. A fourth explanation is that rudists hitherto believed to be restricted to the Fredericksburg may have survived into the early Washita. In any case, it is clear that the overall hypothesis advanced by Waite et al. (2007) may be locally correct, but not of regional significance; other explanatory hypotheses may arise, and more comprehensive study is clearly needed to resolve this question.

CONCLUSIONS

The Kiamichi Member of the Georgetown Formation in North Texas and the East Texas Basin, the Regional Dense Member of the Person Formation in the Balcones Fault Zone and adjacent subsurface, and the Burt Ranch Member of the Segovia Formation in the Edwards Plateau are stratigraphic equivalents, based on physical stratigraphy and ammonite zonation, all in the *Adkinsite bravoensis* Ammonite Zone. The Georgetown, Person, and most of the Segovia Formation are also lateral equivalents, assigned to the lower Washita sub-cycle (Cycle F–lW2). Thus the Person Formation is properly assigned to the lower Washita, not the Fredericksburg. As shown herein, claims to the contrary rely upon faulty or incomplete evidence, ignore established geological relationships, or require highly implausible geologic conditions for which no physical evidence exists.

This dispute has highlighted interesting new topics for further stratigraphic inquiry:

(1) The physical characteristics, lateral extent, and appropriate stratigraphic utilization of hardgrounds in carbonate stratigraphy;

(2) How to reconcile stratigraphic sequences in adjacent regions having different depositional histories;

(3) What is the distribution of Fredericksburg and lower Washita reef facies on the Central Texas Platform?

ACKNOWLEDGMENTS

The writer expresses his appreciation for the interaction of Prof. Robert W. Scott in ongoing studies of Fredericksburg and Washita stratigraphic issues in Texas. He also thanks Mr. Joel Lardon for executing all figures and Ms. Elizabeth Sherry for preparing the final manuscript. Special thanks go to reviewers Dr. Tom Ewing and Mr. Brian Hunt, and to editor Dr. Barry Katz for improving the manuscript. No public or private grants were used for research or preparation. This paper is dedicated to the memory of Delos R. Tucker and Keith P. Young.

APPENDIX

This Appendix describes five large regional stratigraphic cross-sections, which are included in the digital version of this paper (Figs. A1–A5) and within a companion paper published in the 2017 *GCAGS Transactions* (Rose, 2017) Together they form an interlocking network defining the Fredericksburg-Washita stratigraphy of Texas (Fig. 2). The cross-sections are based mostly on measured sections, plus a few cores, mostly from very shallow wells.

Stratigraphic cross-section #1 (Fig. A1) passes eastward from Trans-Pecos Texas across the Edwards Plateau to the Balcones Fault Zone, where it veers southeastward beneath the Gulf Coastal Plain, ending near Cuero, Texas. This provides a stratigraphic transect along the southwestern flank of the San Marcos Arch, from the Boracho Basin across the gradually shoaling western margin of the Central Texas Platform into the platform interior, then across the Stuart City Reef and into the Albian Gulf of Mexico. Stratigraphic cross-section #1 intersects all four of the other cross-sections.

Stratigraphic cross-section #2 (Fig. A2) passes from the west flank of the East Texas Basin southward across the San Marcos Arch and the southwest flank of the Central Texas Platform, southwestwards across the Devils River Trend and then westward along the north side of the Maverick Basin. South and west of Austin, it is based on mostly shallow cores augmented by measured sections; northward, it is based entirely on measured sections. Cross-section #2 intersects all four of the other cross-sections.

Stratigraphic cross-section #3 (Fig. A3) follows the Pecos River Valley southeastward from south of Odessa to Del Rio, Texas. It begins in the Boracho Basin, traverses the southwest flank of the Central Texas Platform, across the Devils River Trend, and ends in the Maverick Basin. Cross-section #3 intersects cross-section #1 and cross-section #2.

Stratigraphic cross-section #4 (Fig. A4) begins about 15 miles north of Barnhart, Texas, and passes eastward to near Christoval, then southward across the Edwards Plateau and the Devils River Trend, ending in the Maverick Basin. This trace starts in the northern, open shallow-marine margins of the Central Texas Platform, traverses the restricted shelf interior and Devils River Trend, and ends in the Maverick Basin. Cross-section #4 intersects cross-sections #1, #2, and #5.

Stratigraphic section #5 (Fig. A5) starts near Belton on the southwestern flank of the East Texas Basin and trends southwestward across the Llano Uplift, the San Marcos Arch, the shelf interior of the Central Texas Platform, and the Devils River Trend, ending in the Maverick Basin. This cross-section intersects cross-sections #1, #2, and #4.

All five cross-sections were originally executed using common vertical (1 inch = 100 feet) and horizontal (1 in = 10 miles) scales, depicted graphically on each section. These are the cross-sections displayed in the poster session. In Rose (2016c), they were reduced to 60% of their original size and scale, but digital versions appended to this paper are provided in their original full 100% scale.

All sections utilize the top of the Buda Limestone as the common stratigraphic datum. In the few areas where the Buda is not present, its thickness was derived from regional isopach mapping by Rose (1972, 2016a). Constituent columnar sections were taken directly from the original sources, mostly Lozo and Smith (1964), Moore (1964, 1967), Smith et al. (2000), and Rose (1972).

Ammonites collected from or near measured sections were mostly identified by B. F. Perkins, C. I. Smith, K. P. Young, and R. W. Scott. All sources are cited on each stratigraphic cross-section.

Physical correlations of Smith et al. (2000) were duplicated on the stratigraphic cross-sections, as were their interpreted correlation surfaces (A through L), based on ammonite occurrences as they relate to the classic Fredericksburg-Washita succession of North Texas (Adkins, 1927, 1933; Young, 1966, 1967, 1974, 1979a, 1979b, 1986; Scott et al., 2003). In North Texas, the ammonite succession and physical stratigraphy were taken from Scott et al. (2003).

Physical stratigraphic correlations of Rose (1972, 2016b, 2016c) were duplicated in the five regional stratigraphic cross-sections. In the restricted shallow-shelf interior settings, where ammonites are extremely rare, I projected the correlation surfaces A through L from Smith et al. (2000) from their adjacent measured sections as dotted lines concordant with my physical stratigraphic correlations, and "closed" all correlation surfaces among the five regional cross-sections, thus reconciling the entire five-section grid.

Stratigraphic correlation section #5 shows a gap of 56 miles where it crosses the Llano Uplift from northeast to southwest. The Edwards, Georgetown, Del Rio, and Buda formations are missing in this gap because of Tertiary erosion. Here I have interpreted Fredericksburg-Washita stratigraphic relations consistent with observed patterns in stratigraphic cross-section #2 and represented the interpreted stratigraphy using dashed lines.

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FREDERICKSBURG-WASHITA STRATIGRAPHY OF TEXAS:

STRATIGRAPHIC CROSS-SECTION # 1

Peter R. Rose

2016

P. R. Rose April 2016

SOURCES

Adkins (1927, 1933); Lozo and Smith (1964); Rose (1972); Abbott (1975); Halley and Rose (1977); Bebout et al. (1977); Fallon (1981); Smith and Brown (1983); Smith et al. (2000); Phelps et al. (2014).

EXPLANATION:

CORRELATION SURFACES FROM SMITH ET AL. (2000):

H – Middle Duck Creek

H – Middle Duck Creek (projected by PRR)

COLLECTED AMMONITES:

Adkinsites bravoensis

A. bravoensis

NORTH
SOUTH
EAST
WEST
FT WORTH COMPOSITE
HILLSBORO COMPOSITE
VALLEY MILLS COMPOSITE
BELTON COMPOSITE
ROUND ROCK COMPOSITE
AUSTIN COMPOSITE
SAN MARCOS COMPOSITE
NEW BRAUNFELS COMPOSITE
U.S.C.E. #1 SELMA C. T.
USGS #1 RANDOLPH 1604 C. T.
USGS #1 CASTLE HILLS C. T.
MACLAY & SMALL (1986) - RIO MEDINA C. T.
TWDB TD 3 C. T.
USGS #1 SABINAL C. T.
WEST NUECES COMPOSITE Smith et al. (2000)
IBWC-1D-22/PH # 4V COMPOSITE Smith et al. (2000)
50 MILES
35 MILES
45 MILES
40 MILES
20 MILES
27 MILES
17 MILES
13 MILES
6 MILES
15 MILES
18 MILES
20 MILES
20 MILES
25 MILES
55 MILES
EAGLE FORD FM.
BUDA LIMESTONE
DEL RIO CLAY
GEORGETOWN FM.
GRAYSON FM.
MAIN STREET MBR.
FT WORTH MBR.
DENTON MBR.
DUCK CREEK MBR.
KIAMICHI FM.
EDWARDS FM.
COMANCHE PEAK FM.
GOODLAND FM.
WALNUT FM.
PALUXY FM.
GLEN ROSE FM.
WASHITA GROUP
EDWARDS GROUP
PERSON FM.
KAINER FORMATION
SALMON PEAK FORMATION
WEST PRONG FORMATION
DEVILS RIVER FORMATION
WEST NUECES FORMATION
MCKNIGHT FORMATION
BASAL NODULAR MBR.
L - MAIN STREET
J - MIDDLE WENO
K - LOWER WENO
I - LOWER DENTON
H - MIDDLE DUCK CREEK
G - UPPER KIAMICHI/UPPER BURT RANCH
F - LOWER KIAMICHI/LOWER BURT RANCH
E - UPPER EDWARDS (NORTH TEXAS)
D - UNIVERSITY MESA/LOWER EDWARDS (NORTH TEXAS)
C - UPPER COMANCHE PEAK/LOWER KIRSCHBERG
B - LOWER COMANCHE PEAK
WEST FLANK EAST TEXAS BASIN
SAN MARCOS ARCH
CENTRAL TEXAS PLATFORM
MAVERICK BASIN
DATUM: TOP BUDA LIMESTONE
FREDERICKSBURG-WASHITA STRATIGRAPHY OF TEXAS:
STRATIGRAPHIC CROSS- SECTION # 2
Peter R. Rose
2016
SOURCES
Lozo, (1959a); Nelson (1959, 1973); Shelburne (1959); Winter (1961);Tucker (1962); Wilbert (1963); Lozo and Smith (1964); Moore (1964, 1996); Young (1966, 1974, 1979, 1986); Bishop (1967); Dixon, 1967); Smith (1970); Rose (1966, 1972, 1986, 2016a, 2016b); Abbot, (1973); Amsbury et al. (1973); Bay (1977): Bolland and Geffert (1979), Smith and Brown (1983), Humphreys (1984), Miller (1984), Maclay and Small (1986), Lemons (1987), Smith, et al. (2000); Hovorka et al. (1996); Scott et al. (2003).
EXPLANATION:
CORRELATION SURFACES FROM SMITH ET AL. (2000):
H – Middle Duck Creek
H – Middle Duck Creek (projected by PRR)
COLLECTED AMMONITES:
Adkinsites bravoensis
A. bravoensis

FREDERICKSBURG-WASHITA STRATIGRAPHY OF TEXAS:

STRATIGRAPHIC CROSS- SECTION # 3

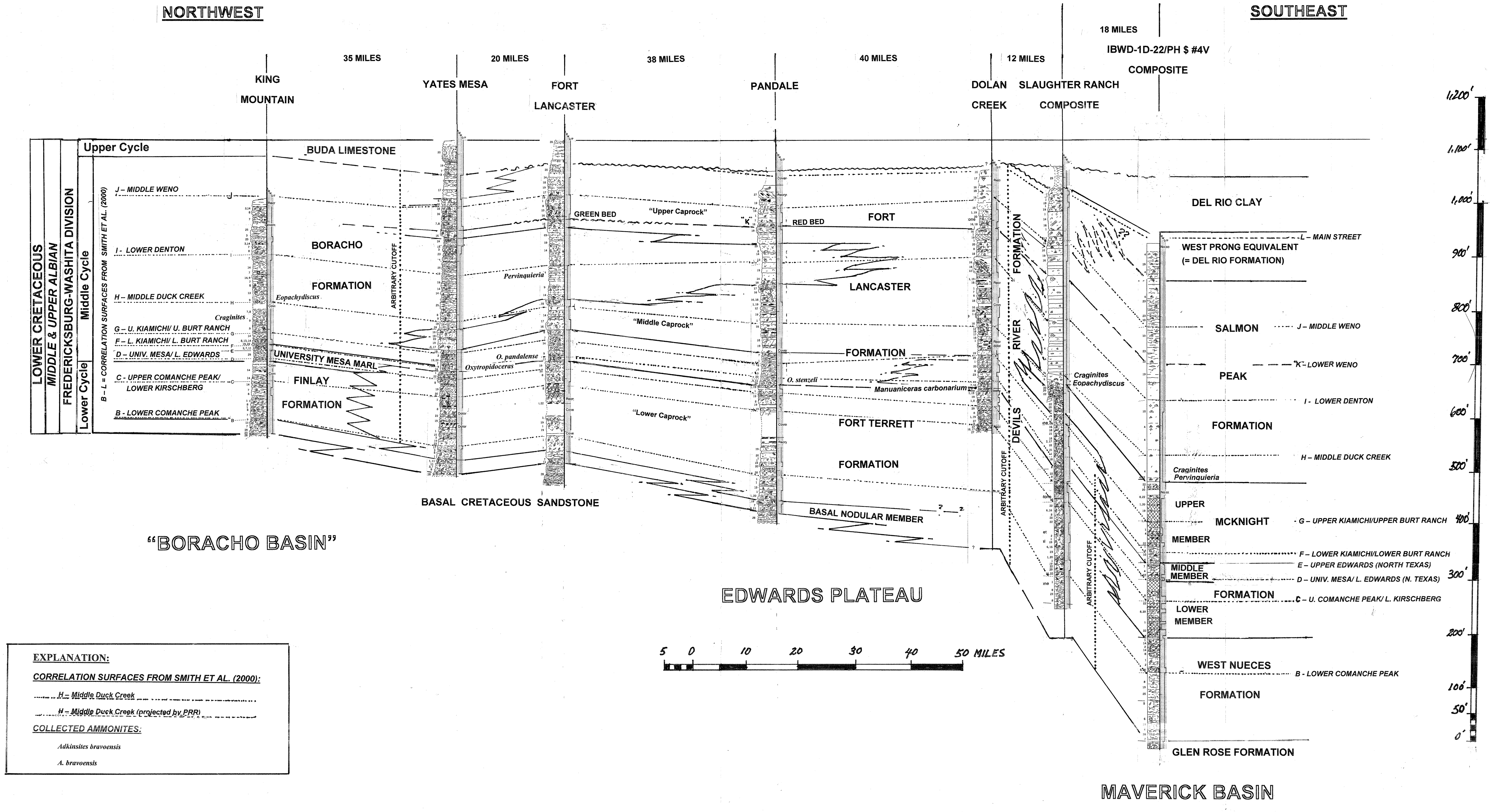
Peter R. Rose

2016

DATUM: TOP BUDA LIMESTONE

SOURCE

Smith et al. (2000).



EXPLANATION:

CORRELATION SURFACES FROM SMITH ET AL. (2000):

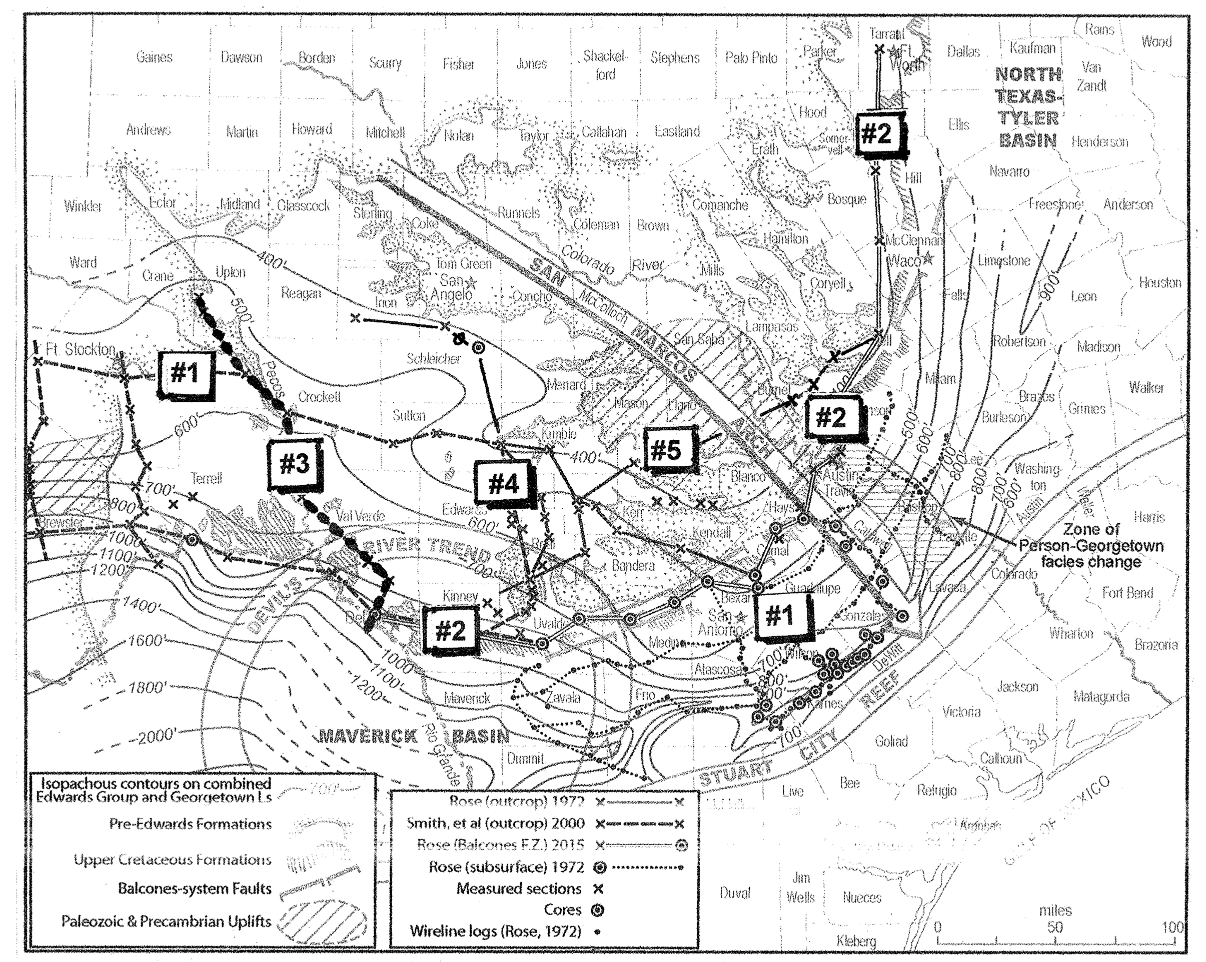
H – Middle Duck Creek

H – Middle Duck Creek (projected by PRR)

COLLECTED AMMONITES:

Adkinsites bravoensis

A. bravoensis



FREDERICKSBURG-WASHITA STRATIGRAPHY OF TEXAS:

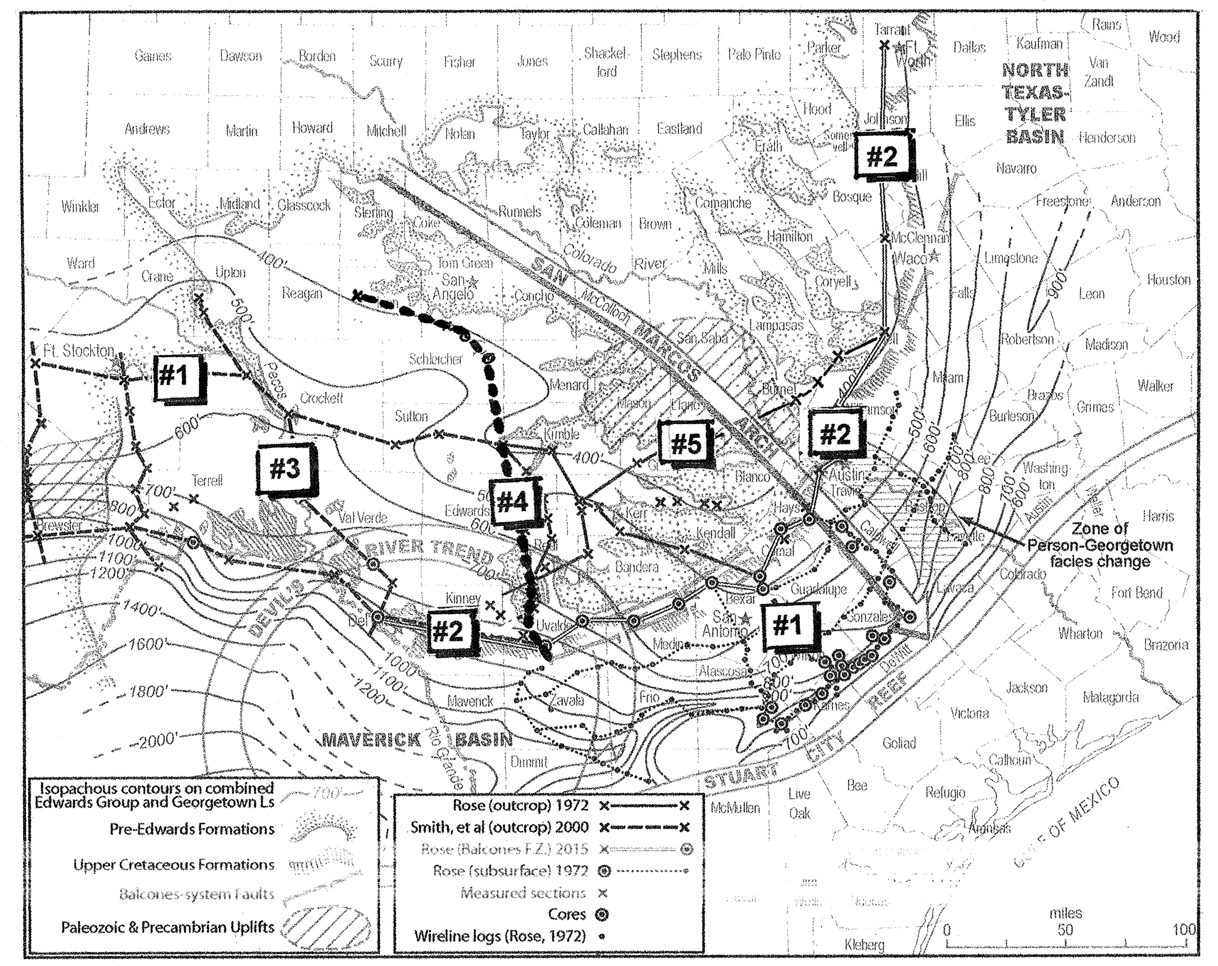
STRATIGRAPHIC CROSS-SECTION # 4

Peter R. Rose

2016

DATUM: TOP BUDA LIMESTONE

SOURCES Moore (1967); Rose (1972); Lozo and Smith (1964); Miller (1984); Smith et al. (2000).



FREDERICKSBURG-WASHITA STRATIGRAPHY OF TEXAS:
STRATIGRAPHIC CROSS- SECTION # 5

Peter R. Rose

2016

DATUM: TOP BUDA LIMESTONE

SOURCES

Nelson (1959, 1973); Lozo (1959a); Lozo and Smith (1964); Moore (1964, 1996); Bishop (1967);Dixon (1967); Rose (1972, 1986, 2016b); Amsbury et al. (1973); Young (1974, 1979a, 1986); Bay(1977); Halley and Rose (1977); Bollard and Geffert (1979); Miller (1984); Lemons (1987); Smith et al. (2000); Scott et al. (2003).