Albian rudist biostratigraphy (Bivalvia), Comanche shelf to shelf margin, Texas

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Highlights

• Barremian-Albian caprinids biostratigraphic zones are revised and integrated with ammonites and benthic foraminifers.
• New caprinid rudist species are the key to revising long-held correlations of Albian strata on the Comanche shelf, Texas.
• On the San Marcos Arch, central Texas, the shallow shelf Person Formation is the upper unit of the Fredericksburg Group.
• The Person underlies the basal Washita Group sequence boundary Al Sb Wa1 and the Georgetown Formation.

Abstract: Rudists were widespread and locally abundant carbonate producers on the Early Cretaceous Comanche Shelf from Florida to Texas, and on Mexican atolls. As members of the Caribbean Biogeographic Province, their early ancestors emigrated from the Mediterranean Province and subsequently evolved independently. Comanchean rudists formed biostromes and bioherms on the shelf interior and at the shelf margin. Carbonate stratigraphic units of the Comanche Shelf record rudist evolution during the Barremian through the Albian ages and an established zonal scheme is expanded.
This study documents new Albian rudist occurrences from the Middle-Upper Albian Fredericksburg and Washita groups in Central and West Texas. Rudists in cores at and directly behind the shelf margin southeast of Austin and San Antonio, Texas, complement the rudist zonation that is integrated with ammonites and foraminifers. These new rudist data test long-held correlations of the Edwards Group with both the Fredericksburg and Washita groups based solely on lithologies. Rudist and foraminifer biostratigraphy indicate that the Edwards Group is coeval with the Fredericksburg not the Washita Group.
In West Texas sections *Caprinuloidea romeri* occurs at the top of the Fredericksburg Group in the Fort Terrett Formation approximately 3 meters below the iron-stained hardground subaerial exposure surface. It is overlain by the Washita Group with the ammonite Eopachydiscus marcianus Zone. *Caprinuloidea romeri* is also documented from the type cored section of the Person Formation in the upper part of the Edwards Group. These species allow a precise correlation of the subsurface Person Formation in Central Texas with the Ft. Terrett Formation cropping out in West Texas. This evidence together with foraminifer and ammonite zones demonstrates that the Person Formation is coeval with Fredericksburg units underlying the basal Washita sequence boundary Al Sb Wa1. The upper Albian Washita Group Kimbleia and Mexicaprina caprinid zones overly the Caprinuloidea Zone and the successive Washita mortonicerid ammonite zones.

Key-words:

• Albian;
• caprinuloid biostratigraphy;
• Comanche shelf;
• Texas.

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Résumé : ***Biostratigraphie de l'Albien au moyen des rudistes (Bivalves), de la plate-forme de Comanche à sa bordure (Texas).-*** Les rudistes furent des producteurs de calcaires largement répandus et localement abondants depuis la Floride jusqu'au Texas sur la plate-forme de Comanche au Crétacé inférieur, ainsi que dans les atolls mexicains. En tant que représentants de la province biogéographique caribéenne, leurs ancêtres lointains ont migré depuis la province méditerranéenne avant d'évoluer indépendamment par la suite. Les rudistes de Comanche ont formé des biostromes et des biohermes à l'intérieur de la plate-forme et à sa bordure. Les unités stratigraphiques carbonatées de la

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plate-forme de Comanche enregistrent l'évolution des rudistes depuis le Barrémien jusqu'à l'Albien. La zonation préexistante est complétée.
Cette étude figure de nouvelles occurrences albiennes de rudistes dans les groupes de Fredericksburg et de Washita à l'Albien moyen et supérieur au Texas central et occidental. Les rudistes identifiés dans les sondages à la bordure de plate-forme et juste derrière, au sud-est d'Austin et de San Antonio (Texas), complètent la zonation des rudistes qui est intégrée à celles des ammonites et des foraminifères. Ces nouvelles données concernant les rudistes permettent de tester la robustesse des corrélations, depuis longtemps établies mais basées uniquement sur les lithologies, du Groupe d'Edwards avec les groupes de Fredericksburg et de Washita. La biostratigraphie des rudistes et celle des foraminifères indiquent que le Groupe d'Edwards est équivalent au Groupe de Fredericksburg, et non à celui de Washita.
Dans les coupes du Texas occidental, *Caprinuloidea romeri* est présente au sommet du Groupe de Fredericksburg dans la Formation de Fort Terrett, environ 3 mètres sous la surface d'émersion sommitale. Cette surface durcie et ferruginisée est surmontée par le Groupe de Washita avec la Zone à ammonite Eopachydiscus marcianus. *Caprinuloidea romeri* est aussi représentée dans la section carottée de référence pour la Formation de Person dans la partie supérieure du Groupe d'Edwards. Ces espèces permettent une corrélation précise entre la Formation de Person reconnue en subsurface dans le Texas central et la Formation de Fort Terrett identifiée à l'affleurement dans le Texas occidental. Cet argument, ainsi que les zones d'ammonites et de foraminifères, démontre que la Formation de Person est équivalente aux unités de Fredericksburg sous-jacentes à la limite de séquence Al Sb Wa1 à la base du Groupe de Washita. Les zones de caprinidés à Kimbleia et Mexicaprina de l'Albien supérieur du Groupe de Washita surmontent la Zone à Caprinuloidea ainsi que les zones successives à ammonites (Mortonicératidés) du Groupe de Washita.

Mots-clefs :

- Albien ;
- biostratigraphie des caprinuloïdés ;
- plate-forme de Comanche ;
- Texas.

Introduction

Early Cretaceous was a time of major diversification of the specialized bivalves of the Order Hippuritida Newell (1965) (Skelton, 2013; Steuber *et al.*, 2016). During this time span foraminifers and nannofossils diversified and ocean-water oxygen composition experienced repetitive oceanic anoxic events (OAEs) (Leckie *et al.*, 2002). Repeated shelf flooding stressed shallow shelf communities of colonial corals and rudist bivalves accompanied by rudist iterative evolution (Scott, 1995).

The Barremian-Early Cenomanian Comanche Shelf was a mixed carbonate-siliciclastic sedimentary province along the southern margin of the North American continent (Fig. 1.A). It extended from Florida westward to southeastern Arizona (Scott, 1993; Yurewitz *et al.*, 1993; Mancini and Scott, 2006). Paleoclimate modeling suggests that Tethyan sea-surface currents flowed westward across the Comanche Shelf, and surface winds varied seasonally from the southwest in summer to the west and northwest in the winter (Glancy *et al.*, 1993).

Rudists were widespread and locally abundant carbonate producers on the Early Cretaceous Comanche Shelf from Florida to Texas, and they occupied the atolls in Mexico. As members of the Caribbean Biogeographic Province (Kauffman, 1973), their early ancestors emigrated from the Mediterranean Province and subsequently evolved independently (Masse *et al.*, 2007). Comanchean rudists formed biostromes and bioherms on the shelf interior and at the shelf margin and were abundant members of reefal paleocommunities (Scott, 1990). Carbonate stratigraphic units of the Comanche Shelf record rudist evolution during the Hauterivian through the Albian ages (Coogan, 1977) and a zonal scheme has been developed (Scott and Filkorn, 2007).

Rudist species are relatively well known from Lower Cretaceous outcrops in Central Texas (Coogan, 1977; Davis-Strickland, 1988; Scott and Filkorn, 2007; Mitchell, 2013a), from shelf-margin cores (Scott, 1990; Mancini and Scott, 2006), and on the outer Devils River platform along the southern reaches of the Pecos River in West Texas (Fig. 1.B) (Kerans *et al.*, 1999; Scott and Kerans, 2004). Rudists are less abundant and less diverse northward/landward on the interior of the Devils River Platform and eastward across the Edwards Plateau. Rudists are common in the subsurface of central Texas on the San Marcos Arch carbonate shelf landward of the shelf margin (Rose, 1972) but unstudied taxonomically.

This study documents new Albian rudist occurrences from the middle-upper Albian Fort Terrett and Fort Lancaster formations on the upper reaches of the Pecos River, West Texas, and in the Kainer and Person formations on the San Marcos Arch (Fig. 2). Rudists are in cores at and directly behind the shelf margin from south Texas northeastward to offshore Louisiana (Coogan, 1977; Scott, 1990). Landward of the shelf margin in Karnes County southwest of Austin, Texas, rudist taxa are reported here for the first time from the Edwards Group, which is comprised of the older Kainer and the younger Person formations (Rose, 1972; Smith *et al.*, 2000) (Fig. 1.B).

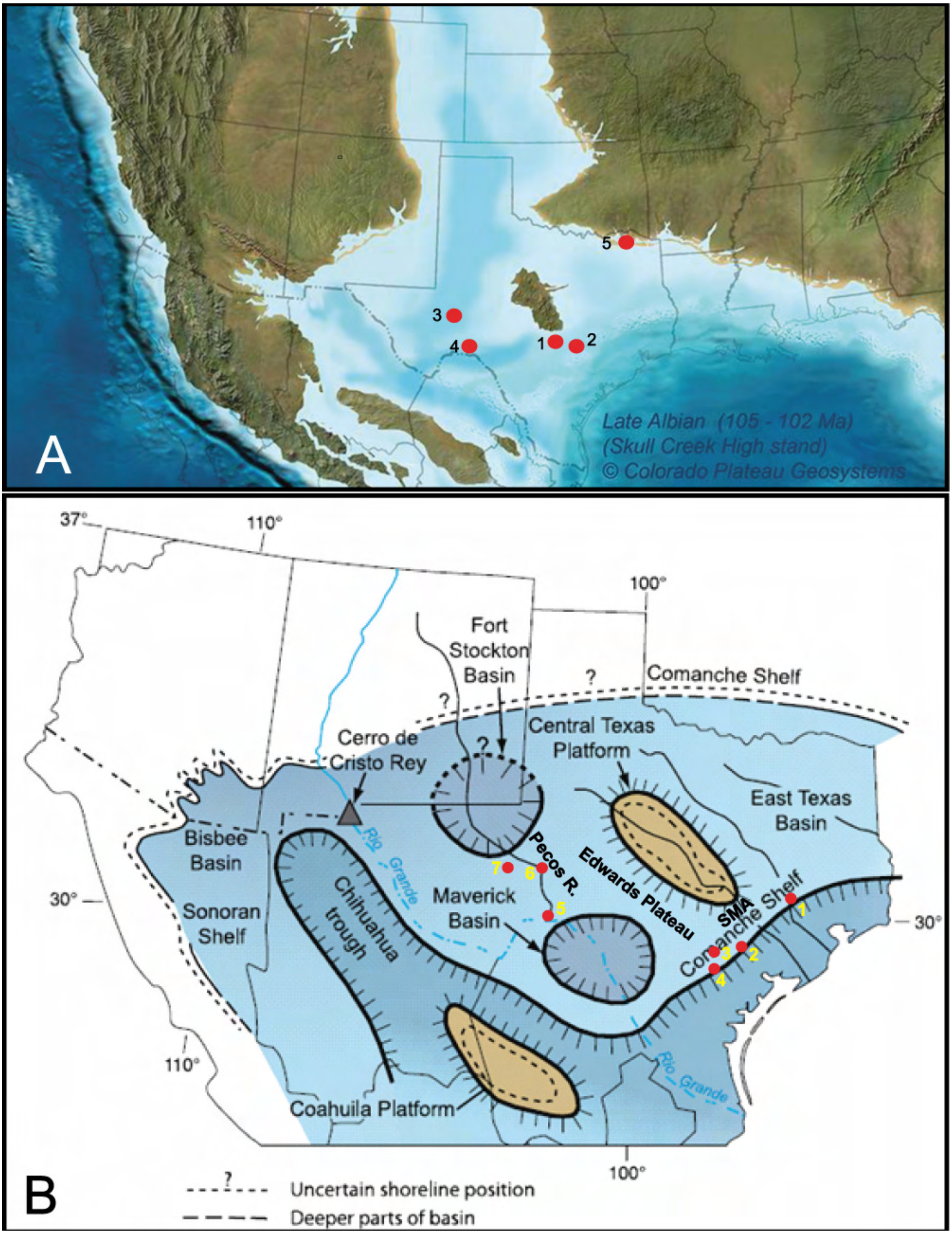


Figure 1: A. Late Albian paleogeographic map in south-central U.S. (Blakey, 2010; © Ron Blakey, Colorado Plateau Geosystems); red dots indicate locations of rudist collections: 1) Karnes County wells and Travis County outcrops; 2) shelf margin cores; 3) Crockett County roadcuts and roadcut in Pecos County; 4) Pecos River outcrops in Val Verde County at Pandale and south to U.S. 90 (Kerans *et al.*, 1999); and 5) Fort Towson, Choctaw County, southeast Oklahoma. B. Middle-Late Albian paleogeographic map of Comanche shelf depositional features and measured sections (orange dots) (map from Scott, 2007). Measured cores and sections: 1. Shell Chapman core, Waller County; 2. Shell Tomasek core, Bee County; 3. Pioneer Myra Kelley core, Dewitt County; 4. Pioneer Schroeder core, Bee County; 5. U.S. 90 Pecos River Bridge, Val Verde County; 6. East Iraan U.S. 190 section, Crockett County; 7. Fort Stockton, Pecos County.

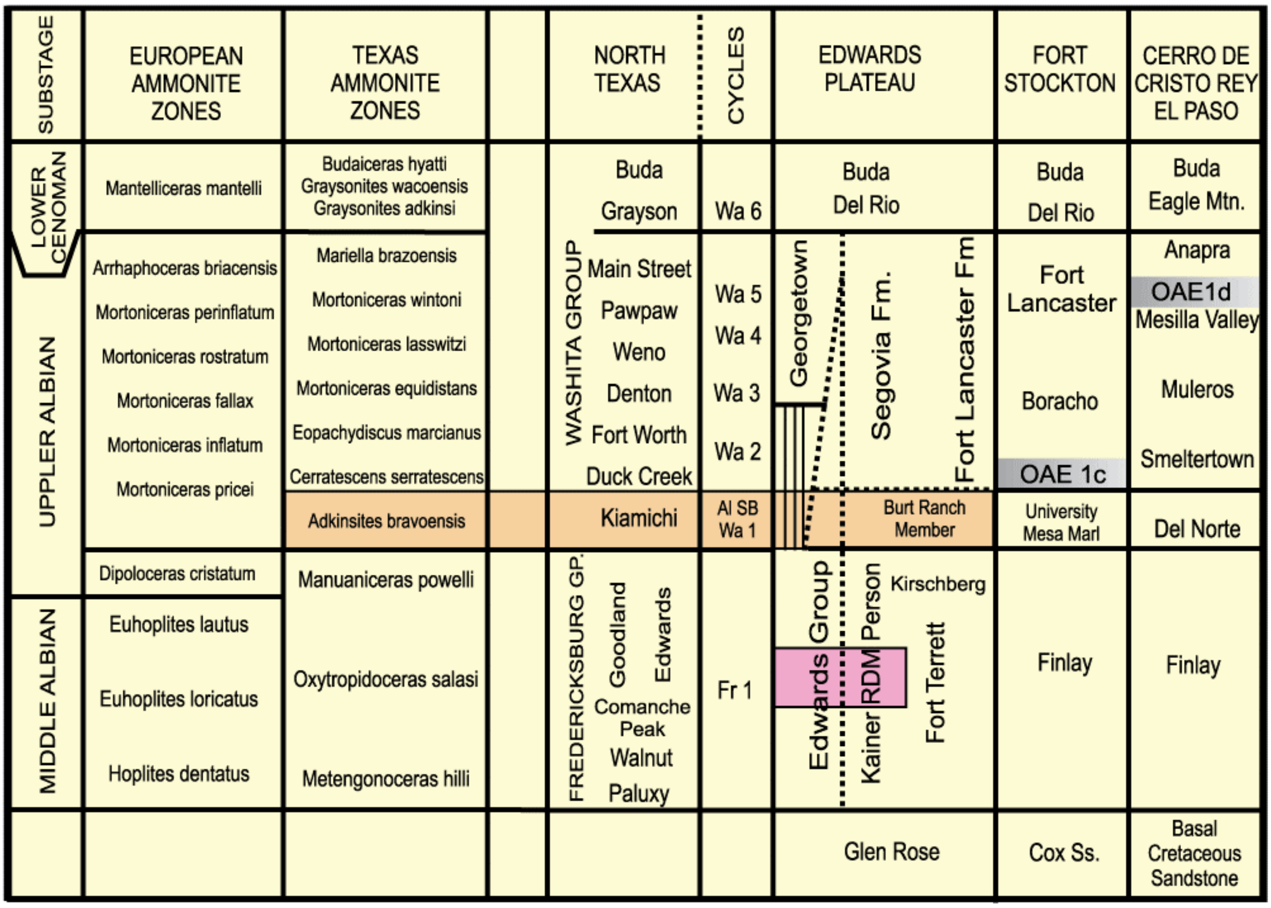


Figure 2: Stratigraphic chart correlating European ammonite zones (Reboulet *et al.*, 2014) with U.S. Gulf Coast zones (Young, 1986) and Comanchean stratigraphy of North Texas (Scott *et al.*, 2003), of the Edwards Plateau (modified from Rose, 1972), and of the Fort Stockton and El Paso sections (Scott and Kidson, 1977; Lucas *et al.*, 2010).

Paleogeography

During the middle to early late Albian the Comanche Shelf was a wide shallow carbonate shelf on which were deposited units of the Fredericksburg Group and the equivalent Edwards Group. During this phase the carbonate shelf prograded into the ancestral Gulf of Mexico (Bay, 1977; Salvador, 1991) (Fig. 1.B). This phase was followed by a widespread late Albian sea-level rise that flooded the shallow shelf and intrashelf basins and deposited the mixed carbonate-siliciclastic Washita Group. The later Albian was a time of carbonate shelf retrograding and drowning. The Georgetown Formation limestone and marl overly shallow-water facies of the Edwards Group (Rose, 1972; Kerans, 2002) and document this sea-level rise. During multiple episodes of shelf retrogradation and progradation extensive rudist buildups developed in depositional cycles (Scott; 1993; Kerans, 2002). The episodes are documented in well-exposed sections along the Pecos River and in spectacular road cuts through the steep banks of the Pecos River. Kerans (2002) subdivided measured sections in the Pecos River Canyon into high frequency cycles that document multiple shoaling-deepening cycles.

Lithostratigraphy

Barremian to Lower Cenomanian strata on the Comanchean shelf are grouped as the Comanchean Series, which is defined by unconformity-bounding surfaces (Fig. 2) (Hill, 1901; reviewed by Scott *et al.*, 2003). The Comanchean Series is comprised of three disconformity-bounded groups in north central Texas: Trinity, Fredericksburg and Washita. The Trinity Group comprises the Hensel and Glen Rose formations; the Fredericksburg Group comprises the Walnut and Edwards/Comanche Peak and Goodland formations; and the Washita Group includes seven shale and limestone formations in the East Texas Basin (Scott *et al.*, 2003).

Southward in central Texas on the San Marcos Arch the formations become dominantly carbonate and comprise a different lithostratigraphy. The Kainer and Person formations make up the Edwards Group (Rose, 1972), which Rose correlated with the Fredericksburg Group and the lower part of the Washita Group. Newly discovered caprinid rudists in the Person challenge this correlation. The overlying Georgetown, Del Rio and Buda formations are part of the Washita Group, which is bounded by disconformities (Rose, 1972).

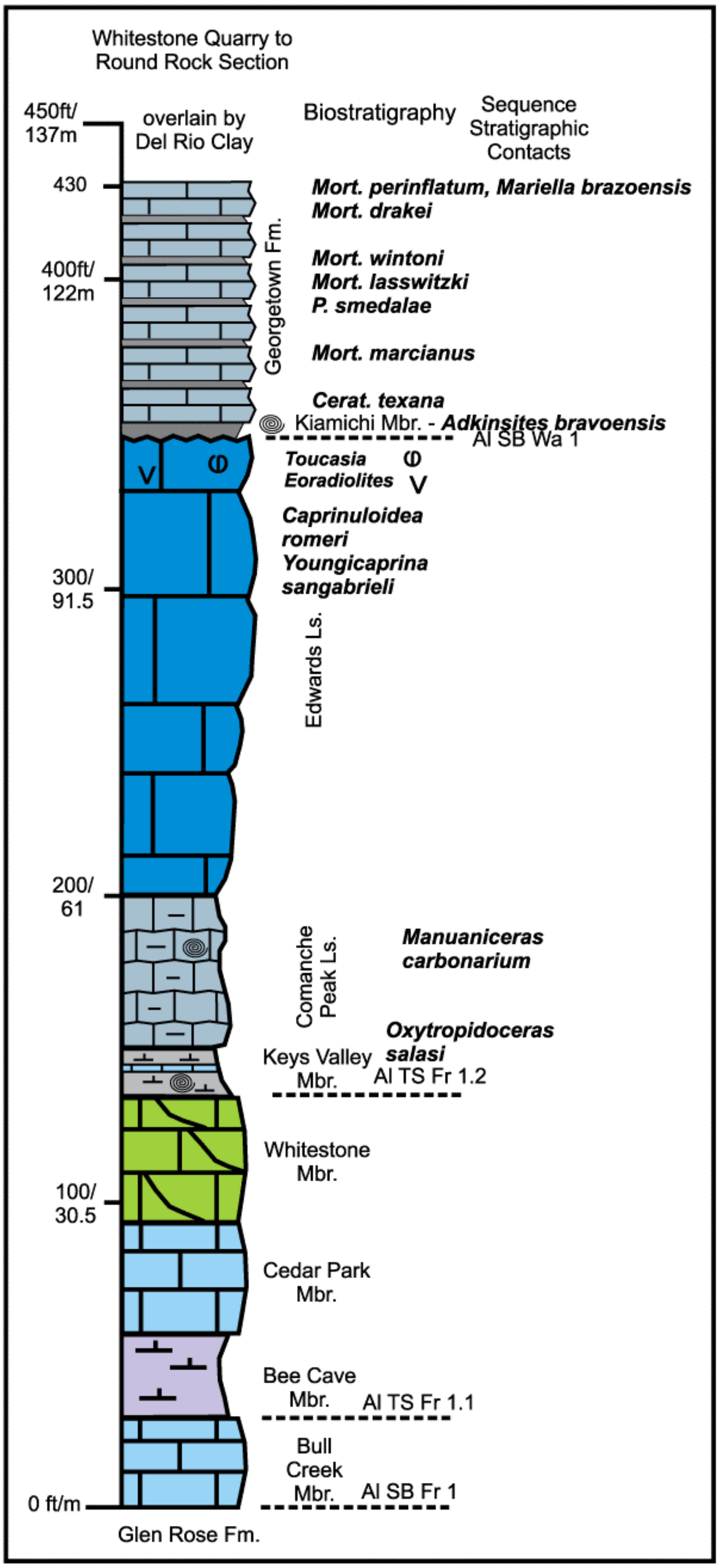


Figure 3: Composited section of middle-upper Albian strata in northeastern Travis and Williamson counties north of the San Marcos Arch. Lithostratigraphy from MOORE (1964), FERAY in HAZZARD (1949), WILBERT (1967), and in SCOTT and WEAVER (2010, Fig. 2). Ammonite biostratigraphy from YOUNG (1957) and KENNEDY *et al.* (1998). Rudist biostratigraphy from MITCHELL (2013a). Sequence stratigraphic notation from SCOTT *et al.* (2003).

Westward on the Edwards Plateau the Fort Terrett and Segovia formations are mapped as the Edwards Group (ROSE, 1972). The Fort Terrett Formation correlates by mapping and biostratigraphy with the Fredericksburg Group. The Segovia correlates with the Washita Group. Westward the Segovia grades into the carbonate shelf Fort Lancaster Formation (SMITH *et al.*, 2000). Each of these units is bounded by disconformities and each hosts biostratigraphically significant caprinids.

Edwards Formation / Group. The Edwards Formation is mapped north of the Central Texas Platform (Fig. 1.B) as the uppermost unit of the Fredericksburg Group. This medium to thick bedded limestone underlies the Washita Group (Fig. 2) (MOORE, 1964; AMSBURY, 2003). Here the Edwards overlies and grades down into the Comanche Peak and Walnut formations (Fig. 3). Middle and basal Upper Albian ammonites in these units define widely correlated zones (YOUNG, 1957, 1966; KENNEDY *et al.*, 1998). Caprinids and other rudists are common in the Edwards Formation in this area and are identified as *Caprinuloidea romeri* (formerly *C. perfecta* PALMER in SCOTT, 2002, and revised by MITCHELL, 2013a) and *Youngicaprina sangabrieli* MITCHELL, 2013a (Fig. 4). *Eoradiolites davidsoni* HILL is the common radiolitid.

In central Texas the Edwards Group is comprised of two limestone/marl formations, the Kainer and Person formations. These units are separated by a thin marl-limestone unit, the "Regional Dense member" (RDM) (ROSE, 1972, p. 25). The Kainer and Person are mapped in outcrops between Austin and San Antonio and down dip in the subsurface towards the Comanche Shelf margin Stuart City trend. Westward across the Edwards Plateau the Fort Terrett and Segovia formations compose the Edwards Group. Farther west the Segovia grades into the Fort Lancaster Formation, which disconformably overlies the Fort Terrett. Southward at the northern margin of the Maverick Basin and the Devils River trend the Edwards Group grades into the Devils River Formation (ROSE, 1972; SMITH *et al.*, 2000).

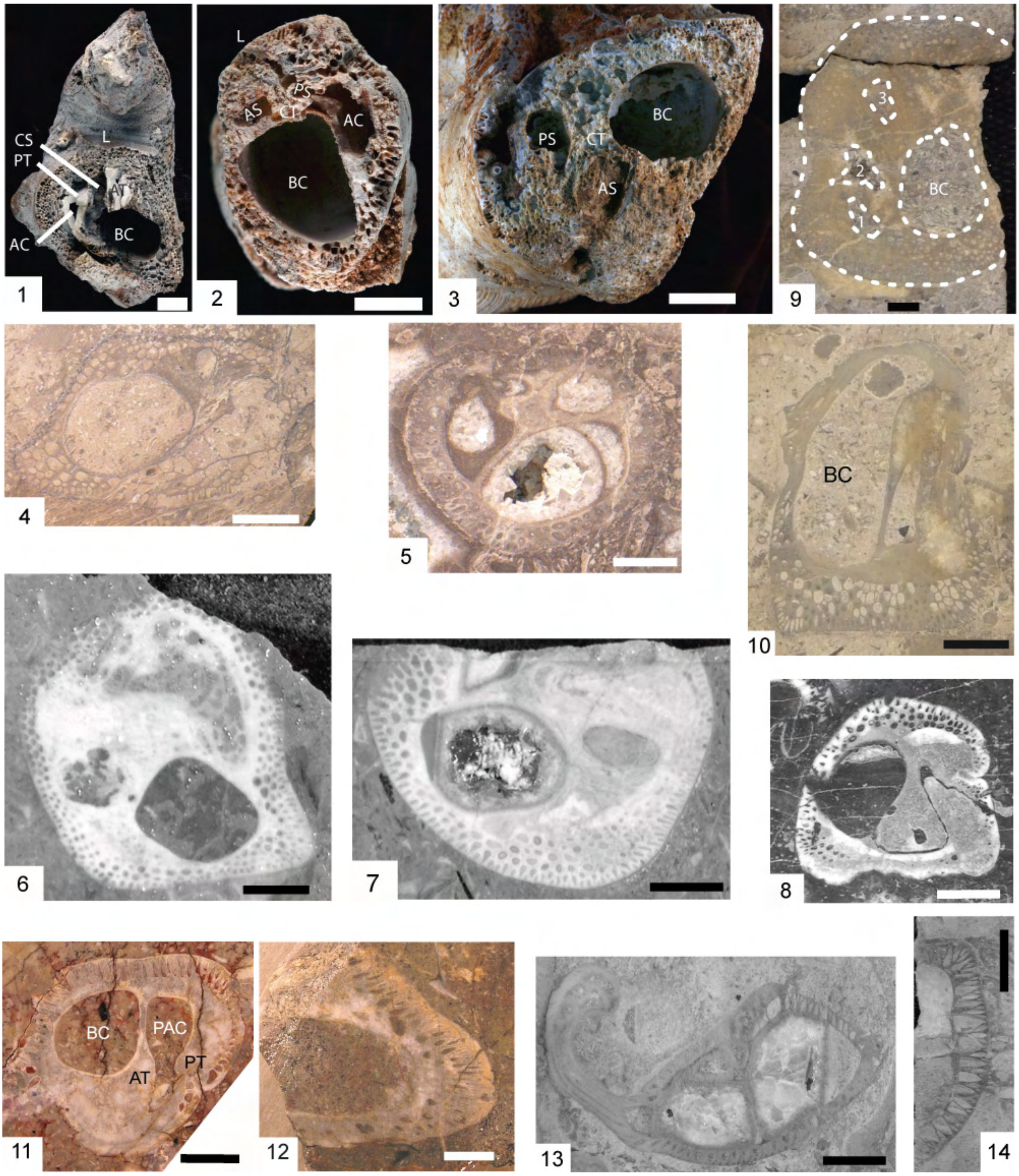


Figure 4: Caprinid specimens from Edwards Formation and Mural Formation outcrops and Stuart City Formation cores. Scale bar is 1 cm.

1-3. *Youngicaprina sangabrieli* MITCHELL; Edwards Formation, Travis County, Texas; silicified specimens. 1, LV NPL 2381; 2, RV UT 11276; 3) RV NPL 15739; Scale bar 1 cm. Accessory cavity (AC); anterior socket (AS); anterior tooth (AT); body cavity (BC); central tooth (CT); central socket (CS); ligament (L); posterior tooth (PT); posterior socket (PS). Photos from SCOTT and WEAVER (2010, Fig. 3).

4-5. *Caprinuloidea romeri* MITCHELL; Stuart City Formation, Pioneer Myra Kelley Gas Unit 3-4, Sawfish Field, Dewitt County, Texas; 4, RV view into valve at 14,789.5 ft and 5, RV view into valve at 14,863 ft.

6-8. *Texicaprina kugleri* BOUWMAN; Stuart City Formation, Pioneer No. 1 Schroeder, Pawnee Field, Bee County, Texas; 6, view into RV at 14,063 ft; 7, view into RV at 14,243; and 8, articulated specimen at 14,296 ft.

9-10. *Youngicaprina sangabrieli* MITCHELL; Stuart City Formation, Pioneer Burns Gas Unit No. 1-2, Moray Field, Dewitt County, Texas; 9, view into RV at 14,812.5 ft, BC = body cavity, 1 is anterior myophore, 2 is anterior socket, 3 is posterior socket; 10, view out of LV at 14,827 ft.

11- 12. *Caprinuloidea perfecta* PALMER. Lower Albian Mural Formation, Los Coyotes Member, Santa Ana section, Sonora, Mexico (GONZÁLES-LEÓN *et al.*, 2008, Fig. 4G-H); 11, LV view into valve (*op. cit.*, Fig. 4H); 12, fragment of RV (*op. cit.*, Fig. 4G).

13- 14. *Coalcomana ramosa* (BOEHM), Stuart City Formation, Pioneer No. 1 Schroeder, Pawnee Field, Bee County, Texas; 13, RV view into valve, 14,735.6 ft; 14, ventral margin of valve fragment, 14,620.2 ft.

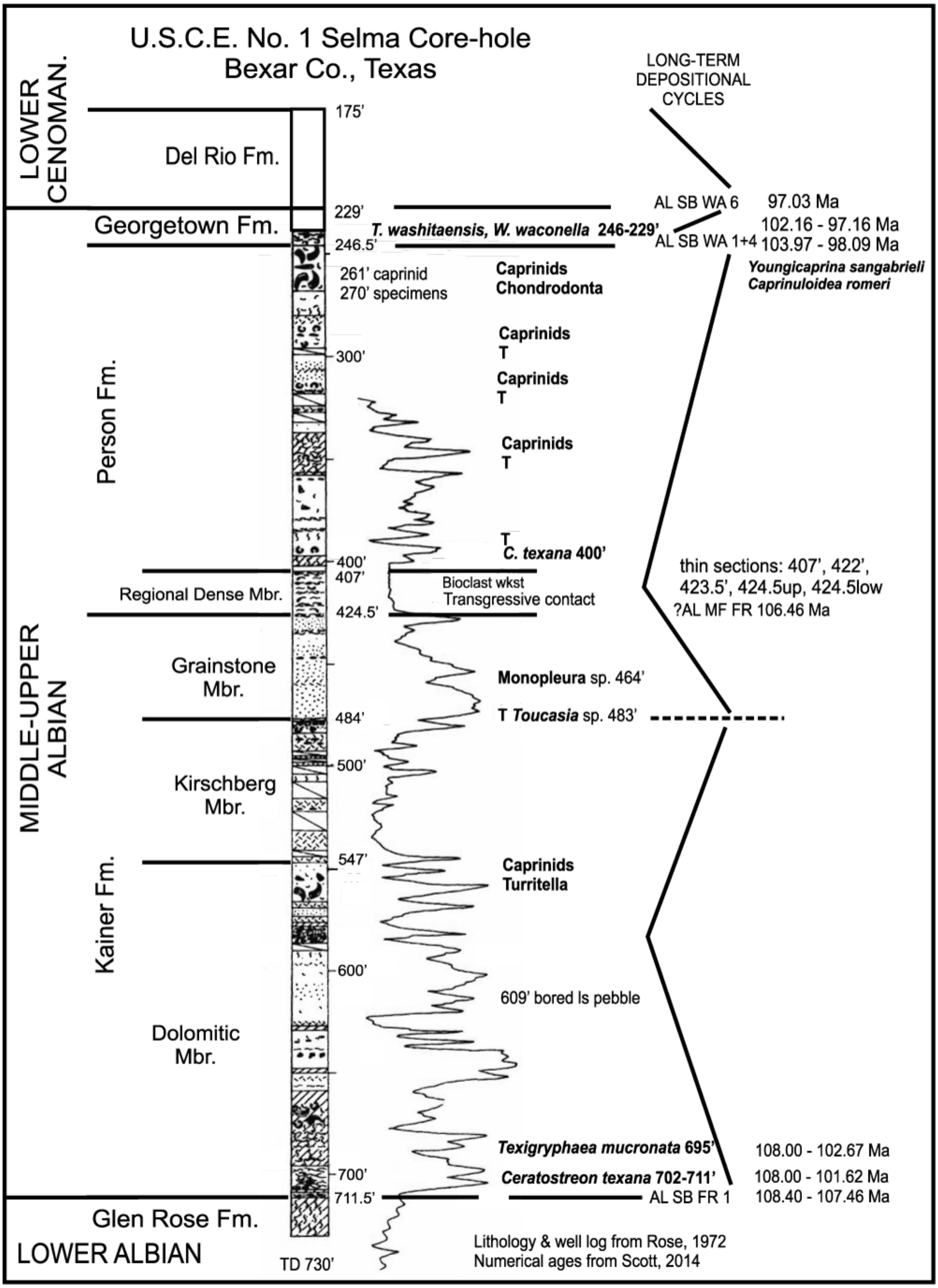


Figure 5: Lithostratigraphy of the Edwards Group in the U.S.C.E. Selma No. 1 (ROSE, 1972, Pl. 4, cross section Z-Z'). The contact between the Georgetown and Del Rio formations is a widespread regional disconformity Al SB Wa 6 (SCOTT *et al.*, 2003). The Washita Group is comprised of the Georgetown, Del Rio and Buda formations.

Kainer Formation. The Kainer Formation is the lower unit of the Edwards Group on the San Marcos Arch at the southeast nose of the Central Texas Platform and in up-dip outcrops (Figs. 2 & 5) (ROSE, 1972, p. 18). In its type well, Shell No. 2 Kainer, the Kainer is 122.6 m thick and in other wells it ranges up to 137 m. The Kainer is comprised of an informal lower dolomite interval and an upper grainstone interval. The Kainer overlies the lower Albian dolomitic Glen Rose Formation with a sharp contact and is overlain by a sharp, locally iron-stained contact with the basal Regional Dense member (RDM) of the Person Formation (Fig. 5) (ROSE, 1972; CAMPBELL, 2016). The Kainer yields diverse shallow-water fossils: miliolids, *Dictyoconus walnutensis* (CARSEY), *Ceratostreon texana* (ROEMER), texigryphaeid oysters, toucasiids, indeterminate caprinids, and gastropods. Because the Kainer is at the base of the Edwards Group (ROSE, 1972), it correlates with the Walnut Formation in nearby updip outcrops, which are composed of similar lithologies (MOORE, 1964).

Person Formation. The Person Formation is the upper unit of the Edwards Group in Central Texas wells and outcrops (Figs. 2 & 5) (ROSE, 1972, p. 19). In its type section, Standard of Texas No. 1 Wiatrek core, the Person is 69.2 m thick and in other wells it ranges up to 95 m thick. The Person is comprised of the basal RDM, which is overlain by a collapsed member, a leached member, a marine member, and a cyclic member. The Person is overlain disconformably by the Georgetown Formation; locally a soil is preserved at the contact and in places borings penetrate into the uppermost bed up to 20 cm; some borings are filled with pelagic mudstone (CAMPBELL, 2016).

Common rudists in parts of the Person Formation are *Caprinuloidea romeri*, *Neokimbleia planata* (CONRAD), *Toucasia texana* (ROEMER), and *Sellaea* sp. (Figs. 6 - 7). The benthic foraminifers are *Barkerina barkerensis* FRIZZELL and SCHWARTZ, *Buccicrenata subgoodlandensis* (VANDERPOOL), *Coskinolinoides texanus* KEIJZER, *Cuneolina parva* HENSON, *Dictyoconus walnutensis,* and *Pseudonummoloculina heimi* (BONET).

The RDM is a bioclastic, peloidal, bioturbated wackestone to lime mudstone. In places miliolids are common together with the larger benthic foraminifers *Barkerina* and *Cuneolina*, texigryphaeid oysters, echinoderms, and ostracodes. Up dip in outcrop the RDM is a moderate yellow gray, argillic lime mudstone with small *Planolites* burrows and the rare infaunal bivalve, *Pleuromya knowltoni* (HILL), which is preserved in life position. In the uppermost Person cyclic interval caprinids are moderately preserved and identifiable as members of the Caprinuloidea Zone (SCOTT and FILKORN, 2007).

Fort Terrett Formation. The Fort Terrett Formation (Fig. 8) is the lower unit of the Edwards Group exposed on the Edwards Plateau (Fig. 2) (ROSE, 1972). The Fort Terrett overlies the Glen Rose Formation or the Hensel Formation, and it disconformably underlies the Segovia Formation and its basal Burt Ranch Member (ROSE, 1972). The Fort Terrett thickens southward towards the Maverick Basin from about 49 m to over 90 m. The formation is comprised of four informal lithological units: a basal nodular limestone and marl, the burrowed resistant limestone unit, an upper dolomitic member, and the uppermost Kirschberg evaporate and breccia member (ROSE, 1972). Fossil abundances vary within the Fort Terrett. Common fossils are echinoid clasts, texigryphaeids, other bivalves, gastropods, miliolids, *Cuneolina*, *Barkerina barkerensis*, *Pseudonummoloculina heimi*, and ostracodes (GARGILI, 2013). A road cut section of the Fort Terrett at the western margin of the Edwards Plateau exposes marl with the ammonite, *Engonoceras hilli* BÖHM, which is overlain by limestone with caprinids (Fig. 9.3-4, 9.7-8) and colonial corals (CAMPBELL, 2016). At multiple localities the carbon isotope profiles at the iron-stained top of the Fort Terrett indicate subaerial exposure (GARGILI, 2013; WANG, 2014; LAI, 2014; CAMPBELL, 2016).

Segovia Formation. The Segovia Formation disconformably overlies the Fort Terrett Formation on the Edwards Plateau and is overlain disconformably by the lower Cenomanian Del Rio or Buda formations (Fig. 8) (ROSE, 1972; YOUNG, 1979; SMITH *et al.*, 2000). Lithologically the Segovia is a heterogenous unit of limestone, marl, dolomite, and collapse breccia. In the upper part of the Segovia oyster beds of *Texigryphaea washitaensis* (HILL) and two lithologically distinct beds are widely mapped (SMITH *et al.*, 2000). The Kimbleia albrittoni (PERKINS) caprinid zone characterizes the upper Segovia, which is the type horizon of *Kimbleia capacis* COOGAN, 1973, the junior synonym of *K. albrittoni* (PERKINS, 1961; MITCHELL, 2013a) (Fig. 10). The Segovia thickens southward from 70 m to 110 m where it grades into the Devils River Formation at the shelf margin of the Maverick Basin (ROSE, 1972).

The basal interval of the Segovia Formation consists of interbedded marl and thin bedded limestone mapped as the Burt Ranch Member (ROSE, 1972). ROSE designated the base at the contact between the lowest marl overlying "porcellaneous micrite breccia" and the top at the base of a miliolid bed overlain by dolomite (ROSE, 1972, p. 35). In many sections the basal contact is a bored, iron-stained surface, and in other sections the top surfaces of several limestone beds are bored, iron-stained and identifi-

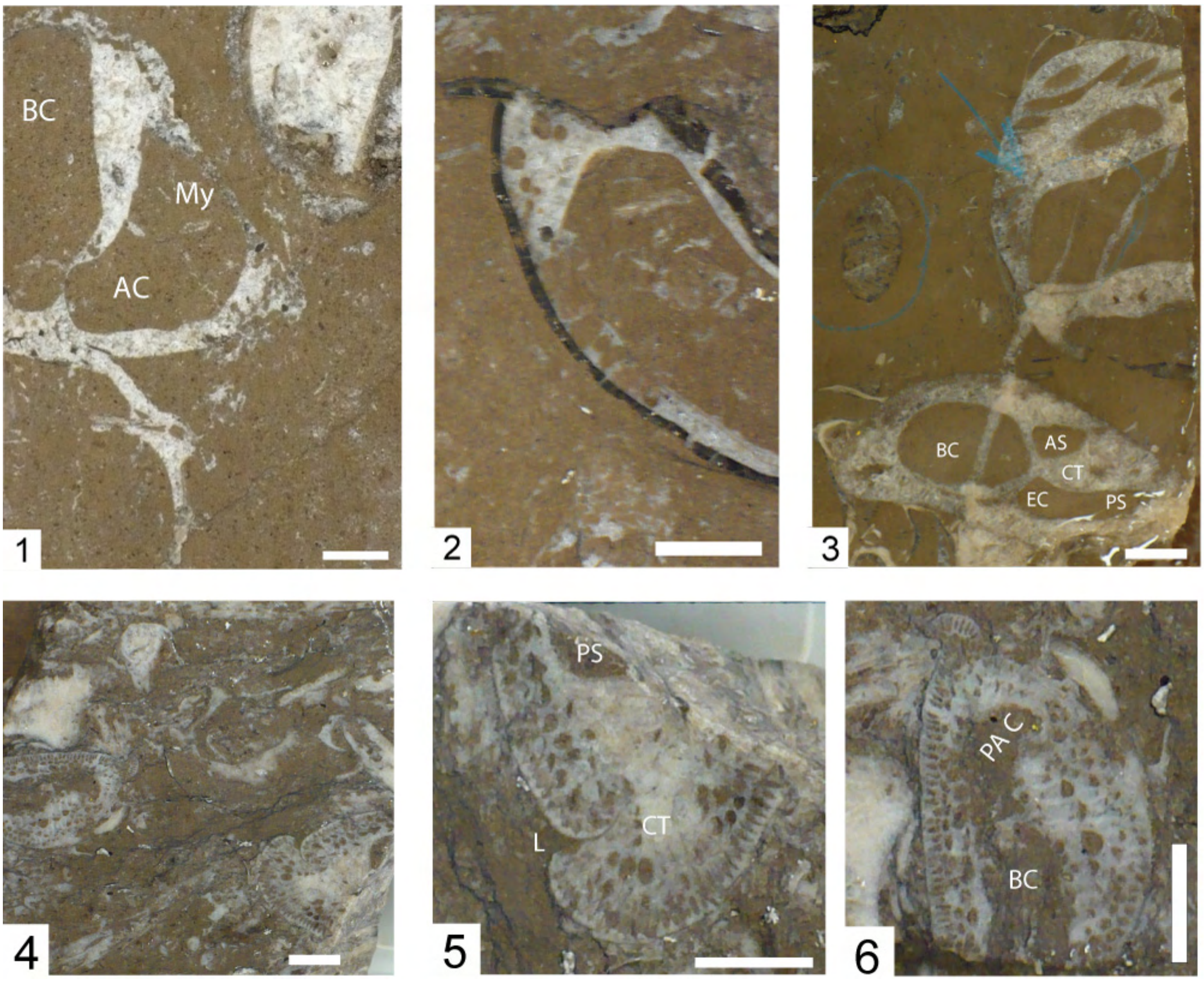
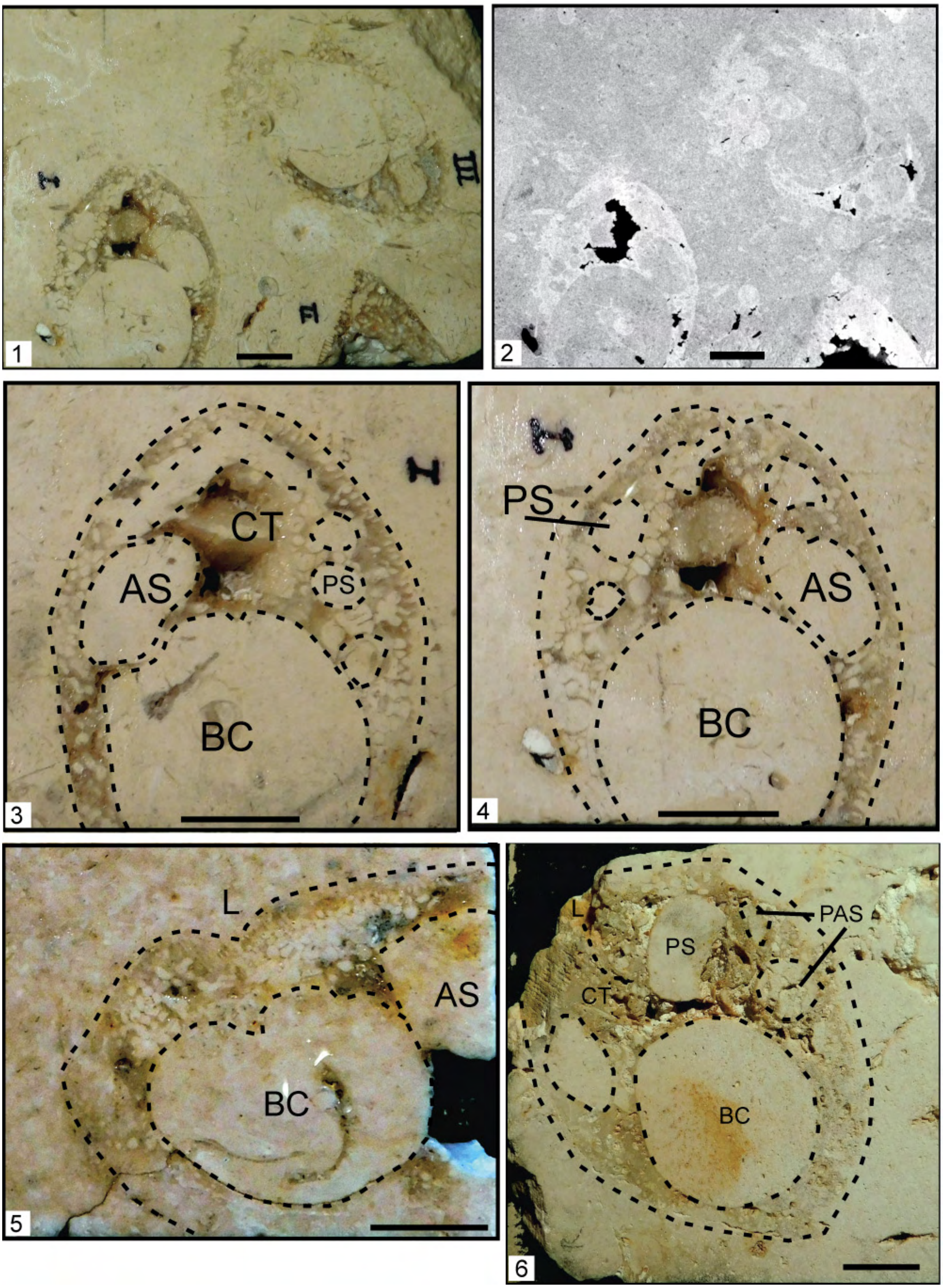


Figure 6: Rudists from interior shelf cores, Karnes County, Texas (CAMPBELL, 2016). Scale bar is 1 cm.
1. *Sellaea* sp., LV with body cavity (BC), accessory cavity (AC) and myophore (MY); Standard of Texas No. 1 Wiatrek, 10,870 ft, Person Formation, marine member.
2. *Toucasia texana* (ROEMER) whorl cross section showing two-layer wall of outer dark brown fibrous calcite and inner sparry calcite; Standard of Texas No. 1 Wiatrek, 10,865 ft, Person Formation, marine member.
3. *Neokimbleia planata* (CONRAD), RV with body cavity (BC), anterior tooth socket (AS), central tooth (CT), posterior socket (PS), and endomyophoral cavity (EC); Shell No. 2 L. Urbanczyk, 10,738 ft, Person Formation, cyclic member. Note solitary coral in left margin.
4-6. *Caprinuloidea romeri* MITCHELL; Shell No. 2 L. Urbanczyk, 10,818.5 ft, Person Formation, marine member; 5. Apertural view into RV showing ligament groove (L), central tooth (CT) and posterior socket (PS).

cation of sequence boundary Al SB Washita 1 is equivocal. Carbon isotope analyses of the basal contact suggest that at some sections it has been subaerially exposed whereas others show no isotopic signal of subaerial exposure (GARGILI, 2013; LAI, 2014; WANG, 2014). Ammonites from the Burt Ranch interval represent the Adkinsites bravoensis (BÖSE) ammonite Zone (YOUNG, 1966), which indicates that this unit correlates with the Kiamichi Formation in North Texas and represents flooding of the Comanche shelf (ROSE, 1972). Therefore *Kimbleia albrittoni* in overlying beds correlates with some part of the upper Washita Group and is in the upper Albian Stage.

Fort Lancaster Formation. The Fort Lancaster Formation is mapped in the western part of the Edwards Plateau and grades east into the Segovia Formation, south into the Devils River Formation and west into the Boracho Formation (Fig. 2) (SMITH *et al.*, 2000). It is comprised mainly of resistant bedded carbonates and at its base is the Burt Ranch Member comprised of interbedded marl and limestone (ROSE, 1972). The Fort Lancaster disconformably overlies the Fort Terrett Formation and underlies the West Prong, Del Rio or Buda formations.

Here the Burt Ranch Member yields the ammonites, *Adkinsites* and *Metengonoceras*, and the oysters *Texigryphaea navia* (HALL) and *Ceratostreon texana*, and the bivalve *Scabrotrigonia emoryi* (CONRAD). These taxa correlate the Burt Ranch with the Kiamichi Formation in North Texas, with the University Mesa Marl and with the Del Norte Formation at Cerro de Cristo Rey near El Paso. The upper seven meters of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the Fort Lancaster are thin to medium bedded bioclastic limestone with the rudists *Kimbleia albrittoni* (PERKINS) and *Mexicaprina quadrata* ALENCÁSTER & OVIEDO-GARCÍA (Fig. 10). These rudists are characteristic of the upper Albian Mexicaprina Zone (SCOTT and FILKORN, 2007). The Del Rio and Buda formations disconformably overlie the Fort Lancaster here.

Devils River Formation. South of the Edwards Plateau and the Fort Stockton Basin the Devils River Formation encircles the northern margin of the Maverick Basin (LOZO and SMITH, 1964; ROSE, 1972; MILLER, 1984). It is an unconformity-bounded unit overlying the Glen Rose Formation and underlying the West Prong, Del Rio or Buda formations (SMITH *et al.*, 2000). At the Pecos River bridge on U.S. 90 the Devils River is about 36 m thick and grades down into the Salmon Peak Formation, a peloid-planktic foraminifer wackestone and fine grained bioclastic wackestone (SMITH and BROWN, 1983; SCOTT, 1990, Fig. 50). In the upper 5 meters multiple caprinid biostromes are separated by hardground contacts and host *Kimbleia albrittoni* and *Mexicaprina minuta* (SCOTT, 1990; WANG, 2014).

Stuart City Formation. The Stuart City Formation forms the narrow Comanche Shelf margin trend in south Texas subsurface (WINTER, 1961; COOK, 1979; WILSON, 1986). In its type area of LaSalle County, Texas, the Stuart City overlies the Aptian-Albian Tamaulipas Formation and underlies the Georgetown Formation or Upper Cretaceous units (Fig. 2). The carbonate shelf sections cored in the Shell No. 1 Chapman, Waller County, and the Shell No. 1 Tomasek, Bee County, serve as lectostratotypes (Figs. 1.A-B - 2) (COOK, 1979, Fig. 18; SCOTT, 1990). The Stuart City rudist-coral facies grades down into pelagic lime mudstone/wackestone of the Tamaulipas Formation (SCOTT, 1990, Fig. 25) and is unconformably overlain by upper Albian Georgetown, or by Cenomanian shale of the Eagle Ford Formation, or even the Coniacian Austin Chalk (COOK, 1979; SCOTT, 1990; WAITE *et al.*, 2007). The Stuart City Formation in the Chapman and Tomasek cores correlates with the Edwards Formation of the Fredericksburg Group in North Texas. The benthic foraminifers, *Dictyoconus walnutensis* and *Coskinolinoides texanus*, and caprinids range to within about 10 meters of the top unconformity (SCOTT, 1990). The caprinids, *Caprinuloidea romeri* MITCHELL and *Texicaprina vivari* (PALMER), now *T. kugleri* (BOUWMAN) according to MITCHELL (2013a), and *Youngicaprina sangabrieli* MITCHELL are the common diagnostic species.

The Stuart City Formation cored in the Pioneer Myra Kelley Gas Unit 3-4, Sawfish Field, DeWitt County, Texas (Figs. 1.A & 3), is 79 m thick and is divided into lower and upper parts by an intraformational unconformity (Fig. 11) (WAITE *et al.*, 2007; PHELPS *et al.*, 2014). The lower part of the Stuart City below 4500 m (14,763 ft) is mainly comprised of peloid-rudist grainstone that grades up into rudist bioclastic packstone and wackestone. *Caprinuloidea romeri* and *Texicaprina kugleri* characterize this interval. *Dictyoconus walnutensis* correlates the lower part of the Stuart City with the Fredericksburg Group (COOGAN, 1977).

The upper part of the Stuart City interval is comprised of deeper-water peloid-bioclast packstone that grades up into coral-algal boundstone and overlies the shallower rudist-dominated assemblage, which indicates a transgressive depositional cycle. The upper interval is unconformably overlain by the Cenomanian-Turonian Eagle Ford Formation. Upper Albian rudist species *Ichthyosarcolites [Mexicaprina] alatus* (AGUILAR *et al.*, 2008; MITCHELL, 2013b) and *Kimbleia albrittoni* (Fig. 12) range to the top of this upper unit. Two agglutinate benthic foraminifers in this interval are *Coskinolinoides texanus* and *Barkerina barkerensis*, both of which range from the middle Albian Fredericksburg Group into the upper Albian Washita Group (SCOTT, 2014).

Offshore Louisiana Lower Cretaceous Carbonates. The Albian section is drilled in numerous wells and cored in a few wells onshore and offshore Louisiana (TYRRELL and SCOTT, 1989; YUREWITZ *et al.*, 1993; SCOTT, 1993; MANCINI *et al.*, 2005). The Chevron State Lease 4894 #2 well was cored in several intervals and rudists were found in two intervals (Fig. 13). The caprinids correlate this interval with the upper Albian Mexicaprina Zone and the upper part of the Washita Group.

◄ **Figure 7:** Edwards Group rudists, Person Formation in U.S.C.E. Selma No. 1 core, Bexar County, Texas (Fig. 5). Scale bar is 1cm.
1-4, *Neokimbleia acutus* MITCHELL, 270.5 ft; 1, Core slab photograph view into RV; 2, CT-x-ray scan; 3- 4, RV, umbonal and abumbonal views, obverse sides of same core slab illustrates ligament groove; posterior accessory cavity (PAC), posterior tooth socket (PS), ligament cavity (L), central tooth dissolved (CT), anterior tooth socket (AS), anterior myophore (AM); specimen II is the acute ventral margin; specimen III is partly etched but shows main interior structures; arrow indicates stratigraphic up.
5-6, *Caprinuloidea romeri* MITCHELL; 5, RV abumbonal view view, depth 261.5 ft. 6, RV abumbonal view at depth of 263.5 ft; anterior socket (AS); body cavity (BC); central tooth (CT); ligament groove (L); posterior accessory cavity (PAS); posterior socket (PS).

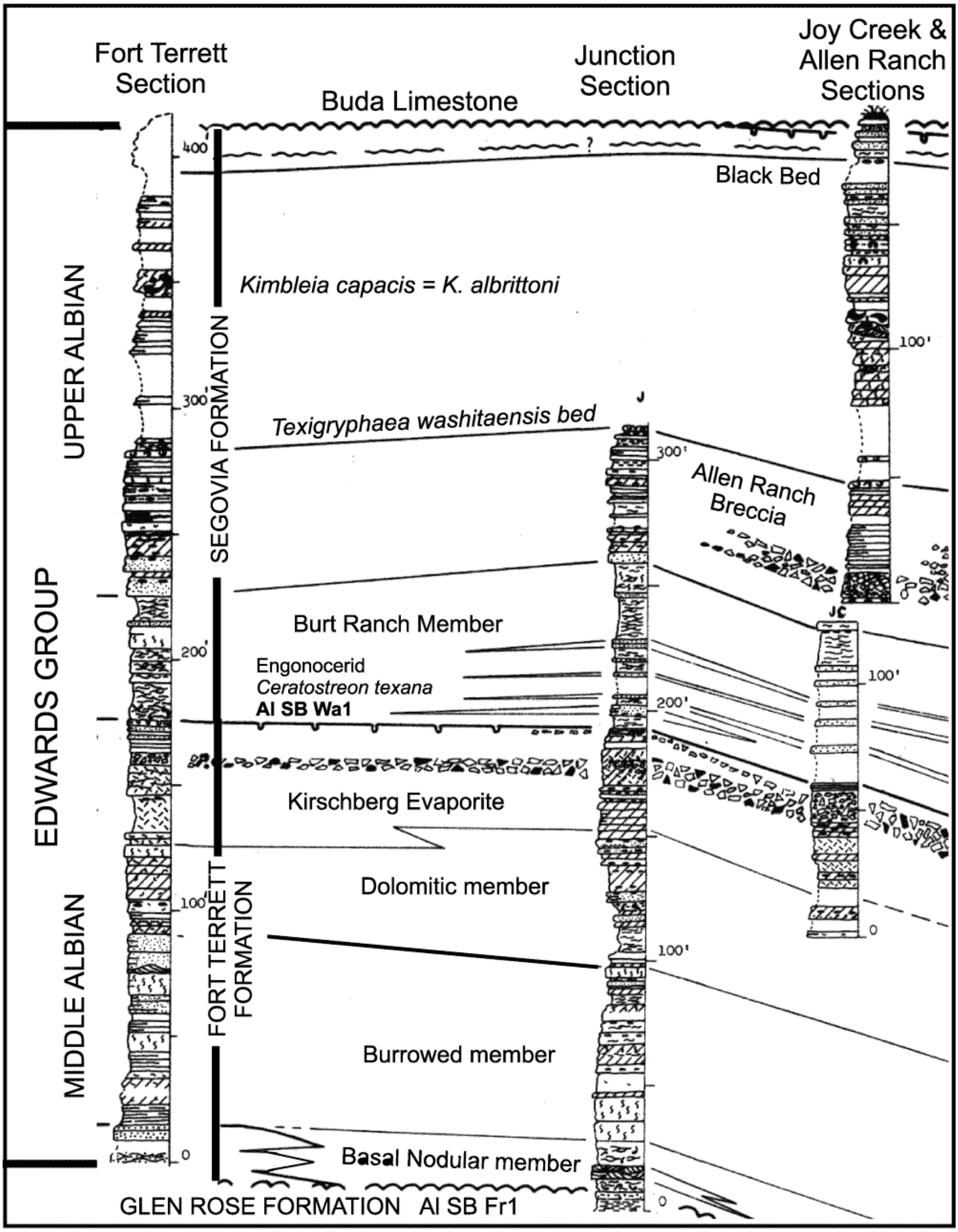
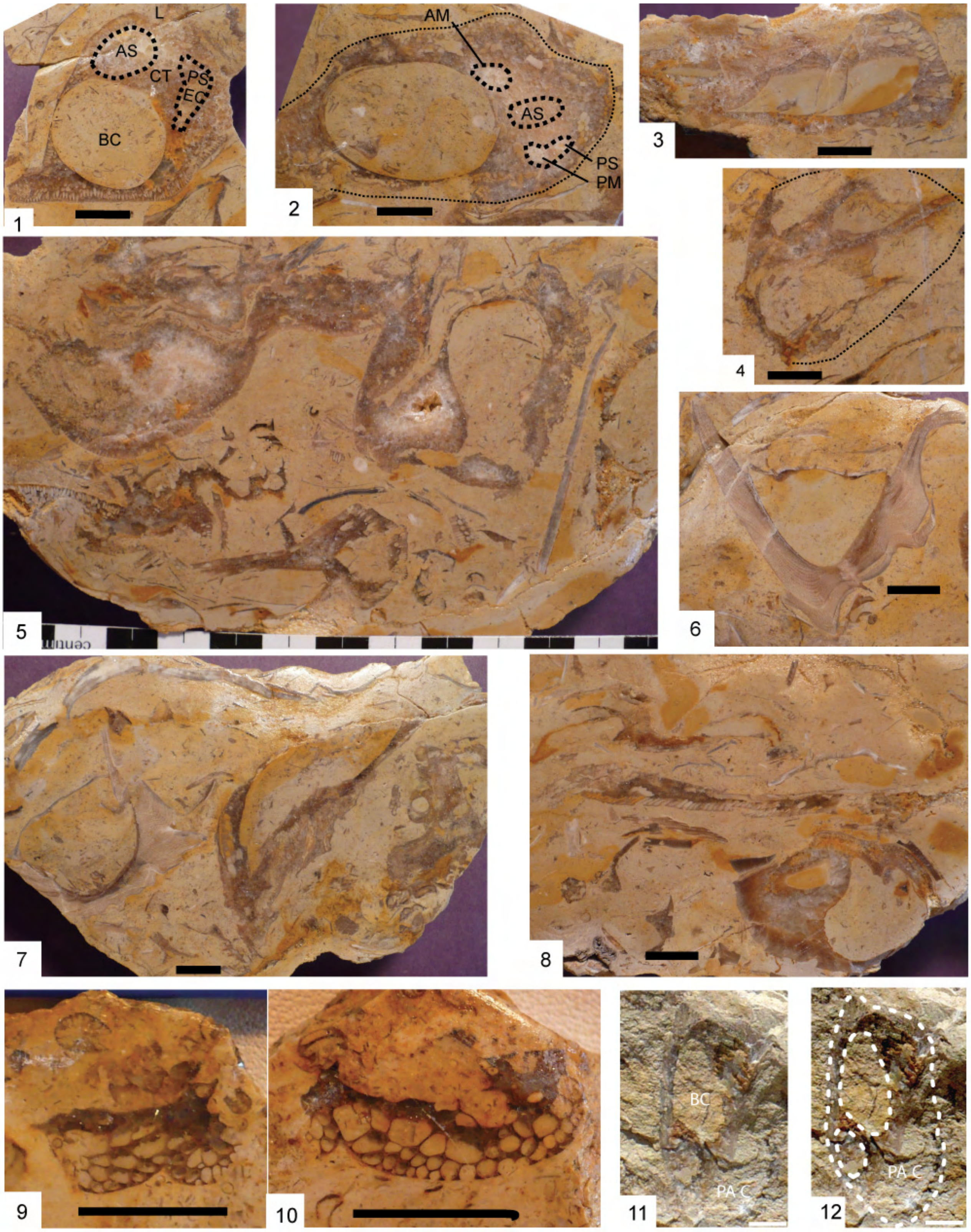


Figure 8: Lithostratigraphy of the Fort Terrett and Segovia formations in Kimble County, Texas (ROSE, 1972, Pl. 4). The outcrop section at the abandon site of Fort Terrett is the type section of the unit. The Joy Creek composited section is the type section of the Segovia Formation (ROSE, 1972) and is composited with the Allen Ranch section of ROSE (1972). Biostratigraphic data from PERKINS (1961), COOGAN (1977) and GARGILI (2013).

▶ **Figure 9:** Rudist specimens from bed FT16 in the upper part of the Fort Terrett Formation exposed in the north roadcut, U.S. 190, east of Iraan, Crockett County, Texas north roadcut beneath picnic area (CAMPBELL, 2016). Scale bar is 1 cm.

1, *Caprinuloidea romeri* MITCHELL; Specimen 2B, view into RV; body cavity (BC), ligament groove (L), anterior tooth socket (AS), central tooth (CT), posterior tooth socket (PS), ectomyophoral cavity (EC). (.../...)



2, *Youngicaprina sangabrieli* MITCHELL; Specimen 4A, view into RV highly recrystallized cardinal platform and abraded margins; anterior myophore (AM), anterior socket (AS), posterior socket (PS), posterior myophore (PM).
3, Indeterminate Caprinid; Specimen 5A, LV with abraded ventral and dorsal margins.
4, Indeterminate Caprinid; Specimen 4B, RV highly abraded dorsal margin.
5, *Caprinuloidea romeri* MITCHELL?; Sample 2A, upper specimen cut through coiled LV, associated with fragment of solitary coral and chondrodontid bivalve shells.
6, *Eoradiolites davidsoni* (HILL, 1893); Specimen 1B, oblique section through.
7, Sample A with broken shells of *Caprinuloidea*, *Eoradiolites* and *Chondrodonta*.
8, Sample 3 with broken subparallel rudists and other bioclasts.
9-10, *Caprinuloidea romeri* MITCHELL; two cross sections of same specimen in upper part, Fort Terrett Formation, U.S. 67/375, 5.8 mi northeast of I-10, 15 mi east of Fort Stockton, Pecos County, Texas (HOJNACKI, 2016).
11-12, *Caprinuloidea romeri* MITCHELL, LV body cavity (BC) and posterior accessory cavity (PAC).

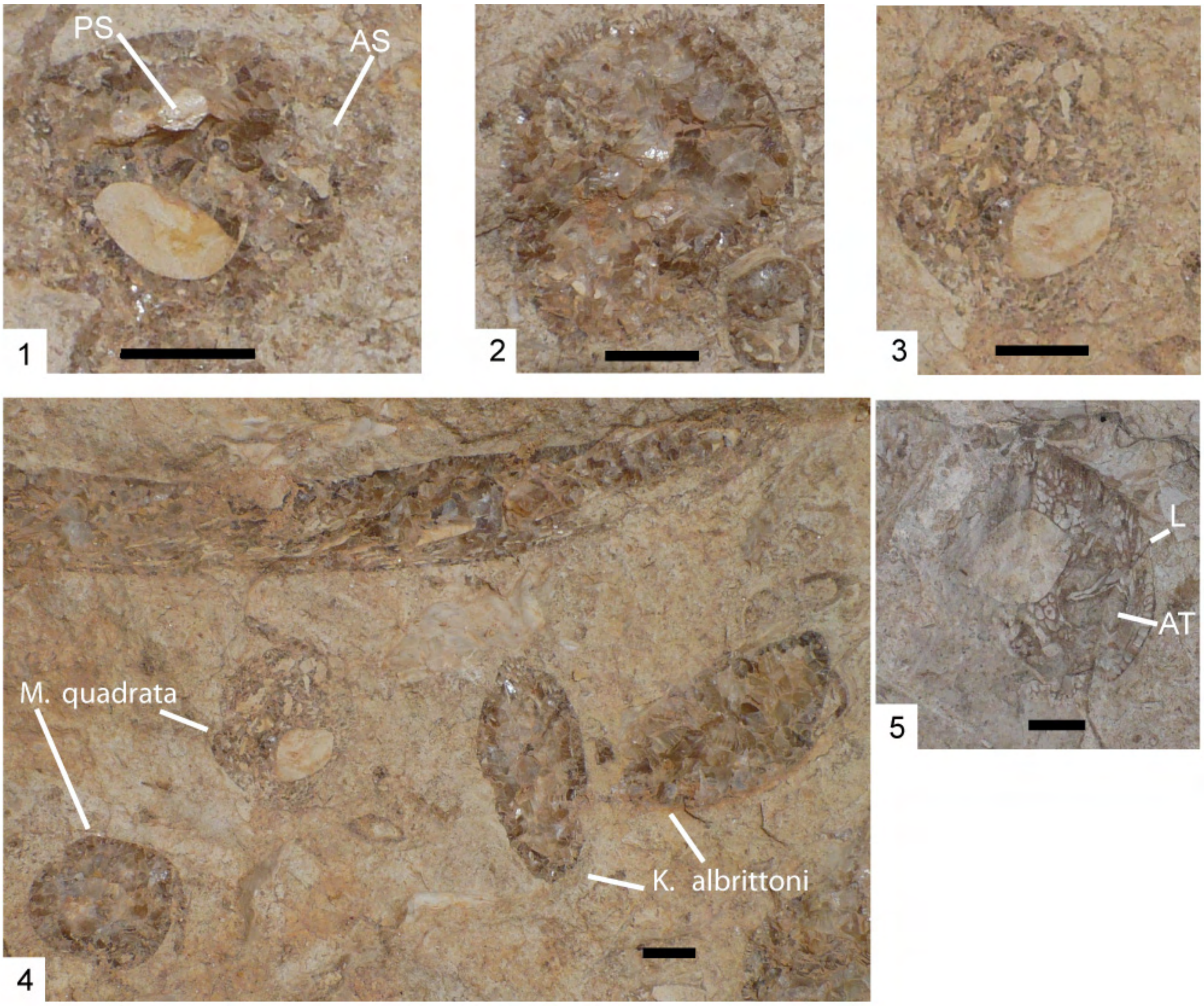


Figure 10: Rudist specimens from upper part of Fort Lancaster Formation exposed in the north roadcut, U.S. 190, east of Iraan, Crockett County, Texas (LAI, 2014). Scale bar is 1 cm.
1, 2, 3, *Mexicaprina quadrata* ALENCÁSTER & OVIEDO-GARCÍA, 1, view out of RV, anterior socket (AS), posterior socket (PS); 2, 3, recrystallized RVs.
4, Subhorizontal specimens of *Mexicaprina quadrata* and *Kimbleia albrittoni*; 5, *Mexicaprina quadrata*, view into LV, anterior tooth (AT), ligament (L).

Biostratigraphy

The Fredericksburg and Washita groups host a diverse assemblage of Brancoceratid ammonites that serve to define precise zones (Fig. 14) (YOUNG, 1966, 1986; KENNEDY *et al.*, 1998, 1999; SCOTT *et al.*, 2003). Numerous middle to lower-upper Albian species of the Subfamily Mojsisovicziinae HYATT, 1903, characterize the Fredericksburg: *Venezoliceras* SPATH, 1925, *Oxytropidoceras* STIELER, 1920, and *Manuaniceras* SPATH, 1925. These genera cross the lower-upper Albian sequence boundary Washita 1 (Al SB Wa1) into the basal Washita Group having survived the sea-level flooding of North America. One genus of this group is new, *Adkinsites* SPATH, 1931, and defines the lowermost Washita zone in the Kiamichi Formation and equivalent units in the Western Interior seaway (YOUNG, 1966, 1986; SCOTT, 1970). The younger stratigraphic units of the Washita Group are characterized by ammonites of the Subfamily Mortoniceratinae H. DOUVILLÉ (KENNEDY *et al.*, 1998, 1999): *Mortoniceras* MEEK, 1876, and its several subgenera. Seven upper Albian mortonicerid zones overlie the Adkinsites bravoensis Range Zone in the Kiamichi Formation (Fig. 14) (YOUNG, 1959, 1986). Co-occurring European species correlate the middle-upper Albian boundary in the upper part of the Fredericksburg Group (KENNEDY *et al.*, 1998, 1999; SCOTT *et al.*, 2003).

Rudist bivalves have undergone multiple Early Cretaceous episodes of extinction and the group rapidly diversified throughout the Early Cretaceous making them an important tool for biostratigraphic correlation (SCOTT and FILKORN, 2007; SKELTON, 2013; STEUBER *et al.*, 2016). Although rudists do not occur in the same beds as ammonites, they are in facies superposed with ammonites. The lower parts of the Fredericksburg Group, the Walnut Formation yields

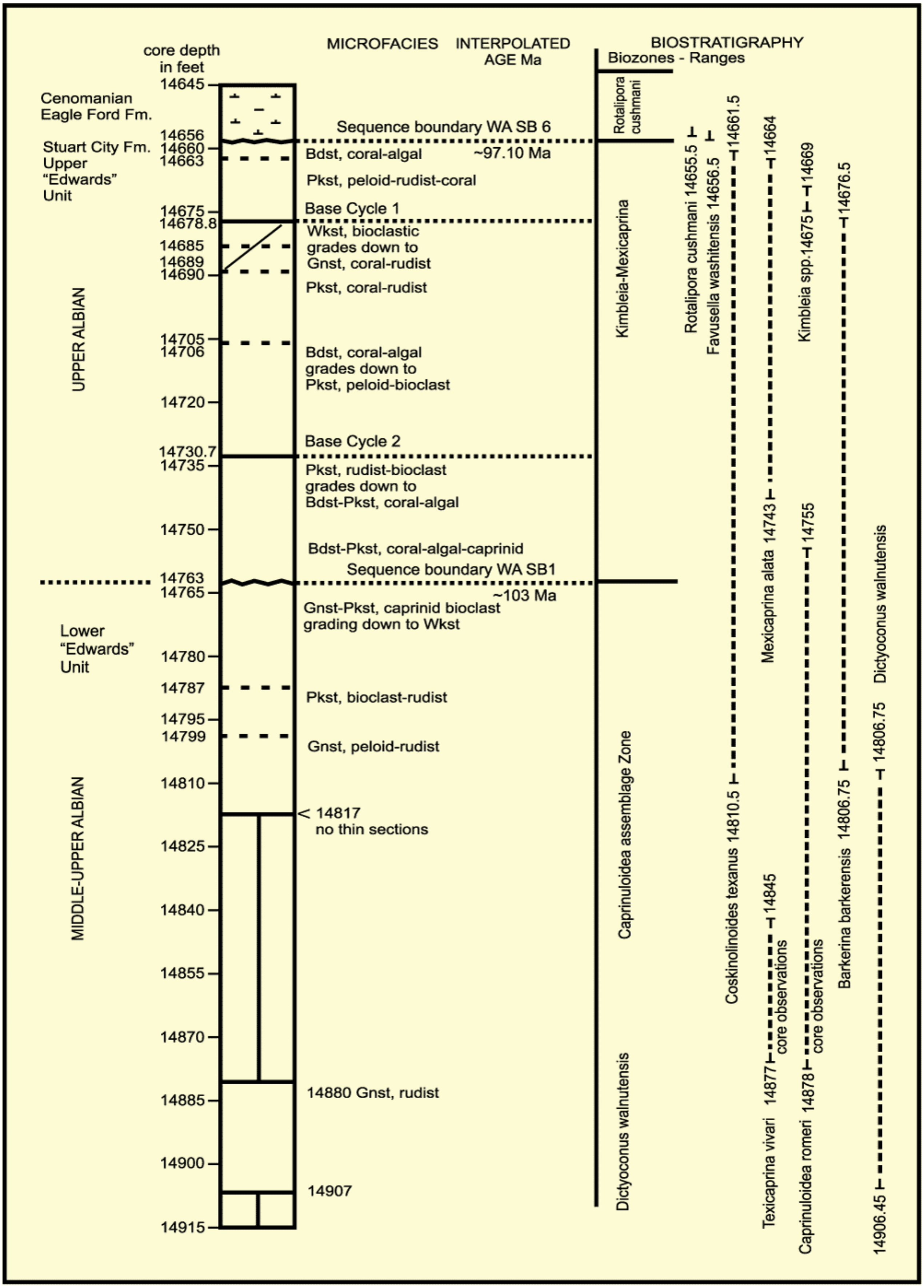


Figure 11: Carbonate microfacies and biostratigraphic log of Pioneer Natural Resources Myra Sue Kelley Gas Unit 3-4, DeWitt County, Texas. Abbreviations: grainstone (Gnst), packstone (Pkst), boundstone (Bdst), wackestone (Wkst).

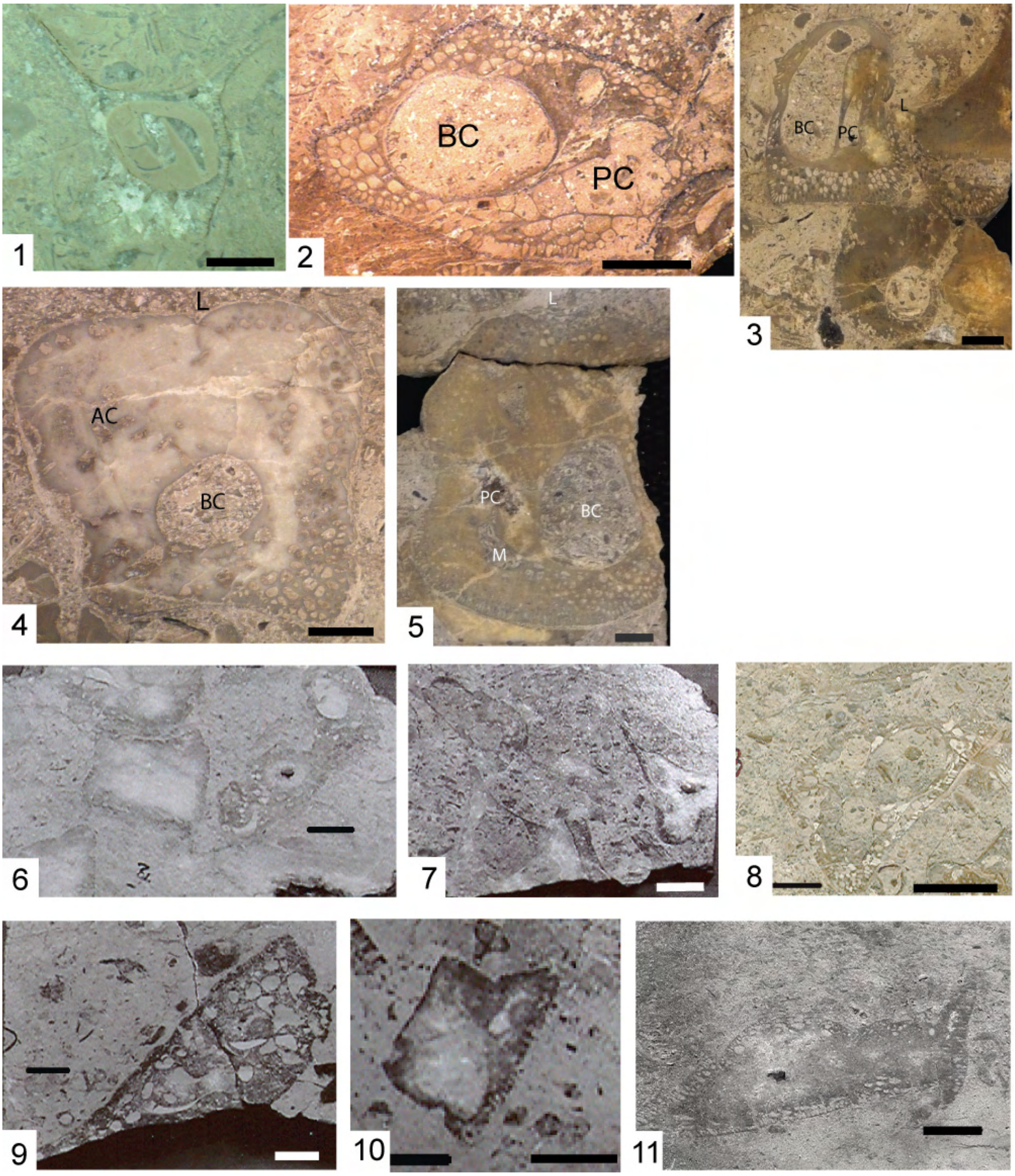


Figure 12:
1-5, Rudists in the Stuart City Formation in DeWitt County, Texas. 1-3 Pioneer Natural Resources Myra Sue Kelly Gas Unit No. 3-4. 1, *Ichthyosarcolites [Mexicaprina] alatus* at 14,743ft. 2, 3, *Kimbleia albrittoni* at 14,789ft and 14,845.5ft. 4, 5, Pioneer Natural Resources Burns 1-2 at 14,812.5ft, 14,827ft.
6-11, Comanche rudists in Chandeleur Sound offshore Louisiana Chevron 4898 #2; scale bar = 1cm. 6, 10, *Mexicaprina quadrata* at 12.810ft and 12,831ft. 7, *Ichthyosarcolites alatus* and *Kimbleia albrittoni* at 12,815.5ft. 8, 9, *K. albrittoni* at 12,820ft and 12,829ft. 11, *Caprinuloidea romeri* at 13,644ft.

numerous middle Albian ammonite species (Fig. 15) (Young, 1966). The upper part of the Edwards Formation spans the middle-upper Albian zones, and hosts common caprinid rudists among other rudist groups. In shelf carbonates of the West Texas Pecos River region rudist genera overlie upper Albian ammonite facies (Scott and Kidson, 1977; Scott and Kerans, 2004).

Five rudist zones in the Comanchean Series are defined by the ranges of sixteen rudist taxa (Scott and Filkorn, 2007). These zones are integrated with Barremian to Albian ammonite zones and foraminiferal ranges in the Trinity, Fredericksburg and Washita groups (Coogan, 1973, 1977; Scott, 1990, 2002). The Caprinuloidea Zone of Scott and Filkorn (2007) is redefined here as the interval between the last appearance of *Coalcomana ramosa* (Fig. 4.13-14) and the last appearance of *Caprinuloidea perfecta*. Mitchell (2013a) revised this group and restricted *C. perfecta* to the Trinity Group. He redefined Fredericksburg specimens previously identified as *Caprinuloidea perfecta* by Scott (2002) as *Caprinuloidea romeri*. This species is diagnostic of the Fredericksburg Group and its zone is the interval between the last appearance of *C. perfecta* (Fig. 4.11-12) and the last appearance of *C. romeri*. This Caprinuloidea romeri Interval Zone spans the middle to lower upper Albian Fredericksburg Group; this zone includes an assemblage of other bivalves and benthic foraminifers that are diagnostic of the Texas Fredericksburg Group. The Caprinuloidea romeri IZ is present in the shelf facies of the Fredericksburg Group and is overlain by the regionally correlated sequence boundary Al SB WA1 located at the base of the overlying Washita Group (Scott and Filkorn, 2007).

In the Pecos River Valley outcrops *Caprinuloidea romeri* occurs in the Fort Terrett Formation approximately 3 meters below the iron-stained hardground subaerial exposure surface that marks the contact at the top of the Fredericksburg Group (Fig. 2). It is overlain by the Eopachydiscus marcianus Zone in gray shale at the base of the Fort Lancaster Formation (Campbell, 2016).

Caprinuloideid rudists, including *Caprinuloidea romeri*, are here documented from the cored type section of the Person Formation in the upper part of the Edwards Group (Rose, 1972) (Figs. 6 - 7, 9 & 14). These specimens enable a precise correlation of the Person Formation with the Fort Terrett Formation cropping out on the Pecos River, and with the Fredericksburg Group. This evidence together with foraminifer and ammonite zones (Scott and Kerans, 2002) demonstrates that the Person Formation is coeval with Fredericksburg units and underlies sequence boundary Al SB Wa1.

The upper Albian Kimbleia albrittoni and Ichthyosarcolites [Mexicaprina] alatus caprinid zones are stratigraphically above the Caprinuloidea romeri Interval Zone (IZ) (Fig. 14) (Scott and Filkorn, 2007). The Kimbleia IZ correlates with three ammonite zones in the lower Washita Group of north-central Texas: the Adkinsites bravoensis IZ, the Eopachydiscus marcianus IZ, and the Drakeoceras wintoni IZ. On the Pecos River in West Texas the Kimbleia IZ spans the lower part of the Upper Devils River Limestone (Scott and Filkorn, 2007). The upper Albian Mexicaprina IZ is the interval of the total range of *Mexicaprina* in the uppermost part of the Upper Devils River Limestone and in the El Abra Limestone in Mexico (Filkorn, 2002; Scott and Filkorn, 2007). This interval correlates with the uppermost Albian Plesioturrilites brazoensis ammonite IZ in the Main Street Formation and directly underlies the Lower Cenomanian Del Rio Shale, which contact is sequence boundary WA SB 6 in the North Texas section (Scott *et al.*, 2003). In the Fort Stockton Basin these rudist zones overly the Boracho Formation, which hosts several mortonicerid ammonite zones (Scott and Kidson, 1977).

Regional correlations

The revised Caprinuloidea romeri Interval Zone is recognized in outcrops on the eastern margin of the Fort Stockton Basin and in the type section of the Person Formation on the subsurface San Marcos Arch (Campbell, 2016; Hojnacki, 2016) (Fig. 15). This species is widespread in the Edwards Formation on the western outcrop margin of the East Texas Basin (Mitchell, 2013a). The C. romeri Zone overlies the Manuaniceras carbonarium Zone in the underlying Comanche Peak Formation (Young, 1986). The C. romeri IZ underlies the Adkinsites bravoensis Zone in the East Texas Basin (Figs. 14 - 15). Thus the Person Formation correlates both physically and biostratigraphically with the Edwards Formation to the northeast and with the Fort Terrett Formation westwards across the Edwards Plateau. The Regional Dense member underlies the C. romeri IZ and is a flooding facies that correlates with the middle part of the Walnut Formation. The lower part of the Edwards Group, which consists of the Fort Terrett, Kainer and Person formations is physically continuous with and biostratigraphically equivalent with the Fredericksburg Group in the East Texas Basin. The Segovia Formation and the Burt Ranch Member at its base correlate with the upper Albian part of the Washita Group in the East Texas Basin.

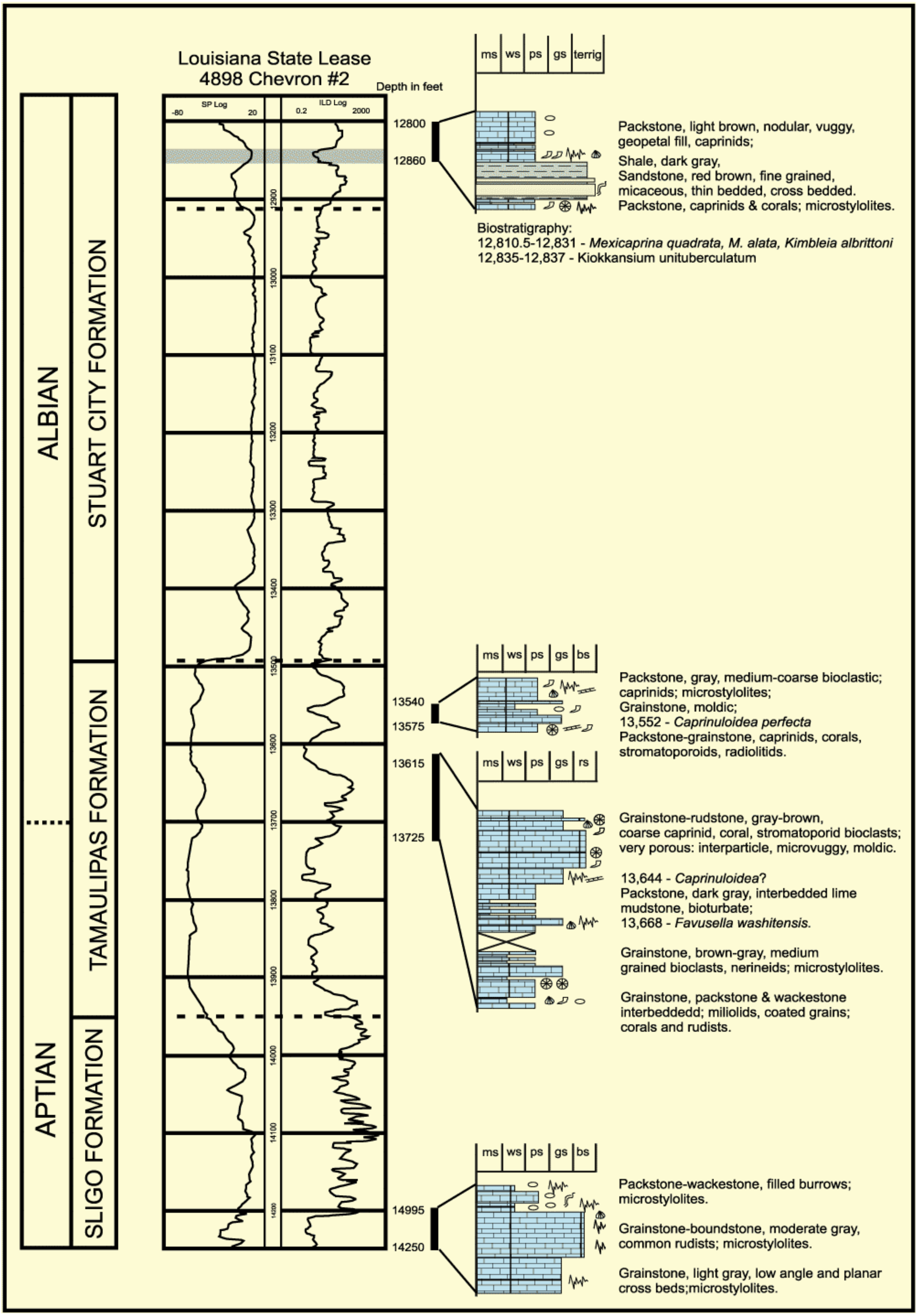
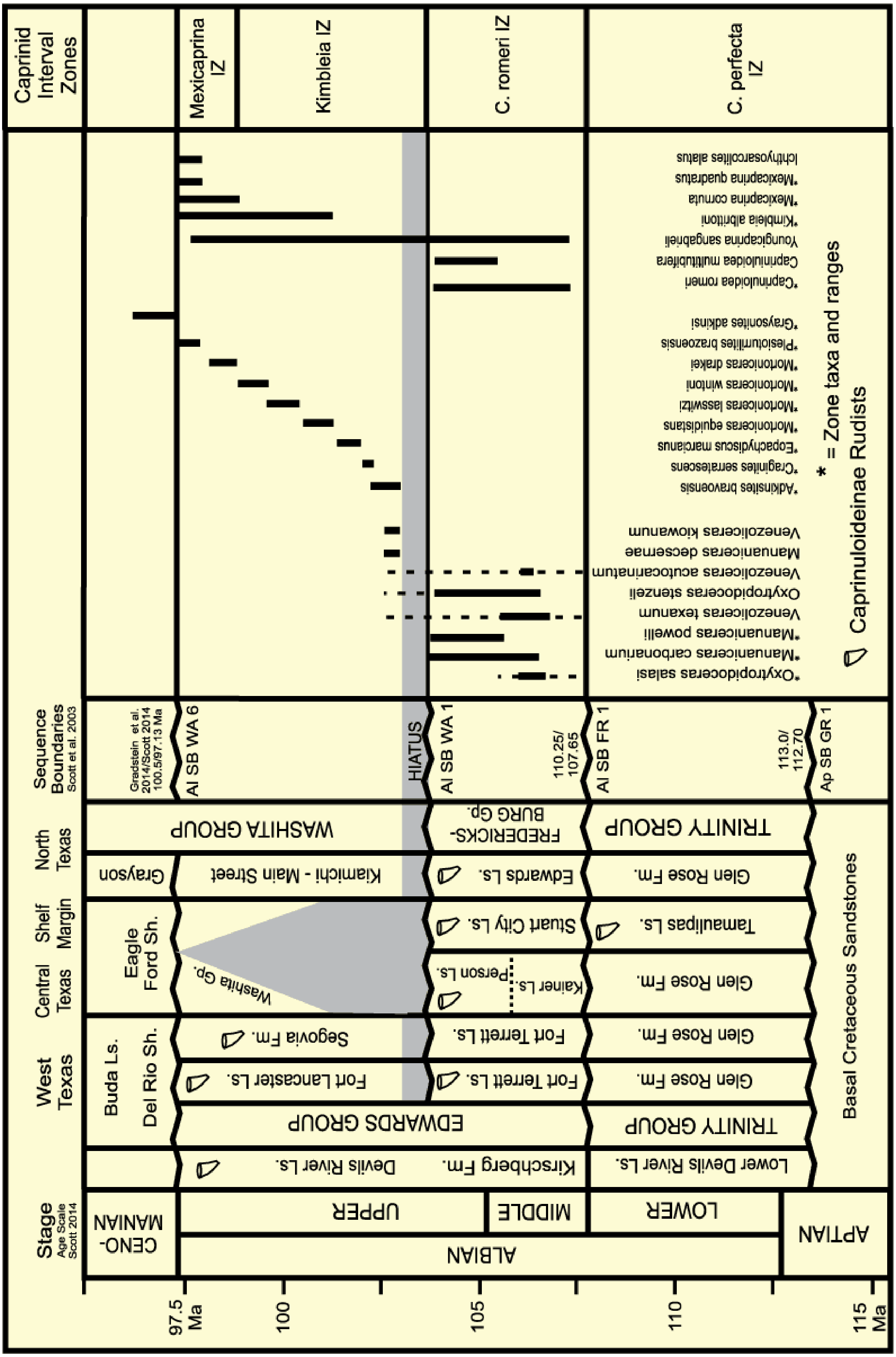
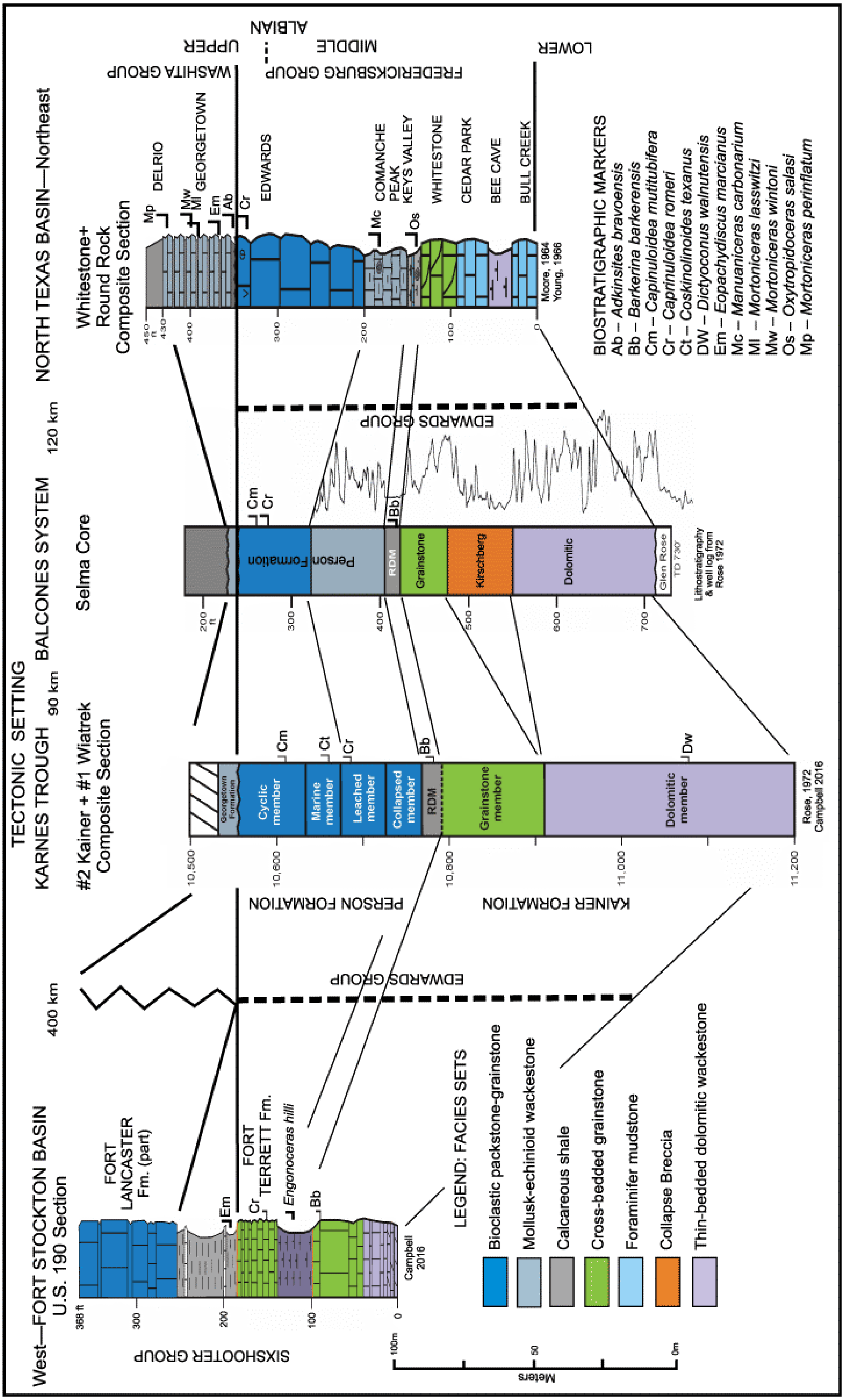


Figure 13: Chevron State Lease 4898 No. 2 Chandeleur Sound Upper Albian; facies (E.A. MANCINI, personal communication), caprinids (R.W. SCOTT, personal communication) and palynomorphs (D.G. BENSON, personal communication).

▶ **Figure 14:** Biostratigraphy of ammonites and rudists. Lithostratigraphy from ROSE (1972) and SMITH *et al.*, 2000). Ammonite biostratigraphy from YOUNG (1966, 1984) and KENNEDY *et al.* (1998, 1999). Rudist biostratigraphy revised from SCOTT and FILKORN (2007).



Caprinid Interval Zones
Mexicaprina IZ
Kimbleia IZ
C. romeri IZ
C. perfecta IZ
Sequence Boundaries
Scott et al. 2003
Gradstein et al. 2014/Scott 2014 100.5/97.13 Ma
Al SB WA 6
HIATUS
Al SB WA 1
110.25/107.65
Al SB FR 1
113.0/112.70
Ap SB GR 1
North Texas
Shelf Margin
Central Texas
West Texas
Stage
Age Scale Scott 2014
CENO-MANIAN
UPPER
MIDDLE
LOWER
ALBIAN
APTIAN
97.5 Ma
100
105
110
115 Ma
Grayson
Kiamichi - Main Street
Edwards Ls.
Glen Rose Fm.
WASHITA GROUP
FREDERICKS-BURG Gp.
TRINITY GROUP
Eagle Ford Sh.
Washita Gp.
Stuart City Ls.
Tamaulipas Ls.
Person Ls.
Kainer Ls.
Buda Ls.
Del Rio Sh.
Segovia Fm.
Fort Terrett Ls.
Fort Lancaster Ls.
EDWARDS GROUP
Devils River Ls.
Kirschberg Fm.
Lower Devils River Ls.
Basal Cretaceous Sandstones
Ichthyosarcolites alatus
*Mexicaprina quadratus
*Mexicaprina cornuta
*Kimbleia albrittoni
Youngicaprina sangabrieli
Caprinuloidea multitubifera
*Caprinuloidea romeri
*Graysonites adkinsi
*Pleiotumilites brazoensis
*Mortoniceras drakei
*Mortoniceras wintoni
*Mortoniceras lasswitzi
*Mortoniceras equidistans
*Eopachydiscus marcianus
*Craginites serratescens
*Adkinsites bravoensis
Venezoliceras kiowanum
Manuaniceras decemae
Venezoliceras acutocarinatum
Oxytropidoceras stenzeli
Venezoliceras texanum
*Manuaniceras powelli
*Manuaniceras carbonarium
*Oxytropidoceras salasi
* = Zone taxa and ranges
Caprinuloideinae Rudists


West—FORT STOCKTON BASIN
U.S. 190 Section
FORT LANCASTER Fm. (part)
FORT TERRETT Fm.
Engonoceras hilli
Campbell 2016
SIXSHOOTER GROUP
Meters
400 km
TECTONIC SETTING
KARNES TROUGH
#2 Kainer + #1 Wiatrek Composite Section
Georgetown Formation
Cyclic member
Marine member
Leached member
Collapsed member
RDM
Grainstone member
Dolomitic member
Rose, 1972 Campbell 2016
PERSON FORMATION
KAINER FORMATION
EDWARDS GROUP
90 km
BALCONES SYSTEM
Selma Core
Person Formation
Grainstone
Kirschberg
Dolomitic
Glen Rose
Lithostratigraphy & well log from Rose 1972
120 km
NORTH TEXAS BASIN—Northeast
Whitestone+ Round Rock Composite Section
DELRIO
GEORGETOWN
EDWARDS
COMANCHE PEAK
KEYS VALLEY
WHITESTONE
CEDAR PARK
BEE CAVE
BULL CREEK
Moore, 1964 Young, 1966
WASHITA GROUP
FREDERICKSBURG GROUP
UPPER
MIDDLE
LOWER
ALBIAN
LEGEND: FACIES SETS
Bioclastic packstone-grainstone
Mollusk-echinioid wackestone
Calcareous shale
Cross-bedded grainstone
Foraminifer mudstone
Collapse Breccia
Thin-bedded dolomitic wackestone
BIOSTRATIGRAPHIC MARKERS
Ab – Adkinsites bravoensis
Bb – Barkerina barkerensis
Cm – Caprinuloidea mutitubifera
Cr – Caprinuloidea romeri
Ct – Coskinolinoides texanus
DW – Dictyoconus walnutensis
Em – Eopachydiscus marcianus
Mc – Manuaniceras carbonarium
Ml – Mortoniceras lasswitzi
Mw – Mortoniceras wintoni
Os – Oxytropidoceras salasi
Mp – Mortoniceras perinflatum

Conclusions

The Albian Caprinuloidea IZ of SCOTT and FILKORN (2007) is revised to consist of *Caprinuloidea perfecta* in the lower Albian part of the Trinity Group. The *Caprinuloidea romeri* IZ is defined as its total range in the Fredericksburg Group (MITCHELL, 2013a). The C. romeri IZ is widespread in the Fredericksburg in northern Texas and in the Fort Terrett Formation in West Texas. It is also recognized in the Person Formation in the Edwards Group in the subsurface of the San Marcos Arch. Thus the upper part of the Edwards Group correlates with the Fredericksburg Group and not with the lower part of the Washita Group as postulated for many years. The disconformity between the Person and Georgetown formations can be traced northward with Albian Sequence Boundary Washita 1 and westward with the flooding disconformity in or at the base of the Burt Ranch Member of the Segovia Formation. In many sections this contact was subaerially exposed in early late Albian Age prior to the sea-level rise that flooded North America. The upper part of the Edwards Group on the Edwards Plateau, the Segovia Formation, does correlate with the Washita Group. In some sections on the Edwards Plateau an interval of multiple iron-stained, bored hardgrounds separate the Fort Terrett from the basal Segovia (ROSE, 1972). We suggest that these hardgrounds formed during the final late highstand stage and only the uppermost is the candidate Albian Sequence Boundary Washita 1.

Systematic paleontology

Order Hippuritida NEWELL, 1965

Suborder Requieniidina SKELTON, 2013

Family Requieniidae KUTASSY, 1934

Subfamily Requieniinae KUTASSY, 1934

Genus *Toucasia* MUNIER-CHALMAS, 1873

(Fig. 6.2)

Type species.- *Requienia carinata* MATHERON, 1842

Discussion.- Two-dimensional cross sections of requieniids are common in cores and outcrops of middle and upper Albian strata on the Comanche shelf. These shells have two layered walls: a dark calcite outer layer and a light sparry calcite inner layer that replaces the original aragonitic layer. Cross sections oriented normal to the whorl spiral axis have flat and gently curved sides. Three species have been identified in outcrop by whole valves, *Toucasia hancockensis* WHITNEY, 1952, in the Glen Rose Formation, and in the Fredericksburg and Washita groups, *Toucasia texana* (ROEMER, 1852) and *Toucasia patagiata* (WHITE, 1884) (COOGAN, 1977; GARCÍA-BARRERA, 1995; AGUILAR PÉREZ, 2008). In Mexico *T. texana* ranges from the Barremian-Aptian Cupido throughout the Albian El Abra formations (AGUILAR PÉREZ, 2008).

Suborder Radiolitidina SKELTON, 2013

Superfamily Radiolitoidea ORBIGNY, 1847

Family Radiolitidae ORBIGNY, 1847

Genus *Eoradiolites* DOUVILLÉ, 1909

(Fig. 9.6)

Discussion.- The type species of this genus, *Eoradiolites davidsoni* (HILL, 1893), recently has been described and illustrated (ALENCÁSTER and GARCÍA-BARRERA, 2008). This species is highly variable and most subsequent Comanchean species have been synonymized by these authors. A new species, *Eoradiolites corrugatus* DAVIS-STRICKLAND, 1988, is somewhat larger than *E. davidsoni* and may be a junior synonym. In core slabs and thin sections *Eoradiolites* is recognized by its distinctive thick reticulated outer shell wall comprised of thin vertical and horizontal laminae. Cross sections parallel to the commissure may intersect the three prominent radial ridges separated by two wide grooves.

Occurrence.- *Eoradiolites davidsoni* is widespread in Texas, Louisiana, Mississippi, and Mexico in middle and upper Albian strata (COOGAN, 1977). It is documented in the upper parts of the Fort Terrett and Fort Lancaster formations (SMITH *et al.*, 2000).

Family Caprinulidae YANIN, 1990

Genus *Sellaea* DI STEFANO, 1889

(Fig. 6.1)

Discussion.- Attached valve-right valve (AV-RV) is divided into three cavities by anterior and posterior myophore plates extending from a large central tooth to anterior and posterior shell walls; anterior shell wall of RV divided into multiple ovate canals by short radial plates; dorsal to central tooth an arcuate ridge connects to posterior cavity/tooth socket; deep ligament groove. Free valve-left valve (FV-LV) has two large teeth separated by a dorsal arcuate socket connected to posterior myophore pit; anterior myophore is an ovate pit ventral to anterior tooth (COX *et al.*, 1969, p. N787).

Occurrence.- In Texas this genus is present in outcrops of the Edwards Formation; it also occurs in Aptian to Cenomanian strata in Italy (COOGAN, 1977; DAVIS-STRICKLAND, 1980). In Oman this genus occurs in Albian inner platform facies (SKELTON and MASSE, 2000).

◄ **Figure 15:** Stratigraphic correlation of Middle-Upper Albian strata west to east from the Fort Stockton Basin to North Texas Basin. Rudist biostratigraphy defined herein; Ammonite biostratigraphy defined by YOUNG (1986). Sequence stratigraphic units defined in North Texas Basin (SCOTT *et al.* 2003).

Superfamily Caprinoidea ORBIGNY, 1847

Family Caprinuloideidae DAMESTOY, 1971

Subfamily Caprinuloideinae DAMESTOY, 1971

Genus *Caprinuloidea* PALMER, 1928

Type species.- Caprinuloidea perfecta PALMER, 1928, in the area of Soyatlan Adentro, Jalisco, Mexico; presumably lower Albian strata (MITCHELL, 2013a).

Diagnosis.- Right valve (RV) profile with flat anterior margin and convex dorsal margin; body cavity and interior canals tabulate; external ligament groove connected to an inner curved or hooked shaped ridge; ventral shell wall with two or more rows of pallial canals; in left valve (LV) flat anterior and posterior myophore plates project into RV, the anterior plate fits onto a ledge and the posterior plate fits into a cavity (MITCHELL, 2013a).

Discussion.- MITCHELL (2013a) includes four species under this genus: *C. perfecta*, *C. septata* PALMER, 1928, *C. multitubifera* PALMER, 1928, and *C. romeri* MITCHELL, 2013a. MITCHELL narrowed the concept of *C. perfecta* to lower Albian specimens having small pallial canals in the central tooth and in myophoral structures in some RV specimens.

Caprinuloidea perfecta PALMER, 1928

(Fig. 4.11-12)

Caprinuloidea perfecta PALMER, 1928, p. 59-60, Fig. 6; Pl. VIII, fig. 8; Pl. IX, figs. 1-2

Caprinuloidea costata PALMER, 1928, p. 62-63, Pl. XI, figs. 2-5; SCOTT and GONZÁLES-LEÓN, 1991, p. 62; SCOTT, 2002, p.410.

MITCHELL (2013a) provides additional synonymy

Type specimens.- Holotype CAS.66651-10 (California Academy of Sciences), PALMER No. 2168 from Soyatlan Adentro, Jalisco, Mexico; housed at California Academy of Science.

Diagnosis.- RV long, straight to curved, LV curved to partly coiled; valve cross section ovate to rectangular with rounded antero-ventral keel; distinct external ligament groove; RV with tooth large, with few small pallial canals and locally canals in myocardinal areas of RVs; LV with two large teeth, triangular to oval in cross section; shell wall with an outer row of ellipsoidal canals and one to three inner rows of ovate canals.

Discussion.- MITCHELL (2013a) considered that the types of *Caprinuloidea perfecta gracilis* PALMER, 1928, to be smaller specimens of *C. perfecta*. PALMER differentiated *C. perfecta gracilis* by its narrower cross section in relation to its great length, which MITCHELL (2013a) includes as a subspecies of *C. perfecta*. This species is also from the Lower Albian Mural Formation, Sonora, Mexico (Fig. 4.11-12 ; GONZÁLES-LEÓN *et al.*, 2008). PALMER (1928) erected *Caprinuloidea costata* for specimens having distinct growth rings. However SCOTT and GONZÁLES-LEÓN (1991) considered these features to be within the range of variation of *C. perfecta* because the type material of each species was from the same locality.

Occurrence.- C. perfecta is from lower Albian strata at Soyatlan de Adentro, Jalisco and El Abra Formation in Tamaulipas, Mexico (AGUILAR PÉREZ, 2008).

Caprinuloidea romeri MITCHELL, 2013a

(Figs. 4.4-5, 6.4-6, 7.5-6, 9.1, 9.5, 9.9-12, 12.11)

Caprinuloidea romeri MITCHELL, 2013a, p. 52-60, Figs. 3A-E, 4A-D

Type specimens.- Holotype at Texas Museum of Natural History TMM.UT10932; paratypes TMM.UT10930.1, 11268, 33867, and 10922; Edwards Limestone, Austin, Texas area.

Diagnosis.- RV long, straight to torted, LV coiled, external ligament groove, pallial canals in RV central tooth and myocardinal areas, LV myophores partly invaded by pallial canals, outer valve wall with narrow tear-drop pallial canals, inner wall with three to six rows of ovate canals (MITCHELL, 2013a).

Discussion.- Until 2013 *C. perfecta* included specimens from both the Trinity and Fredericksburg groups (COOGAN, 1977; SCOTT, 2002; SCOTT and FILKORN, 2007). However MITCHELL (2013a) distinguished *C. romeri* from *C. perfecta* by internal properties. *C. perfecta* has small pallial canals in the central tooth of the RV and rarely in the myocardinal area as opposed to *C. romeri*, which has large pallial canals in the myocardinal area. PALMER (1928) noted that *C. perfecta* has canals in the large central tooth of the RV and in the ridge connecting it to the outer wall.

MITCHELL (2013a) assigned most specimens in the Edwards Formation to *Caprinuloidea romeri* MITCHELL, "because their pallial canals are regularly developed and some pallial canals invade the myophores." He included in *C. romeri* the silicified Edwards specimens illustrated by SCOTT and WEAVER (2010). Because, many specimens in the Edwards are partly recrystallized and pallial canals are not clearly visible in the central tooth and myocardinal area, a broad concept of *C. perfecta* was practical and useful for biostratigraphy. However, Edwards specimens having an external ligament groove are now identified as *C. romeri* and can be distinguished from those without a groove, which are now placed in the species *Youngicaprina sangabrielensis* MITCHELL, 2013a.

The outcrop specimens in the uppermost beds of the Fort Terrett Formation (Fig. 6.1,6.5, 6.9-12) have an ovate shape with a distinct anterior-ventral rounded keel. Therefore the specimens from the Fort Terrett Formation are placed in *C. romeri*.

The two specimens in the marine member of the Person Formation in the Shell No. 2 L. Urbanczyk at 10,818.5 ft (Fig. 6.4-6) show the external groove and curved ligament and the characteristic pallial canals in the shell wall, so they are identified as *C. romeri*. However pallial canals in the myocardinal area are partially obscured by recrystallization.

Occurrence.- Type specimens of *C. romeri* are from limestones of the Edwards Group in the Austin area and in central Texas (MITCHELL, 2013a). Here this species is reported in the Fort Terrett Formation in Crocket County and in the Person Formation in the subsurface of Karnes County. In contrast, *C. perfecta* is from lower Albian outcrops at Soyatlan de Adentro, Jalisco, Mexico; the species has been reported widely in the Caribbean Province including in the Edwards Limestone (COOGAN, 1977) and in the Los Picachos and Espinazo del Diablo formations in Sonora, Mexico (SCOTT and GONZÁLES-LEÓN, 1991). *C. perfecta* was included as a member of the Caprinuloidea Interval Zone of the middle to basal upper Albian, which characterizes the Fredericksburg Group in Texas (SCOTT and FILKORN, 2007). However, specimens reported from strata of the Fredericksburg and Edwards groups are now re-assigned to *C. romeri*, which becomes the diagnostic taxon of the Caprinuloidea Zone and *C. perfecta* characterizes a zone of the Glen Rose Formation.

Genus *Mexicaprina* COOGAN, 1973

Type species.- *Mexicaprina cornuta* COOGAN, 1973.

Mexicaprina quadrata ALENCÁSTER & OVIEDO-GARCÍA, 1998

(Figs. 10.1-5 & 12.6-10)

Mexicaprina quadrata ALENCÁSTER & OVIEDO-GARCÍA, 1998, p. 172, Fig. 6.2

Holotype.- RV IGM-4581.

Type locality.- El Madroño, Queretaro, Mexico.

Diagnosis.- Cross section ovate, valve margins flat, keeled at corners; LV conical with acute apex (ALENCÁSTER and OVIEDO-GARCÍA, 1998, p. 172).

Discussion.- Specimens in the uppermost part of the Fort Lancaster Formation are somewhat larger in diameter than most of the Mexican specimens, 30 to 35 mm compared to 22 mm. The recrystallized cardinal area precludes detailed comparisons of these specimens with the free specimens from El Madroño. *M. quadrata* lacks the ridges characteristic of *Mexicaprina cornuta* COOGAN (1973) and the long spine-like keels of *Ichthyosarcolites [Mexicaprina] alatus* (FILKORN, 2002) (MITCHELL, 2013b) (Fig. 12.7).

Occurrence.- *Mexicaprina* species were first described from the El Abra Formation in the Taninul quarry east of Valles, San Luis Potosi, Mexico. In Texas *M. cornuta* is in uppermost Albian strata (SCOTT, 2002). The genus characterizes the uppermost upper Albian Mexicaprina Interval Zone (SCOTT and FILKORN, 2007).

Genus *Kimbleia* COOGAN, 1973

(Figs. 10.4 & 12.2-5)

Type species.- *Kimbleia capacis* COOGAN, 1973, p. 58, Pl. 1, figs. 1-3.

Type specimens.- Deposited in Instituto de Geología, Universidad de Mexico, Mexico.

Kimbleia albrittoni (PERKINS, 1961)

Caprinuloidea? albrittoni PERKINS, 1961, p. 78-81, Pl. 22, figs. 14-17; Pl. 23, figs. 1-5.

Type specimens.- Deposited University of Michigan Museum of Paleontology (U.M.M.P.) 32847, 32848-32850.

Discussion.- COOGAN (1977) differentiated *Kimbleia capacis* from *Kimbleia albrittoni* (PERKINS, 1961) by the former's "much larger, suboval to subrectangular canals next to the body cavity and tooth plus accessory cavity in the inner row of marginal canals, and in having two to three rows of polygonal canals" (COOGAN, 1977, p. 64). *K. albrittoni* is indistinguishable from *K. capacis* and has priority (SCOTT, 2002; MITCHELL, 2013a).

Occurrence.- *Kimbleia albrittoni* was described from the upper 38 m (125 ft) of the Aurora Limestone in Sierra de Tlahualilo, Coahuila (PERKINS, 1961). This species occurs with other taxa that correlate the upper Aurora section with the Washita Group in Texas (PERKINS, 1961), which COOGAN (1973) considered to be upper Albian. Other locales with *Kimbleia* are in the upper Albian Segovia, Fort Lancaster and Devils River formations (COOGAN, 1973; SCOTT, 2002). The genus characterizes the late Albian Kimbleia Interval Zone overlying the basal Washita sequence boundary Al SB WA 1 (SCOTT and FILKORN, 2007).

Genus *Neokimbleia* MITCHELL, 2013a

Type species.- *Neokimbleia acutus* MITCHELL, 2013a.

Diagnosis.- The LV anterior tooth (AT) is larger than the posterior tooth (PT), which has a posterior ridge; the anterior myophore is connected to the anterior tooth; the posterior myophore is long, blade-like inserted into the RV into an elongate cavity. No external ligament groove; ligament is a pear-shaped cavity (MITCHELL, 2013a, p. 57).

Neokimbleia acutus Mitchell, 2013a

(Fig. 7.1-4)

Neokimbleia acutus Mitchell, 2013a, p. 57, 59, Fig. 6A.

Holotype.- RV IGM-4586.

Type locality.- El Abra Formation, El Madroño, Querétaro, Mexico.

Diagnosis.- "A species of *Neokimbleia* with a bifid AT and a triangular flange on the ventral shell margin" (Mitchell, 2013a, p. 57.

Discussion.- The diagnostic ventral flange is illustrated by specimen II (Fig. 7.1). The genus *Neokimbleia* is characterized by the presence of the internal ligament in a "pear-shaped cavity" and the absence of an external ligamental groove. The posterior tooth cavity is triangular and the myophore cavity is elongate. The anterior myophore is connected to the anterior tooth. Mitchell (2013a) proposed that *Neokimbleia* evolved from *Kimbleia* by loss of the external ligament groove.

Occurrence.- The holotype was collected from the upper Albian part of the El Abra Formation at El Madroño, Querétaro, Mexico.

Neokimbleia planata (Conrad, 1855)

(Fig. 6.3)

Caprina planata Conrad, 1855, p. 268.

Neokimbleia planata (Conrad, 1855) Mitchell, 2013a, p. 59-60, Figs. 6B-E; provides complete synonymy.

Holotype.- RV USNM 9891.

Type locality.- Fort Lancaster reference section on U.S. Highway 290, east of Fort Lancaster State Park, Crockett County, Texas.

Diagnosis.- "A species of *Neokimbleia* with a single, non-bifid anterior tooth, the shell flattened in an anterio-posteriorly direction, with the shell smoothly rounded, without flanges" (Mitchell, 2013a, p. 59).

Discussion.- The specimen in the Person Formation has the same oval, smoothly rounded valve outline characteristic of the holotype. It has a large oval body cavity, an arcuate elongate endomyophoral cavity ending in a narrow tooth socket and an ovate small anterior tooth socket. No external ligament groove is present. The marginal ellipsoidal pallial canals are cut obliquely and are largely recrystallized. Because the original inner shell is recrystallized, no other canals are visible.

Occurrence.- The presence of this species in the Person Formation with *C. romeri* and *Y. sangabrieli* indicates that its range is in the Fredericksburg Group. Mitchell (2013a) reported Scott's opinion that the holotype was collected near the Fort Lancaster reference section in Crockett County, Texas, near the site of Fort Lancaster State Park. Subsequent study of this section has failed to identify similar specimens in either the Fort Terrett or the Fort Lancaster formations, although in the Fort Lancaster specimens of *Kimbleia* and *Mexicaprina* have been found at this locality (Gargili, 2013; Lai, 2014).

Subfamily Youngicaprininae Mitchell, 2013a

Discussion.- The myocardinal arrangement of this subfamily is distinct from that of the Caprinuloideinae. The LV anterior myophore is a low platform that connects to the anterior tooth and the posterior LV myophore is tooth-like and not connected to the posterior tooth (Mitchell, 2013a). Whereas the LV myophores of the Caprinuloideinae are in cavities separate from the body cavity wall and not connected to the teeth. Mitchell (2013a) included three genera in this subfamily, *Texicaprina* Coogan, 1973, *Jalpania* Alencáster & Aguilar-Pérez, 1995, and *Youngicaprina* Mitchell, 2013a. The subfamily ranges from lower to upper Albian in Texas and Mexico.

Genus *Texicaprina* Coogan, 1973

Type species.- *Sabinia kugleri* Bouwman, 1937, p. 58-59; not *Sabinia vivari* Palmer, 1928; see discussion in Mitchell (2013a, p. 61).

Texicaprina kugleri (Bouwman, 1937)

(Fig. 4.6-8)

Synonymy.- See Mitchell 2013a, p. 63.

Lectotype.- NHMB.G7220 (Natural History Museum Basel, Switzerland); Bouwman, 1937, Figs. 1, 8-9 (designated by Mitchell, 2013a, p. 63).

Type locality.- Point-a-Pierre, Trinidad.

Diagnosis.- "A species of *Texicaprina* with a weakly tooth-like elongate, posterior myophore separated from the posterior tooth by a gutter filled with pallial canals, and an anterior myophore that envelops the anterior-side of anterior tooth and is ribbed with the ribs comprised of compact shell material and the furrows filled with pallial canals" (Mitchell, 2013a, p. 63).

Occurrence.- The lectotype is from a limestone block displaced out of stratigraphic position in Trinidad so its age is uncertain; it has been presumed to be upper Albian (Mitchell, 2013a). The illustrated specimens are from the upper part of the Stuart City Formation, which is overlain by Upper Albian marl. Associated fossils are *Caprinuloidea romeri*, and the foraminifers *Barkerina barkerensis* and *Dictyoconus walnutensis*. This species is reported from the upper Albian Devils River Formation on the Pecos River in West Texas (Scott and Kerans, 2004). The Devils River here overlies the Fort Terrett Formation; the species is in the uppermost part of local high frequency cycle AL 19, which correlates with the upper part of the Duck Creek Formation in North Texas (Fig. 2).

Genus *Youngicaprina* MITCHELL, 2013a

Type species.- *Youngicaprina gloria* MITCHELL, 2013a, p. 61, from upper Albian carbonates, El Madroño, Querétaro.

Youngicaprina sangabrieli MITCHELL, 2013a

(Fig. 4.1-3, 4.9-10)

Youngicaprina sangabrieli MITCHELL, 2013a, p. 69-71, Figs. 10, 11A-F.

Holotype.- TMM.UT-36135.5; paratypes TMM.UT-36135.1-4, BEG.2523.1, UT.3388, UT.33871.

Type locality.- Roy Gunn Ranch on North Fork San Gabriel River is now flooded by Lake Georgetown; Edwards Limestone overlies the Walnut Formation and underlies Georgetown Formation. Although MITCHELL (2013a, p. 69) reported that the Roy Gunn ranch was on the South San Gabriel River, historical records indicate that it was on the North San Gabriel River (Linda SCARBROUGH, "A Tale of The Gunns," The Sunday Sun, March 23, 1986, Georgetown).

Discussion.- This species is characterized by a coiled LV, in which the anterior myophore has four or five ribs at an angle to the margin; also it has five to seven rows of pallial canals. The type specimens are from a locality in the Edwards Limestone now drowned by Lake Georgetown. Silicified specimens in the Texas Museum of Non-Vertebrate paleontology are from the Edwards Group in Travis County. It is also found in the Segovia Formation with *Kimbleia*. Its complete range is from the upper part of the Fredericksburg into the Washita. Rare specimens also are in the Person Formation in the USCE No. 1 Selma core at -261 ft.

Occurrence.- The holotype is from the Edwards Formation. It also occurs in the Segovia Formation with *Kimbleia albrittoni* (MITCHELL, 2013a, p. 71).

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