U. S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

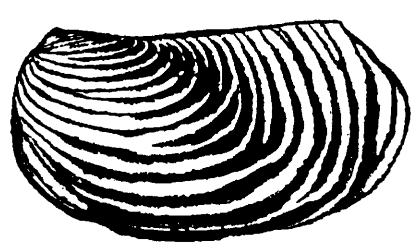
SOME MACROFOSSILS FROM THE CRETACEOUS (CAMPANIAN) ANACACHO LIMESTONE OF TEXAS

BY

WILLIAM P. ELDER[1]

U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 94-551



This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

[1] Menlo Park, California

ABSTRACT

The Anacacho Limestone was deposited during the Campanian and represents two time intervals, one of early Campanian and one of middle Campanian age. These two intervals correspond to transgressive periods following major sea level drops near the base and top of the lower Campanian. This study focuses on the molluscan paleontology of the middle Campanian interval in the eastern part of the Anacacho exposure belt in Medina County, Texas. Molluscan assemblages in this area are indicative of inner to mid-shelf environments. No significant reef components are present. These eastern Anacacho deposits are interpreted to represent more offshore, deeper water environments than those to the southwest, where reef and lagoonal deposits have been reported. Compilation of macrofossil lists from these eastern localities has expanded the number of invertebrate species known from the Anacacho Limestone by nearly three-fold. This increase in diversity, based on a small amount of new work, suggests that many more taxa are yet to be identified, particularly in the western part of the exposure belt in Uvalde and Kinney Counties. The Anacacho fauna documented herein closely resembles that of the Snow Hill calcareous member of the Black Creek Formation in North Carolina.

INTRODUCTION

The paleontologic data presented in this report are the result of a cooperative project carried out between the Texas Bureau of Economic Geology and the U. S. Geological Survey on the New Braunfels, Texas 1:100,000 map sheet. During the course of this work, the faunas of the Anacacho Limestone and correlative Pecan Gap Chalk were investigated in order to assess their paleoecology and stratigraphic relationship. This report provides the most current and extensive invertebrate fossil information for the Anacacho Limestone. Data are almost entirely derived from material collected during a five day site visit in 1990 and from fossils studied at the Texas Memorial Museum, University of Texas, Austin, in 1992. The total number of taxa identified from these two sources far exceeds that indicated in the published literature, which forms the third source of information used to compile the faunal list below. Collections from the Anacacho Limestone that reside in the U. S. Geological Survey (USGS) collections housed at the U. S. National Museum were not reviewed for this paper. Anacacho collections housed at the USGS in Denver, Colorado, were inspected, but were found to contain only ammonites and inoceramid bivalves; the ammonites are documented by Cobban and Kennedy (in press), and are included in the list below. Somewhat surprisingly, the bivalve and gastropod material collected on the short collecting trip in 1990 was as extensive as that in the museum collections, indicating a general lack of interest in collecting the mostly poorly preserved molluscan fauna of the Anacacho Limestone.

It is evident from the literature (e.g., Luttrell, 1977; Wilson, 1984; Rodgers, 1988) that the most fossiliferous parts of the Anacacho Limestone are reefal to lagoonal facies developed around volcanic cones exposed in the western part of the outcrop area in Uvalde and Kinney Counties and also found in the subsurface in Zavala and Dummit Counties. These shallow-water western localities were not sampled in this study, which is concentrated on localities here interpreted as being deposited in more offshore, deeper-water settings in Medina and Bexar Counties. These more-eastern localities have received the most attention in past reports referring to molluscan paleontology (e.g., Stephenson, 1937; Young, 1963; Brown, 1965; Cobban and Kennedy, in press), and, therefore, the potentially most-diverse molluscan faunas of the Anacacho Limestone are yet to be documented.

The most fossiliferous portions of the Anacacho Limestone, other than the skeletal limestones, where all fossils are highly fractured, are typically chalky limestones and marlstones in which aragonite is not preserved. Therefore, most of the molluscan material, other than the oysters, inoceramids, and pectens, is represented only by molds. In addition, the fossils are typically somewhat compacted and deformed to varying degrees. These preservational vagaries make positive identification difficult, particularly for the aragonitic gastropods and bivalves. This taxonomic uncertainty is reflected by the large number of comparisons to described species (*cf.*), rather than actual assignment to those taxa in this report. The generally poor preservation of mollusks in many Taylor-age units of Texas, may be one reason for the general lack of taxonomic studies of Campanian age bivalves and gastropods in the state.

LITHOFACIES

The Anacacho Limestone was originally described in the Anacacho Mountains of Texas by Hill and Vaughan (1898), who identified this limestone-rich interval in Kinney and Uvalde Counties, Texas, as occupying the same stratigraphic position as the less carbonate-rich Taylor marl to the east and the Upson clay to the west in Texas. The Anacacho is mainly composed of bioclastic and argillaceous limestones with subsidiary clay and marl interbeds. The unit represents a small carbonate bank (160 km east-west by 30-40 km north-south) of up to over 150 m in thickness that lapped onto and around the flanks of the Uvalde Salient (Rodgers, 1988). Skeletal carbonate material was supplied to this bank from patch reefs, beaches, and lagoons that were developed around scattered Campanian igneous intrusions and volcanoes (Luttrell, 1977; Wilson, 1986; Rodgers, 1988). The skeletal limestones are primarily composed of red and green algae, foraminifers, bryozoans, and molluscan and echinoid fragments, but yield few identifiable macrofossils (Luttrell, 1977; Rodgers, 1988). In contrast, localized rudistid patch reef and lagoonal facies apparently contain many whole macrofossils, as do the apparently more offshore argillaceous limestone and marlstone facies studied in this report. High porosity developed in the Anacacho Limestone and facies equivalents, particularly in the grainstone facies, has allowed hydrocarbon influx, providing asphalt deposits (Wilson, 1984) and petroleum reservoir rocks of economic importance (e.g., Luttrell, 1977; Thompson, 1986).

CORRELATION AND AGE

Because the Anacacho Limestone was deposited around numerous volcanic highs and islands that developed through an extended period in south Texas (Ewing, 1986), its stratigraphic relationship to surrounding units is complex. Near the type area in the Anacacho Mountains, the Anacacho is conformably overlain by the San Miguel Formation and grades laterally to the west and south into the Upson Formation and the lower part of the San Miguel (Spencer, 1965; Sohl et al., 1991). To the east, along the outcrop belt, the Anacacho thins and apparently grades into the upper part of the Pecan Gap Chalk near San Antonio. The top of the Anacacho becomes uncomformable to the east of the Anacacho Mountains, where it is overlain by the Maastrichtian Escondido or Corsicana Formations, but then again may become conformable with the upper part of the Taylor marl near the eastern limit of the Anacacho (Brown, 1965).

The relationship of the basal Anacacho Limestone to underlying units is unclear. Ammonite distributions suggest that at least two time intervals are represented by the Anacacho in the type area and probably elsewhere; a lower Campanian and a middle Campanian interval. The lower interval, corresponding to the lower Anacacho of Hazzard (1956), contains *Hoplitoplacenticeras*, *Menabites (Delawarella)*, and *Placenticeras*. These ammonites suggest a correlation to the Gober Chalk at the top of the Austin group in northeast Texas (Hazzard, 1956; Young, 1963; Cobban and Kennedy, in press). Young (1963) listed Anacacho Limestone localities containing this fauna as far east as Bexar County, at least 160 km (100 mi) east of the Anacacho Mountains. This lower unit is approximately the same age as the facies equivalent McKown Formation (Garner and Young, 1976), which is associated with the Pilot Knob volcanics near Austin, and also may correlate to the subsurface Dale lime, which lies near the Austin-Taylor contact to the east in Bastrop County (Thompson, 1986).

Hazzard (1956) placed an unconformity, representing the Austin-Taylor contact, between his lower Anacacho unit and the overlying middle Campanian Milam chalk and proposed a comformable contact between the lower Anacacho and the Big House Chalk below. In contrast, most subsequent workers (e.g., Brown, 1965; Wilson, 1984) have placed the Austin-Taylor contact at an apparent unconformity at the base of the lower Anacacho or at the base of the Upson Formation, which was included in the basal Anacacho as originally described by Hill and Vaughan (1898). In support of this latter placement, a restudy of the type Anacacho section by Longoria (1991) indicates an angular unconformity at the base of the Anacacho as originally described (=base of lower Anacacho of Hazzard, 1956). Further study of the biostratigraphy and lithostratigraphic relationships near the type Anacacho are warranted in order to clarify the placement and extent of unconformities in the section. The widespread presence of a lower Campanian ammonite fauna in an Anacacho-like facies near the base of the Anacacho Formation does suggest, however, that, at least locally, the Anacacho Limestone, as defined as a mapable lithostratigraphic unit, includes Austin-age rocks.

The upper part of the Anacacho Limestone is the most widely exposed and recognized part of the formation. It is composed of the upper Anacacho Limestone and the underlying Milam chalk of Hazzard (1956); the latter unit apparently only being developed in the Anacacho Mountains area (Rodgers, 1988). These units contain the middle Campanian ammonite assemblage described by Cobban and Kennedy (in press) and listed in this paper. This assemblage is essentially the same as that in the Pecan Gap Chalk and contains *Trachyscaphites spiniger porchi* (Adkins), tying it to the Western Interior *Baculites mclearni* to *B. asperiformis* zones (Cobban and Kennedy (1994). Cobban and Kennedy (in press) noted that the occurrence of *Bostrychoceras polyplocum* (Römer), which is found near the top of the Anacacho section on Seco Creek, suggests a slightly older age for this locality, than indicated by the other components of the upper Anacacho fauna found elsewhere. However, this older age seems unlikely since components of the "younger" fauna appears to occur in and below the beds containing *B.*

polyplocum on Seco Creek (Brown, 1965), and *B. polyplocum* apparently co-occurs with the entire fauna at King's Water Hole on Hondo Creek (see Appendix A, locality M8696). The taxa reported herein all lie in the middle Campanian Anacacho interval.

PALEONTOLOGIC BACKGROUND

Little recent taxonomic literature exists for Campanian age macrofossils of Texas, other than papers by Cobban and Kennedy (e.g., 1993, 1994, in press) on the ammonites. Many of the taxa were named in early papers by Römer (1852), Conrad (1857, 1858), and Craigin (1893). The echinoid fauna has been dealt with in some detail by Clark (1893) and Cooke (1953). Kniker (1918) described the pectinids, and Adkins (1929) and Young (1963) provided taxonomic data of the ammonites of the Anacacho Limestone and correlative units. The Campanian bivalves and gastropods of Texas have been largely ignored, with the bulk of taxonomic papers pertinent to taxa found in the Anacacho describing faunas from other Gulf and Atlantic Coast States. Of particular importance are Whitfield (1885, 1892), Weller (1907), Gardner (1916), Stephenson (1923), Wade (1926), and Sohl (1960, 1964a,b). In addition to these monographic works, several papers noting species present in the Anacacho Limestone and correlative Pecan Gap Chalk are available; the most important of which are Brown (1965) for the Anacacho and Stephenson (1919) for the Pecan Gap.

Comparison of the bivalve and gastropod fauna from the Anacacho Limestone to those described in the above monographs indicates that the Anacacho assemblage bears a strong resemblance to that of the Snow Hill calcareous member of the Black Creek Formation of North Carolina as described by Stephenson (1923). Stephenson (1923) originally thought the Snow Hill member was late Campanian in age. However, Sohl and Owens (1991) have shown that the type Snow Hill is early Campanian in age, placing it in their Tar Heel Formation, and that Stephenson (1923) mistakenly included some taxa from their middle to upper Campanian Bladen Formation with what he thought to be his Snow Hill fauna. Both the Tar Heel and Bladen Formations contain species in common with the Anacacho Limestone.

RESULTS

This study is based on limited field work and the examination of collections at the Texas Memorial Museum. Taxa lists compiled from this work are listed in Appendixes A and B. The field work involved recollection of two of the classic eastern exposures of the Anacacho Limestone, the lower part of the Seco Creek section and the King's Water Hole section on Hondo Creek. In addition, a locality was collected just east of Rio Medina near the Medina-Bexar County line (locality M8700, Appendix A). This locality is approximately equivalent to Texas Memorial Museum locality 800 (Appendix B). Finally, a collection was made in a pipeline ditch being excavated in a massive chalk unit mapped as the Pecan Gap Chalk less than 1 km (0.6 mi) east of the easternmost Anacacho exposure mapped on the Geologic Atlas of Texas, San Antonio Sheet (1983). This locality is apparently slightly stratigraphically lower than the Anacacho mapped in this area.

SECO CREEK SECTION

Access was only obtained to the lower part of the Anacacho section on Seco Creek, where Station I, beds "a" through "i" of Brown (1965) were collected. Brown (1965) questioned whether the calcarenitic interval from beds "a" through "d" belonged to the Austin Group or the Anacacho Limestone. None of the fossils collected from bed "b" (M8690, Appendix A) in this study are restricted to the Anacacho or the Austin. However, if the *Pycnodonte* in this sample is *Pycnodonte (Phygraea) mutabilis* (Morton), this would suggest an age younger than the Austin Group, as the species is only questionably known from rocks as old as the Austin. In addition, the *Spondylus* specimens from this bed have a greater number of spinose primary radial costae than is typical of *Spondylus guadalupae* Römer (ca. 14 versus ca. 10) of the Austin Chalk, and fewer non-spinose secondary radials (3-4 versus 4-6). The degree of variation in *Spondylus guadalupae* is unknown, however. It is possible that this lower calcarenitic interval represents the lower Campanian Austin-age Anacacho interval indicated elsewhere, but further collecting is needed to verify the age of these beds. The overlying fossils collected from beds "f" through "i" (M8691, Appendix A) are typical of the middle Campanian Anacacho interval elsewhere, although this is the only locality where *Turritella (Sohlitella) trilira* Conrad has been positively identified.

HONDO CREEK SECTION

The entire section of Anacacho Limestone exposed at King's Water Hole at Hondo Creek crossing 5 km (3 mi) north of Hondo was measured and sampled in detail. The stratigraphic section with abbreviated lithologic descriptions and fossil sample intervals is shown in Figure 1. Taxonomic occurrences are plotted in Figure 2. The taxonomic ranges shown in Figure 2 are probably environmentally controlled rather than indicative of age constraints. Age determination of the basal skeletal limestone exposed in the creek bed was not possible because no identifiable fossils were recovered. This skeletal calcarenite is very similar in character to the basal beds on Seco Creek, which may lie in the lower Campanian Anacacho interval. The first age-indicative fossil, *Baculites taylorensis* Adkins, was found approximately 1.5 m above the basal calcarenite. This ammonite and others found in units 4 through 8 are typical of the middle Campanian Anacacho interval.

Relatively diverse assemblages of deep- to shallow-infaunal bivalves, epifaunal bivalves, gastropods, and ammonites are found at this section, where the marlstone and chalk beds are typically more fossiliferous than the limestones. Infaunal bivalves are the most diverse and common in the lower, more marly units 3 through 5, where the deep infaunal bivalve, *Panopea* n. sp. aff. *decisa* Conrad, is typically found in life position. Also, in the lower part of the section, *Pycnodonte* and ammonites tend to be concentrated near the tops of the limestone beds. Higher in the section (units 11 through 14)

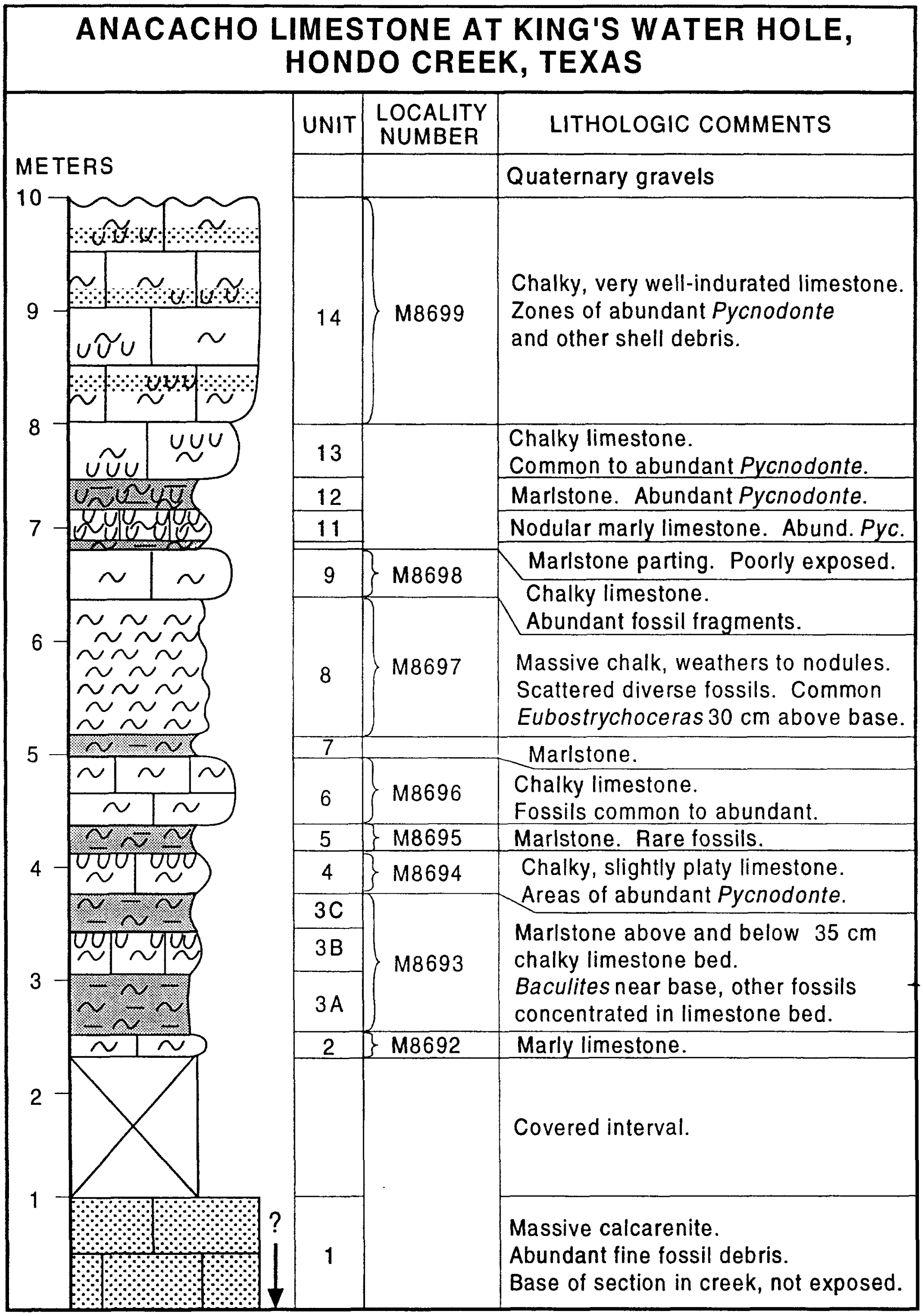


Figure 1. Stratigraphic section of the Anacacho Limestone exposed at King's Water Hole on Hondo Creek. Lithologic units, fossil locality numbers, and an abbreviated lithologic description are plotted against the lithologic column.

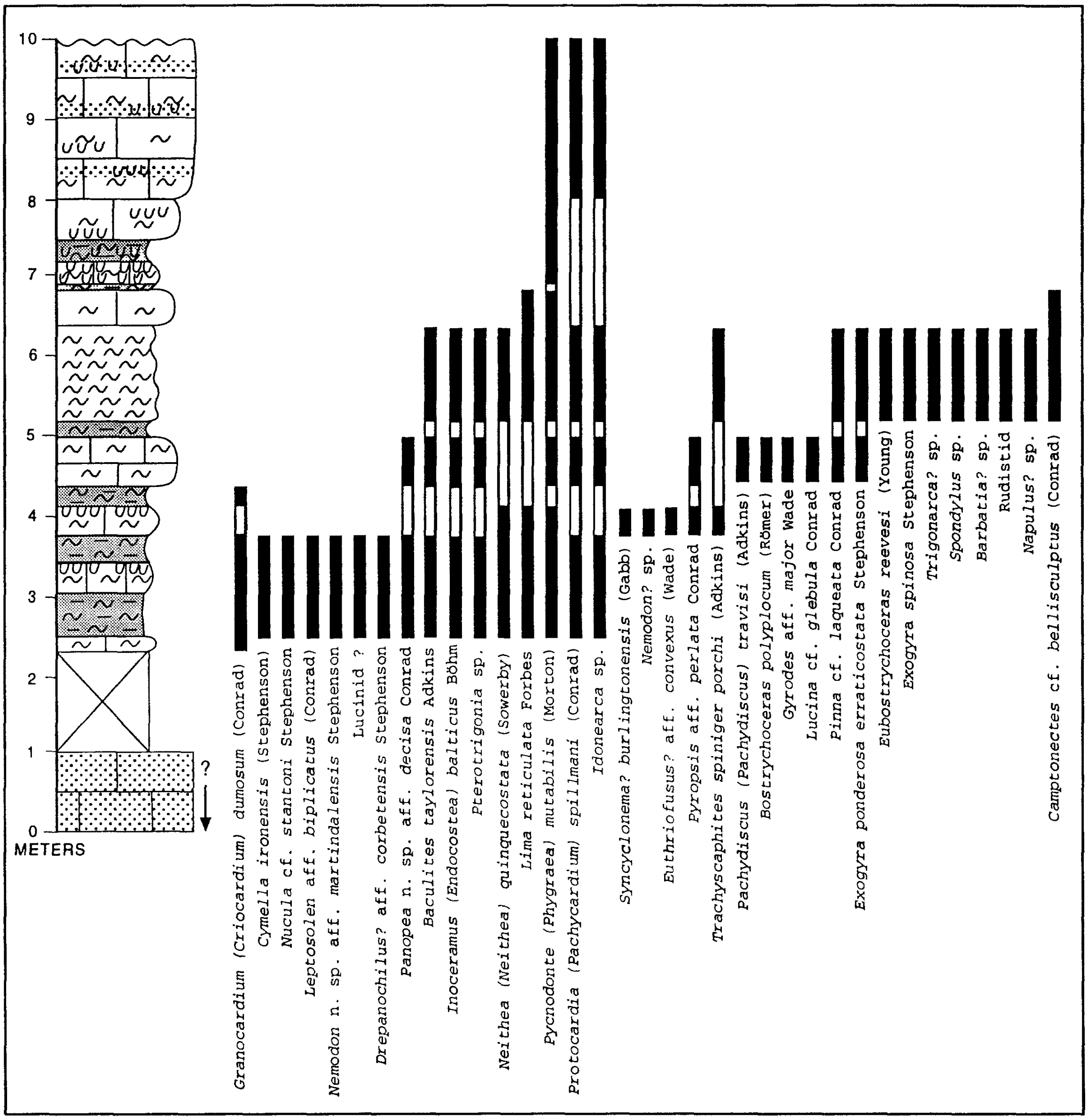


Figure 2. Molluscan fossil distributions in the exposed Anacacho Limestone section at King's Water Hole on Hondo Creek, Texas.

Pycnodonte accumulations become more abundant as other taxa become less common and shell breakage increases.

These data suggest an open marine, shelf-depth habitat with relatively stable benthic conditions during the deposition of units 2 through 10, followed by increased current or wave activity during deposition of units 11 through 14. It is possible that the lower marly and chalky interval corresponds to the Milam chalk to the west and the overlying limestone interval to the upper Anacacho, but further work is needed to verify this tentative correlation.

EASTERN LOCALITIES

Locality M8700, in a cut on Road 1957, 3.2 km (2 mi) east of the town of Rio Medina, contains a molluscan fauna typical of the middle Campanian Anacacho Limestone interval (Appendix A). The basal bed exposed at this locality is a hard chalk of at least one meter in thickness. Most of the fossils listed from this locality were found in the overlying two-meter-thick marlstone bed. Above, the top of the exposed section is capped by a oyster-rich skeletal calcarenite bed of more than a meter in thickness. This section contains the most diverse gastropod assemblage identified in the Anacacho. The bivalve assemblage is very similar to that from the nearby Texas Memorial Museum locality 800 (Appendix B).

The fossils at locality M8702 were collected from material excavated from a three-meter-deep pipeline trench on Road 1957, 0.4 km (0.25 mi) west of junction of Road 151 in San Antonio. The white chalk exposed at this locality was mapped as Pecan Gap Chalk on the Geologic Atlas of Texas, San Antonio Sheet (1983), and apparently immediately underlies the easternmost exposure of Anacacho Limestone 1 km to the west. In contrast, Stephenson (1937, p. 136) considered white chalk exposed 13 km (8mi) to the east at the Cementville cement pit to lie in the Anacacho Limestone. Although no age-indicative ammonites were found at M8702, the molluscan assemblage is consistent with those found in middle Campanian Taylor-age rocks elsewhere. At least seven of the fourteen taxa found at this locality have not been identified from the Anacacho Limestone to the west, suggesting some facies control on the fossil distributions.

COMPARISONS WITH TEXAS MEMORIAL MUSEUM COLLECTIONS

In general, taxa in the Anacacho Limestone collections studied at the Texas Memorial Museum were well represented in the collections gathered during the field work of this project. Only four species (indicated by single asterisks in Appendix C) of the approximately 17 molluscan species identified in the museum collections (Appendix B plus several ammonites not listed) were not found in the field collections, the latter of which contain a total of about 45 species. Museum collections were largely lacking from the western exposures of the Anacacho Limestone in Uvalde and Kinney Counties, which apparently are more fossiliferous than the eastern part studied herein. This suggests the potential for a much expanded taxa list when the western area is studied in detail.

DEVELOPMENT OF THE ANACACHO LIMESTONE AND EUSTATIC SEA LEVEL HISTORY

The two Campanian time intervals preserved in the Anacacho Limestone apparently reflect eustatic sea-level changes. The lower Campanian interval probably correlates to the *Scaphites hippocrepis* II or III zones in the Western Interior region, and the middle Campanian interval is coeval with the *B. asperiformis* zone and possibly part of the *Baculites mclearni* zone (Kennedy and Cobban, 1993; Cobban and Kennedy, in press). These two preserved time intervals correspond to transgressive periods following major sea-level drops near the base and top of the lower Campanian (at 80 and 85 Ma on Haq et al. 1987; see Elder and Kirkland, 1994, fig. 2). In the east Texas basin, these also are times of maximum carbonate development during deposition of the Gober and Pecan Gap Chalks. Therefore, the development and preservation of the Anacacho limestone beds during a time interval typified by marly sedimentation in southwest Texas, is probably the combined result of decreased siliciclastic input, due to eustatic sea level rise, and the prolonged buildup of reefs and carbonate banks around volcanic highs present during these periods of sea-level rise. In contrast, the sea-level fall events are represented by unconformities.

CONCLUSIONS

Ammonite distributions in the Anacacho Limestone indicate that the formation represents two time intervals, one in the early Campanian and one in the middle Campanian, separated by an unconformity. These two time intervals correspond to transgressive events following major sea level drops at the base and top of the lower Campanian. This study is focused on the molluscan paleontology of the middle Campanian interval in the eastern part of the exposure area of the Anacacho in Medina County. The molluscan assemblage in this area, which mostly is derived from marly and chalky beds, is indicative of inner to mid-shelf environments and contains no significant reef components. These beds are interpreted to represent more-offshore, deeper water facies than those to the southwest, where reef and lagoonal deposits have been reported (Luttrell, 1977, Rodgers, 1988).

The Anacacho invertebrate fauna has been largely ignored, particularly the bivalve and gastropod components. Macrofossil lists compiled herein, based mainly on four days of collecting plus review of the Texas Memorial Museum collections, have expanded the number of invertebrate species known from the Anacacho Limestone by nearly three-fold, from approximately 22 indicated in the literature to the 58 listed in Appendix C. This increase in diversity, based on such a small amount of new work, suggests that many more taxa are yet to be identified, particularly in the western part of the exposure belt in Uvalde and Kinney Counties. When the Anacacho fauna listed here is compared to the few well-documented middle Campanian molluscan assemblages of the Gulf and Atlantic coastal regions, it most closely resembles the fauna of the Snow Hill calcareous member of the Black Creek Formation documented by Stephenson (1923) in North Carolina.

REFERENCES CITED

Adkins, W.S., 1929, Some Upper Cretaceous Taylor ammonites from Texas: University of Texas Bulletin 2901, p. 203-211, pls. 5-6.

Brown, N.K., 1965, Stratigraphy of upper Cretaceous beds in the vicinity of D'Hanis, Medina County, Texas, *in* Upper Cretaceous asphalt deposits of the Rio Grande embayment: Corpus Christi Geological Society Guidebook, p. 23-30.

Bureau of Economic Geology, 1983, Geologic atlas of Texas, San Antonio Sheet: University of Texas at Austin, Bureau of Economic Geology, Map scale 1:250,000, 7 p.

Clark, W.B., 1893, A Mesozoic Echinodermata of the United States: U. S. Geological Survey Bulletin 97, 207 p., 50 pls.

Cobban, W.A., and Kennedy, W.J., 1993, Middle Campanian ammonites and inoceramids from the Wolfe City Sand in northeastern Texas: Journal of Paleontology, v. 67, p. 71-82, 8 figs.

Cobban, W.A., and Kennedy, W.J., 1994, Middle Campanian (Upper Cretaceous) ammonites from the Pecan Gap Chalk of central and northeastern Texas, *in* Sando, W.J., ed., Shorter Contributions to Paleontology and Stratigraphy 1993: U. S. Geological Survey Bulletin 2703, p. D1-D9, 5 pls.

Cobban, W.A., and Kennedy, W.J., in press, Middle Campanian ammonites from the Anacacho Limestone of south-east Texas, *in* Sando, W.J., ed., Shorter Contributions to Paleontology and Stratigraphy: U. S. Geological Survey Bulletin.

Conrad, T.A., 1857, Description of Cretaceous and Tertiary fossils, *in* Emory, W.H., Report on the United States and Mexican Boundary Survey: U. S. 34th Congress, 1st session, House of Representatives Executive Document 135, v. 1, p. 141-174, pls. 1-21.

Conrad, T.A., 1858, Observations on a group of Cretaceous fossil shells, found in Tippah County, Mississippi, with descriptions of fifty-six new species: Academy of Natural Sciences of Philadelphia, Journal, 2nd series, v. 3, p. 323-336.

Cooke, C.W., 1953, American Upper Cretaceous Echinoidea: U. S. Geological Survey Professional Paper 254-A, 44 p., 16 pls.

Craigin, F.W., 1893, A contribution in the invertebrate paleontology of the Texas Cretaceous: Geological Survey of Texas, Annual Report 4, pt. 2, p. 141-194, pls. 25-46.

Elder W.P., and Kirkland, J.I., 1994, Cretaceous paleogeography of the southern Western Interior region, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., eds., Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section SEPM, p. 415-440.

Ewing, T.E., 1986, Late Cretaceous igneous rocks of the Uvalde area, southwest Texas: South Texas Geological Society, 1986 Fall Field Trip Guide Book, p. 1-34.

Gardner, J.A., 1916, Systematic paleontology, Mollusca, *in* W. B. Clark and others, Upper Cretaceous: Maryland Geological Survey, p. 371-733, pls. 12-45.

Garner, L.E., and Young, Keith, 1976, Environmental geology of the Austin area -- an aid to Urban planning: University of Texas at Austin, Bureau of Economic Geology, Report of Investigations 86, 39 p.

Haq, B.U., Hardenbol, J., and Vail, P.R., 1987, Chronology of fluctuating sealevels since the Triassic: Science, v. 235, p. 1156-1167.

Hazzard, R.T., 1956, Cretaceous rocks south of Tarpley to Del Rio *in* Four provinces field trip: San Angelo Geological Society Field Trip Guidebook, pt. III, p. 43-72.

Hill, R.T., and Vaughan, T.W., 1898, Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Texas: U.S. Geological Survey, 18th Annual Report, p. 199-321.

Kennedy, W.J., and Cobban, W.A., 1993, Lower Campanian (Upper Cretaceous) ammonites from the Merchantville Formation of New Jersey, Maryland, and Delaware: Journal of Paleontology, v. 67, p. 828-849.

Kniker, H.T., 1918, Comanchean and Cretaceous Pectinidae of Texas: University of Texas Bulletin 1817, 56 p., 10 pls.

Longoria, J.F., 1991, Microfacies analysis as a lithocorrelation tool applied to the Austin/Anacacho problem -- Surface and subsurface of Bexar County, *in* Chuber, Stewart, ed., Austin chalk exploration symposium -- Geology, geophysics, and formation evaluation: Abstracts and short papers of the South Texas Geological Society, San Antonio, Texas, p. 89-99.

Luttrell, P.E., 1977, Carbonate facies distribution and diagenesis associated with volcanic cones -- Anacacho Limestone (Upper Cretaceous), Elaine Field, Dimmit County, Texas, *in* D.G. Bebout and R.G. Loucks, eds., Cretaceous carbonates of Texas and Mexico: Bureau of Economic Geology, The University of Texas at Austin, Report of Investigations Number 89, p. 260-285.

Rodgers, R.W., 1988, The Anacacho Limestone of southwest Texas: Geological Society of America Centennial Field Guide, South-Central Section, p. 441-444.

Römer, Ferdinand, 1852, Die Kreidebildungen von Texas, und ihre organischen Einschüsse: Adolph Marcus, Bonn, 100 p. 10 pls.

Sohl, N.F., 1960, Archeogastropoda, Mesogastropoda, and stratigraphy of the Ripley, Owl Creek, and Prairie Bluff formations: U. S. Geological Survey Professional Paper 331-A, 151 p., 18 pls.

Sohl, N.F., 1964a, Neogastropoda, Opisthobranchia, and Basommatophora from the Ripley, Owl Creek, and Prairie Bluff formations: U. S. Geological Survey Professional Paper 331-B, p. 152-344, pls. 19-52.

Sohl, N.F., 1964b, Gastropods from the Coffee Sand (Upper Cretaceous) of Mississippi: U. S. Geological Survey Professional Paper 331-C, p. 345-394, pls. 53-57.

Sohl, N.F., Martínez, R., Salmerón-Ureña, P., and Soto-Jaramillo, F., 1991, Upper Cretaceous, in Salvador, A. (ed.), The Gulf of Mexico Basin: Boulder, Colorado, Geological Society of America, The Geology of North America, v. J, p. 205-244.

Sohl, N.F., and Owens, J.P., 1991, Cretaceous stratigraphy of the Carolina coastal plain, *in* Horton, J.W., Jr., and Zullo, V.A., eds., The geology of the Carolinas: Carolina Geological Society Fiftieth Anniversary Volume, p. 191-220.

Spencer, A.B., 1965, Alkalic igneous rocks of Uvalde County, Texas, *in* Upper Cretaceous asphalt deposits of the Rio Grande embayment: Corpus Christi Geological Society Guidebook, p. 13-21.

Stephenson, L.W., 1919, A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geological Survey Professional Paper 120, Shorter contributions to general geology, 1918, p. 129-163.

Stephenson, L.W., 1923, Cretaceous formations of North Carolina: North Carolina Geological and Economic Survey, v. 5, pt. 1, 604 p., 102 pls.

Stephenson, L.W., 1937, Stratigraphic relations of the Austin, Taylor, and equivalent formations in Texas: U. S. Geological Survey, Professional Paper 186-G, p. 133-146.

Stephenson, L.W., 1947, New Upper Cretaceous fossils from Mississippi and Texas. Part 1. Fossils from two deep wells in Mississippi: U. S. Geological Survey Professional Paper 210-E, p. 161-196, pls. 31-33.

Thompson, M.E., 1986, Stratigraphy of the Dale Lime and its relation to structure at Bateman Field, Bastrop County, Texas, *in* Strapp, W.L., ed., Contributions to the geology of south Texas: South Texas Geological Society, San Antonio, Texas, p. 356-367.

Wade, Bruce, 1926, The fauna of the Ripley Formation on Coon Creek, Tennessee: U. S. Geological Survey Professional Paper 137, 272 p., 72 pls.

Weller, S., 1907, Cretaceous faunas: New Jersey Geological Survey, Paleontology, v. 4, 1106 p., 111 pls.

Whitfield, R.P., 1885, Brachiopoda and Lamellibranchiata of the Raritan clays and greensand marls of New Jersey: U. S. Geological Survey, Monograph 9, 269 p., 35 pls.

Whitfield, R.P., 1892, Gastropoda and Cephalopoda of the Raritan clays and greensand marls of New Jersey: U. S. Geological Survey, Monograph 18, 402 p., 50 pls.

Wilson, D.H., 1984, Geology of the Anacacho Formation in southwest Texas, *in* Wilson, W.F., and Wilson, D.H., Meteor impact site, Anacacho asphalt deposits: South Texas Geological Society Field Trip Guidebook, p. 60-98.

Wilson, D.H., 1986, Paleoenvironments of the Upper Cretaceous Anacacho Formation in southwest Texas, *in* Strapp, W.L., ed., Contributions to the geology of south Texas: South Texas Geological Society, San Antonio, Texas, p. 352-355.

Young, Keith, 1963, Upper Cretaceous ammonites from the Gulf Coast of the United States: University of Texas Publication 6304. 373 p., 34 figs., 82 pls.

APPENDIX A

Locality and fossil information for Anacacho Limestone and Pecan Gap Chalk collections made during 1990 field work.

USGS Mesozoic Locality: M8690.
Medina County, Texas, San Antonio 1:250000 quadrangle.
Marl interbed (bed "b" of Brown, 1965) in calcarenitic limestone in Seco Creek on Road 1796, ca. 3.2 km (2 mi) north of D'Hanis.
Latitude: 29 degrees 21.70' N; Longitude: 99 degrees 17.00' W;
Collector: W. P. Elder, 1990; Field Identifier: 90ET-3A.
Stratigraphic unit: Anacacho Limestone?

TAXA PRESENT

BIVALVES

Spondylus aff. *guadalupae* Römer
Exogyra cf. *ponderosa erraticostata* Stephenson
Pycnodonte (Phygraea) aff. *mutabilis* (Morton)
Lyriochlamys? sp.

ECHINOID

Phyllobrissus cubensis (Weisbord)

USGS Mesozoic Locality: M8691.
Medina County, Texas, San Antonio 1:250000 quadrangle.
Marls overlying limestone (beds "f" through "i" of Brown, 1965) in Seco Creek on Road 1796, ca. 3.2 km (2 mi) north of D'Hanis.
Latitude: 29 degrees 21.70' N; Longitude: 99 degrees 17.00' W;
Collector: W. P. Elder, 1990; Field Identifier: 90ET-3B.
Stratigraphic unit: Anacacho Limestone

TAXA PRESENT

AMMONITE

Baculites sp.

BIVALVES

Panopea n. sp. aff. *decisa* Conrad

Pycnodonte (Phygraea) mutabilis (Morton)
Cardiid?

GASTROPOD

Turritella (Sohlitella) trilira Conrad

USGS Mesozoic Locality: M8692 to M8699.
Medina County, Texas, San Antonio 1:250000 quadrangle.
Anacacho Limestone at King's Water Hole. Hondo Creek crossing 5 km (3 mi) north of Hondo. See Figure 2 for stratigraphic positions of sampled units at localities M8692 to M8699.
Latitude: 29 degrees 23.50' N; Longitude: 99 degrees 9.15' W;
Collector: W. P. Elder, 1990; Field Identifier: 90ET-4.
Stratigraphic unit: Anacacho Limestone

Unit 2; USGS Mesozoic Locality: M8692.

TAXA PRESENT

BIVALVE

Granocardium (Criocardium) dumosum (Conrad)

Unit 3; USGS Mesozoic Locality: M8693.

TAXA PRESENT

AMMONITE

Baculites taylorensis Adkins

BIVALVES

Pycnodonte (Phygraea) mutabilis (Morton)
Protocardia (Pachycardium) spillmani (Conrad)
Neithea (Neithea) quinquecostata (Sowerby)
Cymella cf. *ironensis* (Stephenson, 1923)
Nucula cf. *stantoni* Stephenson
Leptosolen aff. *biplicatus* (Conrad)
Lima reticulata Forbes
Idonearca sp.

Granocardium (Criocardium) sp.
Nemodon n. sp. aff. *martindalensis* Stephenson
Panopea n. sp. aff. *decisa* Conrad
Inoceramus (Endocostea) cf. *balticus* Böhm
Pterotrigonia sp.
Lucinid?

GASTROPOD

Drepanochilus? aff. *corbetensis* Stephenson

OTHER

Nautiloid?
Scaphopod

Unit 4; USGS Mesozoic Locality: M8694.

TAXA PRESENT

AMMONITE

Trachyscaphites spiniger porchi (Adkins)

BIVALVES

Neithea (Neithea) quinquecostata (Sowerby)
Lima reticulata Forbes
Pycnodonte (Phygraea) mutabilis (Morton)
Syncyclonema? burlingtonensis (Gabb)
Nemodon? sp.

GASTROPODS

Pyropsis aff. *perlata* Conrad
Euthriofusus? aff. *convexus* (Wade)
Naticid

Unit 5; USGS Mesozoic Locality: M8695.

TAXA PRESENT

BIVALVE

Granocardium (Criocardium) dumosum (Conrad)

Unit 6; USGS Mesozoic Locality: M8696.

TAXA PRESENT

AMMONITES

Baculites taylorensis Adkins
Pachydiscus (Pachydiscus) travisi (Adkins)
Bostrychoceras polyplocum (Römer)

BIVALVES

Exogyra ponderosa erraticostata Stephenson
Protocardia (Pachycardium) spillmani (Conrad)
Idonearca sp.
Panopea n. sp. aff. *decisa* Conrad
Pinna cf. *laqueata* Conrad
Inoceramus (Endocostea) balticus Böhm
Lucina cf. *glebula* Conrad
Trigoniid

GASTROPODS

Pyropsis aff. *perlata* Conrad
Gyrodes aff. *major* Wade

Unit 8; USGS Mesozoic Locality: M8697.

TAXA PRESENT

AMMONITES

Baculites taylorensis Adkins
Eubostrychoceras reevesi (Young)
Trachyscaphites spiniger porchi (Adkins)

BIVALVES

Exogyra ponderosa erraticostata Stephenson
Exogyra spinifera Stephenson
Protocardia (Pachycardium) spillmani (Conrad)
Idonearca sp.
Pinna cf. *laqueata* Conrad
Inoceramus (Endocostea) balticus Böhm
Lima reticulata Forbes
Pycnodonte (Phygraea) mutabilis (Morton)
Neithea (Neithea) quinquecostata (Sowerby)
Trigonarca? sp.
Camptonectes cf. *bellisculptus* (Conrad)
Spondylus sp.
Barbatia? sp.
Rudistid
Pterotrigonia sp.

GASTROPOD

Napulus? sp.

Unit 9; USGS Mesozoic Locality: M8698.

TAXA PRESENT

BIVALVES

Lima reticulata Forbes
Pycnodonte (Phygraea) mutabilis (Morton)
Camptonectes cf. *bellisculptus* (Conrad)

Unit 14; USGS Mesozoic Locality: M8699.

TAXA PRESENT

BIVALVES

Pycnodonte (Phygraea) mutabilis (Morton)
Idonearca sp.
Protocardia (Pachycardium) spillmani (Conrad)

ECHINOID

Irregular echinoid

USGS Mesozoic Locality: M8700.
Medina County, Texas, San Antonio 1:250000 quadrangle.
Road 1957, 3.2 km (2 mi) east of Rio Medina in road cut on hill.
Latitude: 29 degrees 25.90' N; Longitude: 98 degrees 51.35' W;
Collector: W. P. Elder, 1990; Field Identifier: 90ET-5.
Stratigraphic unit: Anacacho Limestone

TAXA PRESENT

AMMONITE

Baculites taylorensis Adkins

BIVALVES

Pycnodonte sp.
Protocardia (Pachycardium) spillmani (Conrad)
Neithea (Neithea) quinquecostata (Sowerby)
Idonearca sp.
Paranomia? cf. *scabra* (Morton)
Exogyra sp.
Crassatella cf. *newkirkensis* (Stephenson) ?
Syncyclonema? burlingtonensis (Gabb)
Liopistha alternata Weller
Inoceramid

GASTROPODS

Capulus aff. *cuthandensis* Stephenson
Paladmete? aff. *cancelleria* (Conrad)
Turritella? sp.
Graphidula? sp.
Gyrodes sp.
Euspira cf. *rectilabrum* (Conrad)

ECHINOIDS

Phyllobrissus cubensis (Weisbord)
Proraster dalli (Clark)
Salenia hondoensis Cooke

USGS Mesozoic Locality: M8702.
Bexar County, Texas, San Antonio 1:250000 quadrangle.
Pipeline excavation on Road 1957, 0.4 km (0.25 mi) west of junction of Road 151.
Latitude: 29 degrees 26.40' N; Longitude: 98 degrees 40.25' W;
Collector: W. P. Elder, 1990: Field Identifier: 90ET-7.
Stratigraphic unit: Pecan Gap Chalk

TAXA PRESENT

AMMONITE

Baculites sp.

BIVALVES

Neithea (Neithea) quinquecostata (Sowerby)
Syncyclonema? burlingtonensis (Gabb)
Granocardium (Criocardium) dumosum (Conrad)
Legumen cf. *ellipticum* Conrad
Crassatella? cf. *conradi* (Whitfield)
Lucina aff. *parva* Stephenson
Nemodon aff. *punctus?* Stephenson
Cymella cf. *ironensis* (Stephenson, 1923)
Inoceramus (Endocostea) balticus Böhm
Pterotrigonia cf. *maroinensis* (Stephenson)

GASTROPODS

Arrhoges? sp.
Turritella (Sohlitella) quadrilira Johnson
Naticid

APPENDIX B

Bivalves and Gastropods identified in Texas Memorial Museum collections from the Anacacho Limestone and Pecan Gap Chalk.

Taxon	Locality	Formation
Crassatella cf. *newkirkensis* (Stephenson)	800	Anacacho
Exogyra spinifera Stephenson	800	Anacacho
Neithea (Neithea) quinquecostata (Sowerby)	800	Anacacho
Plicatula cf. *clarki* Stephenson	800	Anacacho
Pycnodonte (Phygraea) mutabilis (Morton)	800	Anacacho
Inoceramus (Endocostea) balticus Böhm	K630	Anacacho
Pycnodonte (Phygraea) mutabilis (Morton)	K653	Anacacho
Inoceramus (Endocostea) balticus Böhm	UT-18225	Anacacho
Graphidula? sp.	UT-42122	Anacacho
Granocardium (Criocardium?) cf. *conradi* (Stephenson)	UT-42135	Anacacho
Paranomia? aff. *scabra* (Morton)	UT-42151	Anacacho
Trachycardium? cf. *vaughani* (Stephenson)	UT-42369	Anacacho
Exogyra ponderosa erraticostata Stephenson	WSA 6318	Anacacho
Protocardia (Pachycardium) spillmani (Conrad)	K629	Anacacho
Volutid	R 17592	Anacacho
Volutomorpha aff. *conradi* (Gabb)	R-17615	Anacacho
Pholadomya ingens Cragin	UT-33050	Anacacho
Syncyclonema? burlingtonensis (Gabb)	UT-42113	Anacacho
Inoceramus (Cordiceramus) sp.	UT-17325	Pecan Gap
Inoceramus (Endocostea) balticus Böhm	UT-17325	Pecan Gap
Ostrea plumosa Morton	UT-46930	Pecan Gap
Exogyra spinifera Stephenson	UT-46957	Pecan Gap
Exogyra spinifera Stephenson	UT-31801	Pecan Gap
Neithea (Neithea) quinquecostata (Sowerby)	UT-8917	Pecan Gap
Inoceramus (Endocostea) balticus Böhm	WSA 18830	Pecan Gap
Ostrea plumosa Morton	UT-31796	Pecan Gap
Inoceramus (Endocostea) cf. *balticus* Böhm	UT-46932	Pecan Gap

APPENDIX C

List of macrofossils from the middle Campanian part of the Anacacho Limestone. List is compiled from field and museum collections and the literature. Taxa present in Texas Memorial Museum collections but not found during field work are prefixed by "*". Taxa only known from literature are prefixed by "**". Taxa known only from locality M8690, which may be older than middle Campanian, are prefixed by "?".

TAXA

	Ammonites	**Literature Source**
	Bostrychoceras polyplocum (Römer)	
	Baculites taylorensis Adkins	
	Eubostrychoceras reevesi (Young)	
**	*Lewyites clinensis* (Adkins)	Cobban and Kennedy (in press)
	Pachydiscus (Pachydiscus) travisi (Adkins)	
	Bivalves	
**	*Atreta cretacea minor* (Stephenson)	Stephenson (1937)
	Barbatia? sp.	
	Camptonectes cf. *bellisculptus* (Conrad)	
	Crassatella cf. *newkirkensis* (Stephenson) ?	
	Cymella cf. *ironensis* (Stephenson, 1923)	
**	*Durania* sp.	Luttrell (1977)
	Exogyra ponderosa erraticostata Stephenson	
	Exogyra spinifera Stephenson	
	Granocardium (Criocardium) dumosum (Conrad)	
	Granocardium (Criocardium?) cf. *conradi* (Stephenson)	
	Idonearca sp.	
	Inoceramus (Endocostea) balticus Böhm	
	Leptosolen aff. *biplicatus* (Conrad)	
	Lima reticulata Forbes	
	Liopistha alternata Weller	
	Lucina cf. *glebula* Conrad	
?	*Lyriochlamys?* sp.	
**	*Monopleura?* sp.	Rodgers (1988)
	Neithea (Neithea) quinquecostata (Sowerby)	
	Nemodon n. sp. aff. *martindalensis* Stephenson, 1941	
	Nucula cf. *stantoni* Stephenson	
	Panopea n. sp. aff. *decisa* Conrad	
	Paranomia? cf. *scabra* (Morton)	
*	*Pholadomya ingens* Cragin	
	Pinna cf. *laqueata* Conrad	

*	*Plicatula* cf. *clarki* Stephenson	
	Protocardia (Pachycardium) spillmani (Conrad)	
	Pterotrigonia sp.	
	Pycnodonte (Phygraea) mutabilis (Morton)	
?	*Spondylus* aff. *guadalupae* Römer	
	Spondylus sp.	
	Syncyclonema? burlingtonensis (Gabb)	
**	Requieniid	Rodgers (1988)
*	*Trachycardium?* cf. *vaughani* (Stephenson)	
**	*Venericardia uvaldana* Stephenson	Stephenson (1947)

Gastropods

	Capulus aff. *cuthandensis* Stephenson	
	Drepanochilus? aff. *corbetensis* Stephenson	
	Euspira cf. *rectilabrum* (Conrad)	
	Euthriofusus? aff. *convexus* (Wade)	
	Graphidula? sp.	
	Turritella (Sohlitella) trilira Conrad	
	Gyrodes aff. *major* Wade	
	Napulus? sp.	
	Paladmete? aff. *cancelleria* (Conrad)	
	Pyropsis aff. *perlata* Conrad	
*	*Volutomorpha* aff. *conradi* (Gabb)	

Echinoids

**	*Echinochorys texanus* (Cragin)	Brown (1965)
	Phyllobrissus cubensis (Weisbord)	
	Proraster dalli (Clark)	
	Salenia hondoensis Cooke	

Other

	Nautiloid?	
	Scaphopod	
**	*Terebratulina* cf. *filosa* Conrad	Stephenson (1937)