Jurassic-Cretaceous Biochronology and Paleogeography of North America,
edited by G.E.G. Westermann,
Geological Association of Canada Special Paper 27, 1984

MID-CRETACEOUS MOLLUSCAN BIOSTRATIGRAPHY AND PALEOGEOGRAPHY OF SOUTHWESTERN PART OF WESTERN INTERIOR, UNITED STATES

William A. Cobban
United States Geological Survey, Federal Center, Denver, Colorado 80225
Stephen C. Hook
Getty Oil Company, Exploration and Production Research Center, Houston, Texas 77215-0070

ABSTRACT

The area of this report comprises part of New Mexico, Arizona, Colorado, and Utah, and centres around the Four Corners. Rocks treated range in age from middle Cenomanian to late Turonian and include at least 17 ammonite zones.

The Western Interior epeiric sea transgressed into the area from the east. A conspicuous embayment, the Seboyeta Bay, formed in central New Mexico early in middle Cenomanian time. By the end of the middle Cenomanian, the Seboyeta embayment had encroached into eastern Arizona. In the late Cenomanian, the sea rapidly transgressed westward over the eastern half of Arizona and much of Utah. Maximum transgression occurred about the end of this stage. By the middle Turonian, the sea retreated northeastward from much of Arizona, but the shoreline in Utah remained nearly stationary. During the late Turonian, the sea was transgressive at first and regressive later.

A few of the regressive near-shore sandstone beds have extensive bivalve and gastropod faunas. Shaly deposits formed farther offshore have sparser faunas usually dominated by inoceramids and thin-shelled bivalves. Ammonite faunas are characterized by Tethyan forms in some areas and Temperate ones in others.

RÉSUMÉ

La région traitée dans ce rapport comprend des parties du Nouveau-Mexique, l'Arizona, le Colorado, le Utah et des centres du voisinage des "Four Corners". L'age des roches traitées s'étend du Cénomannien moyen au Turonnien avancé et comprennent au moins 17 zones d'ammonites.

La transgression de la mer de l'Intérieur Ouest débuta du côté est de cette région. Une baie importante, la Baie de Seboyeta, se forma au centre du Nouveau-Mexique au début du Cénomannien moyen. Par la fin du Cénomannienmoyen, la Baie de Seboyeta atteigna l'est de l'Arizona. Durant le Cénomannien avancé, la mer a subit une transgression rapide vers l'ouest et noya la moitié est de l'Arizona ainsi que la plupart du Utah. Cette évènement marqua la transgression marine maximale. Au Turonnien moyen, la mer effectua une régression nord-est de la plupart de l'Arizona. Cependant, la côte du l'Utah demeura quaisiment stationnaire. Au Turonnien avancé, la mer a subit une transgression en premier suivie d'une régression plus tard.

Quelques strates sableuses d'avant-côte formeés durant la régression (i.e., "regressive nearshore sandstone beds") renferment des faunes importantes de bivalves et gastéropodes. Des dépots de "shale" sont retrouvés plus aux large et contiennent des faunes moins importantes ordinairement domineés par des inocéramides et des bivalves au coquillage mince. Les faunes d'ammonites sont caractérisées par des formes Téthyienne dans certains endroits et des formes tempérées dans d'autres.

INTRODUCTION

Rocks and fossils reported in this paper range in age from middle Cenomanian through most of the late Turonian. The area investigated includes much of the Four Corners States, the western two-thirds of New Mexico, the northeastern half of Arizona, much of the southeastern half of Utah and much of the southwestern half of Colorado.

Faunal data are based on collections made by many members of the United States Geological Survey and the New Mexico Bureau of Mines and Mineral Resources, as well as by students and other individuals. Guide fossils to many of the zones are lacking in some areas, however, and many collections contain specimens that may be diagnostic species but cannot be identified with certainty owing to poor preservation or fragmentary condition. At best, this paper is a preliminary report giving our interpretations of changes of transgressions and regressions and their effects on molluscan distribution.

ROCKS INVESTIGATED

Cenomanian-Turonian rocks in the area investigated are assigned to many formations and members (Fig. 1). In general, the names Dakota Sandstone and overlying Mancos Shale have been applied in all four states, but in the eastern more open seaway area, other names are used in place of Mancos. Likewise, along the southwest margin of the seaway, other names are used locally.

New Mexico

In east-central New Mexico, the standard Great Plains nomenclature has long been applied: Dakota Sandstone (oldest), Graneros Shale, Greenhorn Limestone, and Carlile Shale (youngest). In recent years, a Thatcher Limestone Member has been recognized in the Graneros Shale (personal observations); the Greenhorn Limestone has been divided into Lincoln Limestone Member (oldest), Hartland Shale Member, and Bridge Creek Limestone Member (youngest); and the Carlile Shale has been divided into Fairport Member (oldest), Blue Hill Member, Codell Sandstone Member, Juana Lopez Member, and an upper unnamed shaly member (e.g., Hook and Cobban, 1980, Fig. 4).

In west-central New Mexico, tongues of sandstone largely of a western source complicate the stratigraphy and necessitate a different nomenclature. The Dakota Sandstone is intertongued extensively with the Mancos Shale, and the sequence is, from oldest to youngest, Oak Canyon Member (of the Dakota), Cubero Tongue (of the Dakota), Clay Mesa Tongue (of the Mancos), Paguate Tongue (of the Dakota), Whitewater Arroyo Tongue (of the Mancos), and Twowells Tongue (of the Dakota) (Landis *et al.*, 1973). Where the Oak Canyon, Cubero, Clay Mesa, and Paguate cannot be differentiated, the sequence consists of the main body of the Dakota overlain by the Whitewater Arroyo Tongue of the Mancos, and that in turn, by the Twowells Tongue of the Dakota (Landis *et al.*, 1973, Fig. 2); or an unnamed shale tongue of Mancos may separate the Paguate Tongue from the main body of the Dakota (Hook *et al.*, 1980,

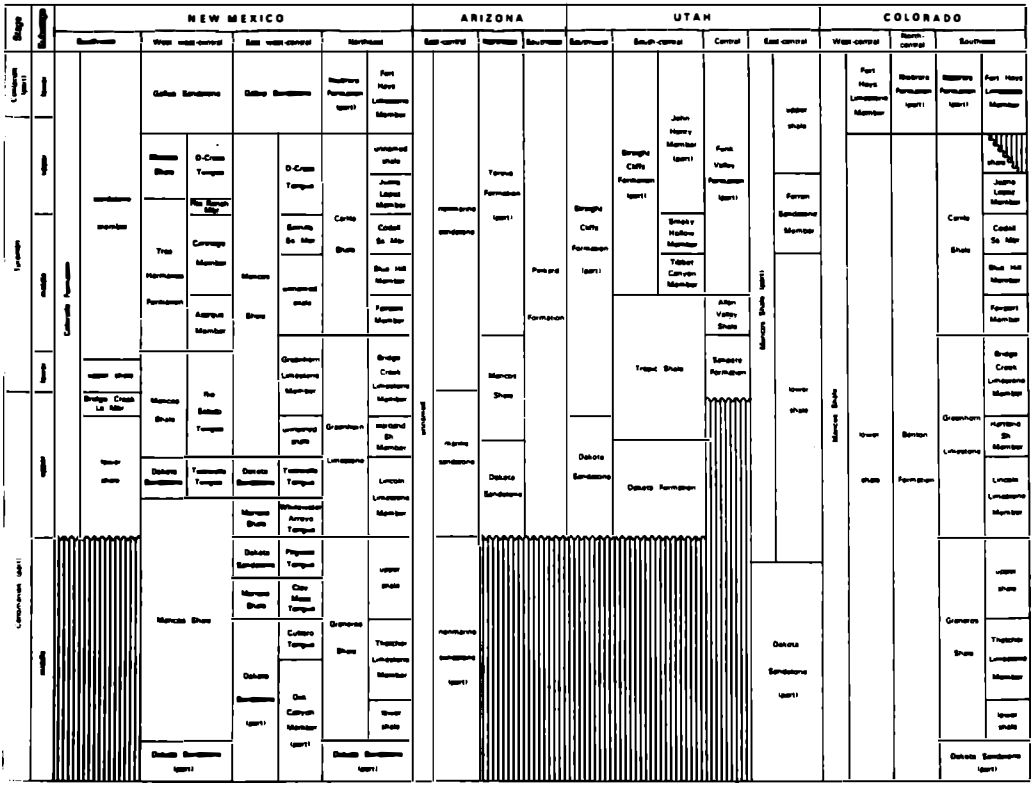

Figure 1. Chart showing correlation of middle Cenomanian to early Coniacian rocks in parts of New Mexico, Arizona, Utah, and Colorado.

Fig. 2); or the Twowells Tongue may be separated from a basal tongue of the Dakota by a thick lower unnamed tongue of Mancos Shale (Hook and Cobban, 1979, Fig. 5).

In much of west-central New Mexico, the Twowells Tongue is overlain by the Rio Salado Tongue of Mancos Shale and that in turn is overlain by the Tres Hermanos Formation and the D-Cross Tongue of the Mancos (Hook *et al.*, 1983). In this part of New Mexico calcareous beds, mainly equivalent to the Bridge Creek Limestone Member of the Greenhorn Limestone farther east, have been referred to as the Greenhorn Limestone (e.g., Molenaar, 1973, Figs. 2, 11). Farther north in the San Juan Basin, these calcareous beds have been referred to as a "limestone unit" in the Mancos Shale (O'Sullivan *et al.*, 1972, p. E-18-E19, Fig. 10) or as the Greenhorn Limestone Member (Peterson and Kirk, 1977, Fig. 2).

Nomenclature of middle Cenomanian-Turonian rocks in southern New Mexico varies considerably owing to major east-west facies changes and the long distances between outcrops. Texas names have been applied in the San Andres Mountains (Eagle Ford Formation by Kottlowski *et al.*, 1956) and in the El Paso area (Boquillas Formation by Strain, 1968). Farther west, Colorado Shale or Colorado Formation is usually applied to these rocks (e.g., Darton, 1916, p. 44; Spencer and Paige, 1935, p. 30; Jones *et al.*, 1967, p. 35; Cunningham, 1974; Elston, 1960; Morrison, 1965).

Arizona

The largest area of mid-Cretaceous rocks in Arizona crops out on Black Mesa in the northeastern part of the State, where Cenomanian-Turonian rocks are included in the Dakota Sandstone, Mancos Shale, and Toreva Formation (Repenning and Page, 1956). Southeast of the Black Mesa along the Arizona-New Mexico boundary, rocks of this age have been assigned to the Dakota Sandstone, Mancos Shale, and Mesaverde Formation (O'Brien, 1956; Young, 1957). South of Black Mesa along the Mogollon Rim in the Show Low area, unnamed marine mid-Cretaceous rocks crop out (Finnell, 1966; McKay, 1972). Much farther south in the south-central part of the State, marine rocks of mid-Cretaceous age have been recorded but not formally named (Campbell, 1904, p. 245; Ross, 1925, p. 25-28). In the Clifton-Morenci area in southeastern Arizona, marine sandstone and shale of late Cenomanian age have been named the Pinkard Formation (Lindgren, 1905a, p. 105; 1905b, p. 73.)

Utah

Mid-Cretaceous rocks crop out extensively in much of Utah. In the southern part in the Kaiparowits basin, marine rocks of late Cenomanian-middle Turonian age are included in the Dakota Formation, Tropic Shale, and lower part of the Straight Cliffs Formation (Peterson and Waldrop, 1965, Fig. 3; Peterson and Kirk, 1977, Fig. 4). Farther west, the Tropic Shale becomes sandy and disappears, and the sequence is then Dakota Formation overlain by Straight Cliffs Formation (Averitt and Threet, 1973). In the Henry Basin in south-central Utah, the sequence is Dakota Formation overlain by Mancos Shale; the latter is divided into several members of which the lower two are Tununk Shale Member (upper Cenomanian-middle Turonian) and Ferron Sandstone Member (middle and upper Turonian) (Peterson and Kirk, 1977, Fig. 4). Farther northwest, a different nomenclature was proposed by Spieker (1946) for mid-Cretaceous rocks in the Sanpete Valley in central Utah where the lower two units, Sanpete Formation and overlying Allen Valley Shale, are of Turonian age. Along the Book Cliffs in east-central Utah the sequence is Dakota Sandstone and Mancos Shale - the latter having a Ferron Sandstone Member that separates a lower unnamed shale from an upper one (Fisher *et al.*, 1960, Pl. 10).

Colorado

Middle Cenomanian-upper Turonian rocks in eastern Colorado are included in the Graneros Shale, Greenhorn Limestone, and Carlile Shale. The sequence is best exposed and documented in the Pueblo area (Cobban and Scott, 1972). The Graneros consists of the Thatcher Limestone Member separating a lower unnamed shale member barren of molluscan fossils from an upper unnamed shale member containing molluscan fossils. The Greenhorn consists of, from oldest to youngest, Lincoln Limestone Member, Hartland Shale Member, and Bridge Creek Limestone Member. Four members usually make up the Carlile Shale; these are, from oldest to youngest, Fairport Member, Blue Hill Member, Codell Sandstone Member, and Juana Lopez Member (Scott, 1969, p. 41-49). Locally, a thin unnamed calcareous shale unit may overlie the Juana Lopez Member.

In the central part of Colorado, Cenomanian-Turonian rocks are usually included in the Benton Formation (e.g., Stark *et al.*, 1949, p. 52-53). Rocks of this age farther west in Colorado are the Dakota Sandstone and Mancos Shale. The latter may have a Ferron Sandstone Member (e.g., Cashion, 1973) or a Juana Lopez Member (e.g., Haynes *et al.*, 1972), or locally, a calcareous Greenhorn Limestone equivalent (e.g., Steven *et al.*, 1974).

AMMONITE SEQUENCE

At least 17 ammonite zones of middle Cenomanian-late Turonian age can be recognized in the Four Corners States. Ten of the better known and more widely-distributed range zones are used in this report to provide time intervals short enough for showing step-by-step changes in transgressions and regressions of the epeiric sea. These zones and their generally accepted ages are:

Ages	Ammonite Range Zones
Late Turonian	*Scaphites whitfieldi*
Middle Turonian	*Prionocyclus hyatti* *Collignoniceras woollgari*
Early Turonian	*Mammites nodosoides*
Late Cenomanian	*Sciponoceras gracile* *Metoicoceras mosbyense* *Calycoceras canitaurinum*
Middle Cenomanian	*Plesiacanthoceras* aff. *wyomingense* *Acanthoceras alvaradoense* *Conlinoceras tarrantense*

BIOSTRATIGRAPHY AND PALEOGEOGRAPHY

Range Zone of *Conlinoceras tarrantense*

The holotype of this species, *Metacalycoceras? tarrantense* Adkins (1928, p. 241, Pl. 28, Fig. 3; Pl. 29, Fig. 1) came from the basal beds of the Eagle Ford Group in Texas. The species has been found in the Oak Canyon Member and Cubero Tongue of the Dakota Sandstone in west-central New Mexico (Cobban, 1977, p. 22, Pl. 3, Fig. 9; Pl. 4, Figs. 1-3, 6). A closely allied form, *C. gilberti* (Cobban and Scott, 1972, p. 61, Pl. 1; Pl. 2, Figs. 5-9, 13-18; Pl. 3, Figs. 5-7, 11; Text-figs. 23, 24) is present in the Thatcher Limestone Member of the Graneros Shale in southeastern Colorado.

During the time of *C. tarrantense*, the Cretaceous epeiric sea transgressed from the east across the eastern two-thirds of Colorado as well as across the northeastern part of New Mexico (Fig. 2). A conspicuous embayment, Seboyeta Bay, extended into west-central New Mexico where the Oak Canyon Member and Cubero Tongue of the Dakota Sandstone were deposited (Hook *et al.*, 1980, p. 44). The western edge of Seboyeta Bay was probably a little east of Gallup; diagnostic marine fossils have not been found west of Crownpoint. The southern limits of the embayment were probably at Socorro inasmuch as *C. tarrantense* occurs only 30 cm above the top of the Dakota Sandstone 40 km north of the former coal-mining town of Carthage, whereas the top of the Dakota is of post-*tarrantense* age at Carthage. Northern limits of Seboyeta Bay are poorly known, but the presence of *Acanthoceras amphibolum* Morrow of post-*tarrantense* age in the Dakota Sandstone near Tierra Amarilla suggests that the shoreline was farther east, possibly near Taos.

The western edge of the seaway in Colorado has not been determined. *Calycoceras tarrantense* has been found in sandy beds near the top of the Dakota Sandstone at one locality in the Delta area. The coal beds in the Dakota Sandstone in western Colorado were probably formed in swamps that were marginal to the *tarrantense* sea.

Molluscan fossils are abundant in the western or shoreward part of Seboyeta Bay especially in the area east and northeast of Grants, New Mexico, where the lower part of the Cubero Tongue of the Dakota and dark brown weathered ferruginous sandstone concretions in the Oak Canyon Member contain a diversified assemblage of bivalves, gastropods, and ammonites (Cobban, 1977, Table 2, Pls. 1-5). Bivalves diagnostic of the Oak Canyon Member and Cubero Tongue include *Inoceramus eulessanus* Stephenson, *Exogyra columbella* Meek, *Plicatula arenaria* Meek, and *Camptonectes symmetricus* Herrick and Johnson. The gastropod *Arrhoges modesta* (Cragin)? is found in great abundance (Cobban, 1977, Pl. 2, Fig. 4). Five genera of ammonites are present, and *Conlinoceras tarrantense* is the most common species.

In southeastern Colorado and northeastern New Mexico, a single bed of hard, ferruginous, silty limestone usually makes up the Thatcher Limestone Member of the Graneros Shale (Cobban and Scott, 1972, Figs. 4-6). Fossils are generally crushed and fragmented. Locally, ammonites may occur abundantly as a single species (Cobban and Scott, 1972, Fig. 7). *Conlinoceras gilberti* Cobban and Scott is the dominant form in most collections. Among the bivalves, *Inoceramus eulessanus* Stephenson and *Plicatula arenaria* Meek are the most common species. A variety of gastropods is present in places.

Range Zone of *Acanthoceras Alvaradoense*

The ammonite species selected as a guide to this zone was described by Moreman (1942, p. 205, Pl. 32, Fig. 6; Text-fig. 20, 27) from the Eagle Ford Group of Texas. *Acanthoceras alvaradoense*, of middle Cenomanian age, has been found as far north as the Black Hills area in eastern Wyoming.

The presence of a well-preserved and diversified *A. alvaradoense* fauna at the base of the Boquillas Formation in New Mexico just northwest of El Paso, Texas (Strain, 1976, p. 82) resting disconformably on lower Cenomanian rocks, reveals a considerable southward transgression of the epeiric sea. Inasmuch as the basal part of the Colorado Formation in the Cooke Range north of Deming, New Mexico contains the *Calycoceras canitaurinum* (Haas) fauna of post-*alvaradoense* age, the western limits of the *alvaradoense* sea were somewhere between there and El Paso (Fig. 2).

In the northern part of New Mexico in the Chama-Tierra Amarilla area, the oldest fossils in the Dakota Sandstone represent the range zone of *Acanthoceras amphibolum* Morrow of post-*alvaradoense* age suggesting that the *alvaradoense* shoreline was somewhere to the east. *Acanthoceras alvaradoense* is present in the Clay Mesa Tongue of the Mancos Shale at several localities southeast, south, and southwest of Grants, which reveals that Seboyeta Bay was still in existence but much broadened.

Records of *A. alvaradoense* in the eastern part of Colorado are lacking, but marine rocks of this age should be present in the post-Thatcher part of the Graneros Shale at Pueblo. The shoreline was probably not far southwest of the Delta-Montrose area in southwestern Colorado, where *A. alvaradoense* has been collected from the top of the Dakota Sandstone.

In contrast to the rich ammonite fauna at El Paso, Texas, rocks of *alvaradoense* age are poorly fossiliferous in New Mexico and Colorado. Only nine taxa have been recorded from the Clay Mesa Tongue of the Mancos Shale (Cobban, 1977, Table 1). *Inoceramus arvanus* Stephenson may be restricted to this tongue, but most of the other species range up into the Paguate Tongue of the Dakota. No gastropods are known from rocks of *alvaradoense* age in New Mexico and Colorado and only three genera of ammonites have been recorded (Cobban, 1977, Table 1).

Range Zone of *Plesiacanthoceras* aff. *Wyomingense*

Plesiacanthoceras wyomingense was described by Reagan (1924, p. 181, Pl. 19, Figs. 1, 2) as *Metoicoceras wyomingensis*. The holotype came from the Frontier Formation in east-central Wyoming where *P. wyomingense* forms a distinct zone above that of *Acanthoceras amphibolum* Morrow. In western New Mexico, a species related to *P. wyomingense* seems to lie in the zone of *A. amphibolum*.

The presence of *P.* aff. *wyomingense* at Mesa Redonda west of St. Johns, Arizona (Kirkland, 1982) reveals a westward expansion of the Seboyeta embayment into eastern Arizona at

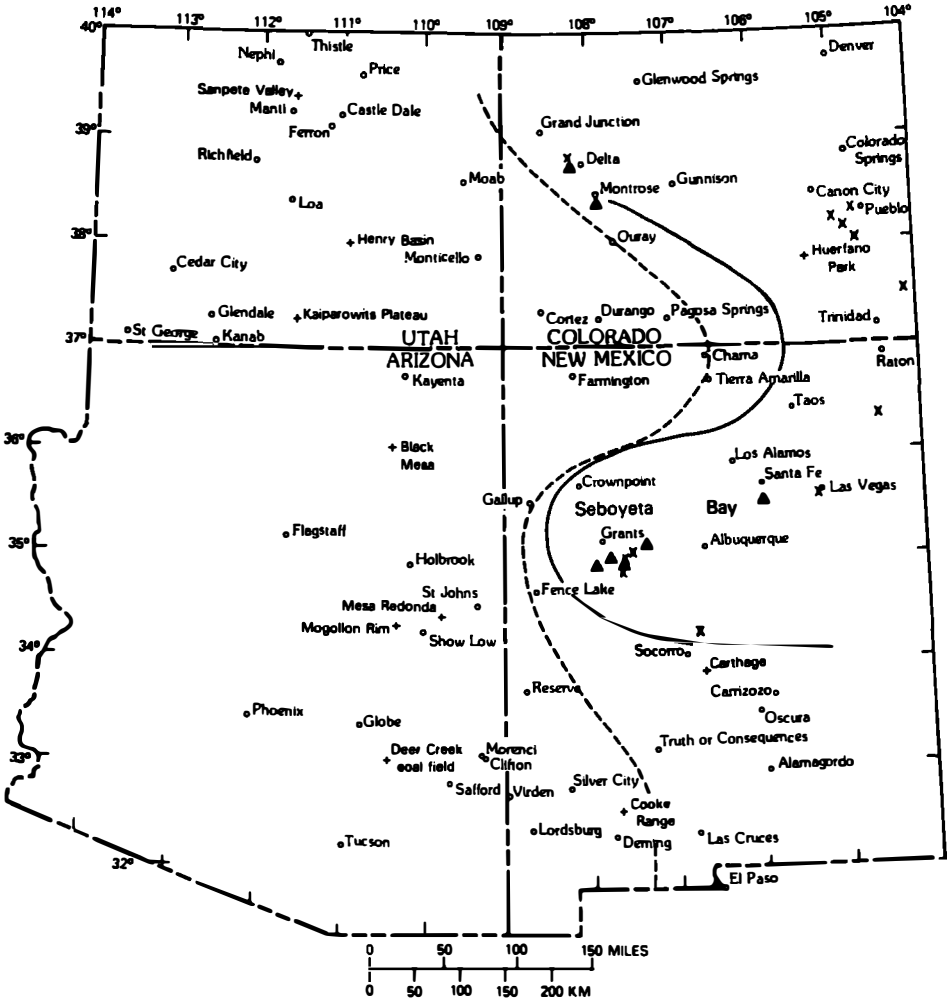

Figure 2. Map of parts of the Four Corners States showing localities (X) where *Conlinoceras tarrantense* (Adkins) has been found. Solid line shows the general position of the shoreline. Solid triangles (▲) mark localities where *Acanthoceras alvaradoense* Moreman has been found, and the general position of the shoreline of that time is marked by short dashes.

the close of middle Cenomanian time (Fig. 3). In southwestern New Mexico, the shoreline remained east of the Cooke Range near Deming. The recent discovery (by G.R. Scott, 1981, pers. commun.) of *Acanthoceras amphibolum* in the upper part of the Dakota Sandstone in the Chama-Tierra Amarilla area in northern New Mexico suggests that the shoreline was not far to the west in that area. The northwest trending shoreline in southwestern Colorado was probably much like that of *alvaradoense* time. However, an encroachment of the sea into eastern Utah is suggested by the possible presence of the marker bentonite bed in the basal part of the Mancos Shale along the Utah boundary area west of Grand Junction, Colorado. The marker

bentonite bed (or X-bentonite bed) (Cobban and Scott, 1972, p. 4-28, Fig. 10) is widely distributed over the Great Plains and in areas farther west in Wyoming, Colorado, and New Mexico; it lies in the range zone of *Acanthoceras amphibolum*.

Fossil molluscs are abundant and varied in the Seboyeta embayment, where they occur in shallow-water sandstone such as the Paguate Tongue of the Dakota (Cobban, 1977, Table 1). Among the more abundant bivalves are *Idonearca blandpiedi* Stephenson, *Pinna petrina* White, *Phelopteria*? cf. *aquilerae* (Bose), *Inoceramus rutherfordi* Warren, *Exogyra trigeri* Coquand, *E. levis* Stephenson, *Ostrea beloiti* Logan, and *Aphrodina* cf. *munda* (Stephenson). A large gastropod fauna is

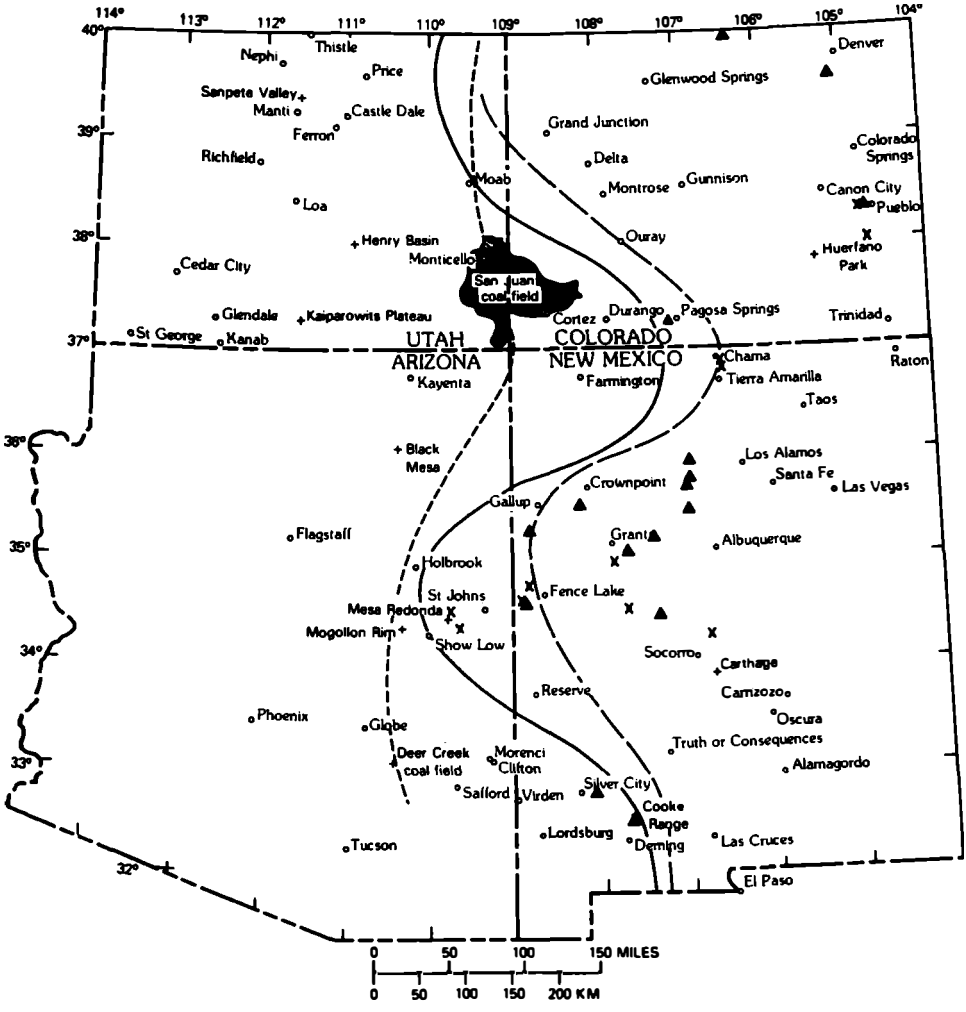

Figure 3. Map of parts of the Four Corners States showing localities (X) where *Plesiacanthoceras* aff. *wyomingense* (Reagan) or *Acanthoceras amphibolum* Morrow has been found. Solid line shows the general position of the shoreline. Solid triangles (▲) mark localities where *Calycoceras canitaurinum* (Haas) has been found, and the general position of the shoreline of that time is marked by short dashes. The approximate position of the shoreline during the time of *Acanthoceras alvaradonese* Moreman is shown by the long dashes.

present as well as nine genera of ammonites. The abundance of *Exogyra* (3 species) and *Pycnodonte* indicates a Tethyan influence as far north as Seboyeta Bay.

Range Zone of *Calycoceras Canitaurinum*

The holotype of *Calycoceras canitaurinum* (Haas, 1949, p. 9, Pls. 1-3; Pl. 4, Figs. 1, 2, 4; Text figs. 1-4) came from the basal part of the Cody Shale in northern Wyoming. This early-Late Cenomanian species, originally assigned to *Mantelliceras*, is widely distributed in the Western Interior from southwestern New Mexico to north-central Montana. The range zone of this species is the same as that of *Dunveganoceras pondi* Haas, which has been a guide to one of the Cretaceous ammonite zones in the Western Interior (Cobban, 1951a, Fig. 2; Cobban and Reeside, 1952, p. 1017). In the area of the present report, *D. pondi* has not been found, whereas *C. canitaurinum* is widely distributed. Accordingly, *C. canitaurinum* is used as the guide fossil to the oldest of the late Cenomanian zones in the southern part of the Western Interior.

During the time of *C. canitaurinum*, the epeiric sea advanced westward across the southwestern and northwestern corners of New Mexico to form a broad embayment into eastern Arizona (Fig. 3). At the Four Corners, the oldest molluscs found are from the upper part of the Dakota Sandstone and represent the range zone of *Metoicoceras mosbyense* Cobban of post-*canitaurinum* age. The *canitaurinum* shoreline may have been here or a little to the east. Western limits of the sea in eastern Utah or possibly in western Colorado are unknown. *Calycoceras canitaurinum* was observed in nonsandy shale about 6 or 7 m above the base of the Mancos Shale at Pagosa Springs, Colorado, and the shoreline should be some distance to the west. Similar shale is present in the lower part of the Mancos Shale above the marker bentonite bed along the Utah boundary west of Grand Junction, Colorado, which suggests that the shore must have been farther west in eastern Utah. Coal beds in the Deer Creek coal field in southeastern Arizona and some of the coal beds in the San Juan coal field in southeastern Utah may have formed marginal to the *canitaurinum* sea.

Molluscan fossils are fairly abundant in the broad Seboyeta embayment, but elsewhere they are sparse. Those in the embayment are in the Whitewater Arroyo Tongue of the Mancos Shale and in the overlying Twowells Tongue of the Dakota Sandstone. Forty-three taxa have been listed from these units (Cobban, 1977, Table 3). Common bivalves include *Idonearca depressa* White, *Pinna petrina* White, *Inoceramus prefragilis* Stephenson, *Plicatula* cf. *ferryi* Coquand, *Pycnodonte* aff. *kellumi* (Jones), *Exogyra trigeri Coquand, and E. levis* Stephenson. Cerithid gastropods are fairly abundant locally. At one locality in west-central New Mexico, a nerineid gastropod was collected. Nerineids are typical of the warmer water of the Tethyan sea. Ammonites are not common, and only five genera have been found.

Range Zone of *Metoicoceras Mosbyense*

The guide fossil was described by Cobban (1953, p. 48, Pl. 6, Figs. 1-14; Pl. 7, Figs. 1-3) from the Mosby Sandstone Member of the Greenhorn Formation of central Montana.

Metoicoceras mosbyense is widely distributed in western New Mexico, eastern Arizona, southeastern Utah, and southwestern Colorado, and reveals a major westward advance of the epeiric sea in mid-late Cenomanian time (Fig. 4). The species occurs in shallow-water sandstone (Twowells Tongue) in westcentral and northwestern New Mexico and the adjoining part of Arizona. In southwestern New Mexico, *M. mosbyense* is found in an argillaceous fine-grained sandstone unit in the Colorado Formation in the Silver City-Virden area, but to the east in the Cooke Range, and to the northwest in the Clifton-Morenci area of Arizona, the species is found in dark grey clay shale. On the north and west sides of Black Mesa in northeastern Arizona and in the Kaiparowits Plateau area in southern Utah, *M. mosbyense* occurs in the uppermost sandstone unit of the Dakota Formation. The trend of the shoreline during this time was probably northwestward in Arizona and northeastward in Utah.

Molluscan fossils collected from an unnamed sandstone unit in the Deer Creek coal field, about 100 km west of Morenci, Arizona, were determined by T.W. Stanton (in Ross, 1925, p. 27) to be *Exogyra* aff. *laeviuscula* Roemer, *Trigonarca* cf. *depressa* (White), *Callista* (*Dosiniopsis*?) n. sp., *Glauconia coalvillensis* (Meek), and *Turritella* sp. The *Exogyra* is probably *E. levis* Stephenson, the *Trigonarca* is probably *Idonearca depressa* Meek, and the *Callista* may be the *Aphrodina* sp. of Cobban (1977, Table 3), all of which suggest the fauna of the Whitewater Arroyo Tongue of the Mancos Shale and Twowells Tongue of the Dakota Sandstone of areas farther northeast in New Mexico. The farthest advance of the late Cenomanian sea into southern Arizona may have occurred during the range zone of *Metoicoceras mosbyense*. In southern Utah some of the coal beds in the Dakota Formation in the San Juan and Kaiparowits coal fields may be also of this age.

Fossils molluscs are locally abundant and varied, especially along the Arizona-New Mexico boundary near St. Johns, where pinnids, exogyras, oysters, pectinids, and other bivalves are well preserved. Gastropods, however, are neither common nor varied, and ammonites are restricted to two genera. An arcuate belt of brackish-water rocks containing abundant *Flemingostrea prudentia* (White) parallels the shoreline in the Black Mesa-Kaiparowits Plateau area (Fig. 4).

Range Zone of *Sciponoceras Gracile*

Sciponoceras gracile, of late late Cenomanian age, was described as *Baculites gracilis* Shumard (1860, p. 596). Shumard's specimens came from the Eagle Ford Group of Texas. The species is known from many localities in the Western Interior from southwestern New Mexico to north-central Montana. In the area of our report, *S. gracile* occurs in the basal part of the Bridge Creek Limestone Member of the Greenhorn Limestone in eastern Colorado (Cobban and Scott, 1972, p. 47, Pl. 17, Figs. 9-29; Text-fig. 18), in the Greenhorn Limestone Member of the Mancos Shale in northwestern New Mexico, in the Bridge Creek Limestone Member of the Colorado Formation in southwestern New Mexico (Hook and Cobban, 1981, Fig. 3), in the basal part of the Mancos Shale in northeastern Arizona (Repenning and Page, 1956, p. 267), and in the lower

part of the Tropic Shale in southern Utah (Stanton, 1893, p. 35; Gregory and Moore, 1931, p. 100).

The presence of *S. gracile* at Glendale in southwestern Utah and farther northwest at a locality 8 km east of Cedar City (Richardson, 1927, p. 470, 473) indicates a continued westward advance of the late Cenomanian sea (Fig. 3). Coal beds in the Harmony coal field southwest of Cedar City may have formed during this time. From the Cedar City area, the shoreline trended northeastward toward the southwestern corner of Wyoming. Two important control points along the way are near Ferron and Thistle, Utah. At a locality 25 km south of Ferron, the ammonite *Euomphaloceras* (*Kanabiceras*) *septem-*

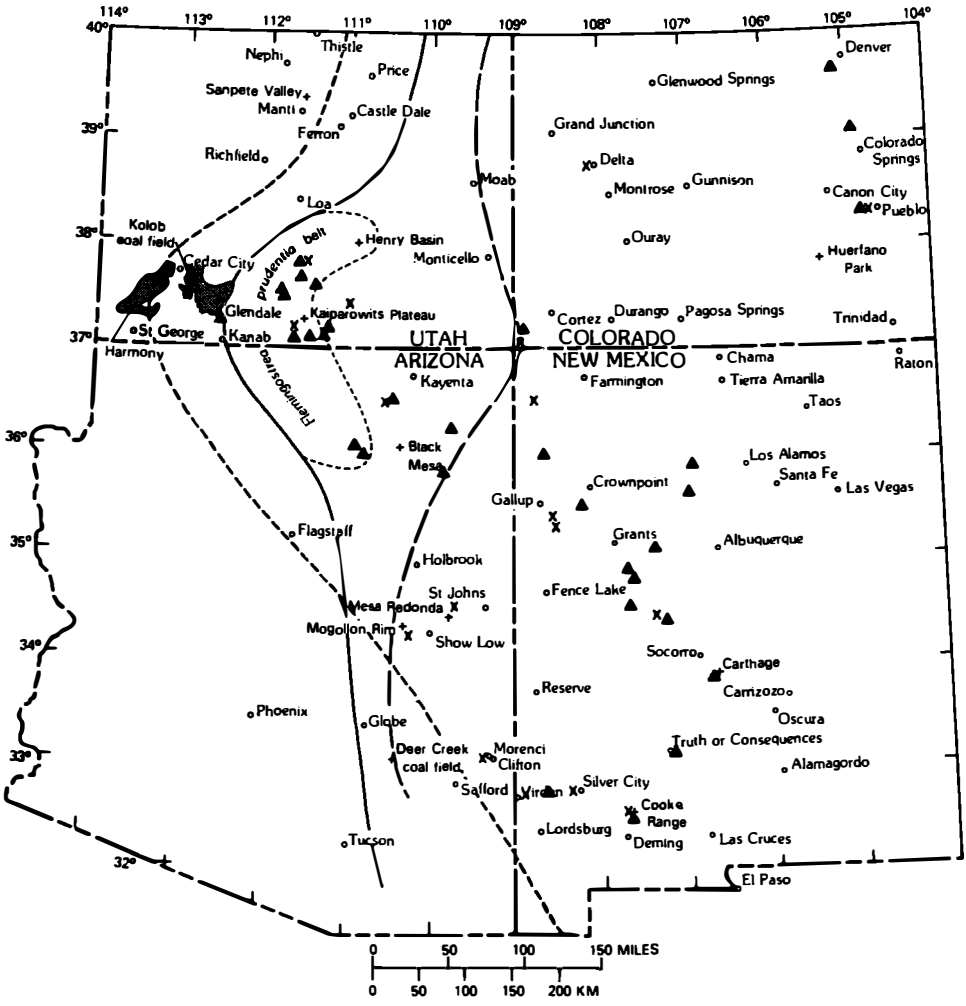

Figure 4. Map of parts of the Four Corners States showing localities (X) where *Metoicoceras mosbyense* Cobban has been found. Solid line shows the general position of the shoreline. Solid triangles (▲) mark localities where *Sciponoceras gracile* (Shumard) has been found, and the general position of the shoreline of that time is marked by short dashes. The approximate position of the shoreline during the time of *Calycoceras canitaurinum* (Haas) is shown by the long dashes.

seriatum (Cragin), restricted to the range zone of *S. gracile*, has been found in sandy beds at the base of the Mancos Shale (Cobban, 1976, p. 120, Pl. 1, Figs. 5, 6). Near Thistle, the oldest marine Cretaceous fossils are in the base of the Sanpete Formation and represent the range zone of *Mammites nodosoides* of post-*gracile* age.

The western limits of the late late-Cenomanian sea are unknown in Arizona. An ammonite, *Metoicoceras geslinianum* (d'Orbigny) of *gracile* age, was discovered recently in silty limestone concretions in a sandstone unit 10 km west of Show Low in the central-eastern part of the State (J.I. Kirkland, pers. commun., 1981). Cretaceous rocks in this area are unnamed and consist largely of fine- to coarse-grained feldspathic sandstone (Finnell, 1966; McKay, 1972). The shoreline was probably not far to the southwest, and a general northeastward retreat of the sea from the Deer Creek coal field area is suggested.

Long ago, Stanton (1893, p. 35) drew attention to the large and varied molluscan fauna in rocks of *gracile* age in southern Utah, and lengthy lists of fossils have been given by later geologists (e.g., Gregory, 1951, p. 36-37). *Pycnodonte newberryi* (Stanton) is the most abundant bivalve and outcrops are locally paved with this form (Lawyer, 1972, Pl. 2, Fig. 4; Rigby *et al.*, 1974, Fig. 40; Hook and Cobban, 1977, Fig. 3). Common bivalve genera found in limestone concretions in the Tropic Shale include *Inoceramus, Exogyra, Pycnodonte, Lima, Psilomya, Camptonectes, Pleuriocardia, Lucina,* and *Corbula*. Sohl (1967, p. 17) listed the gastropods *Turritella, Cerithiella, Perissoptera, Pseudomaura, Cerithioderma?, Mesorhytis, Paladmete,* and *Ringicula,* and noted that these represented a variety of feeding types (deposit feeders, plant browsers, filter feeders, carnivores). A variety of ammonites is also present in these concretions and includes *Sciponoceras, Allocrioceras, Worthoceras, Scaphites, Placenticeras, Euomphaloceras* (*Kanabiceras*), *Metoicoceras,* and at least one undescribed genus. In the Black Mesa area in northeast Arizona, *Calycoceras, Pseudocalycoceras,* and *Moremanoceras* are also present. Molluscs are much less varied in southeastern Colorado and northeastern New Mexico, where the rocks are represented by limestone and limy shale rather than by limestone concretions in calcareous shale. Gastropods are sparse, and only a few genera of bivalves are present (Cobban and Scott, 1972, p. 24). Ammonites, however, are abundant and varied including some genera not recorded from Utah. Molluscs, other than *Pycnodonte newberryi* (Stanton), are not common or varied in southwest New Mexico (Hook and Cobban, 1981, Fig. 3).

Range Zone of *Mammites Nodosoides*

Mammites nodosoides (Schlüter) has long been accepted as a guide to the lower Turonian (de Grossouvre, 1901, Table 35). A lectotype from the lower Turonian of Czechoslovakia has been selected recently (Wright and Kennedy, 1981, p. 76, Fig. 23).

In the area of our report, *M. nodosoides* has been recorded from southeastern Colorado (Cobban and Scott, 1972), northern New Mexico (Pillmore and Eicher, 1976), west-central New Mexico (Cobban and Hook, 1979), eastern Arizona (Miller and Breed, 1963), and southern Utah (Lawrence, 1965; Lawrence and Stokes, 1965; Lawrence *et al.*, 1966) (Fig. 5). The eastern Arizona record was based on an ammonite now assigned to *Plesiacanthoceras* aff. *wyomingense* (Reagan).

Problems arise concerning fossils identified as *M. nodosoides* in the Western Interior. An ammonite described by Morrow (1935, p. 467, Pl. 51, Fig. 2; Pl. 52, Fig. 2a-c; Text-fig. 2) as *Mammites wingi* is easily confused with *M. nodosoides* unless specimens are well preserved or show their septal sutures.

Mammites nodosoides ranges through most of the upper half of the Bridge Creek Limestone Member of the Greenhorn Limestone in southeastern Colorado. The species has been found also in the Greenhorn Limestone Member of the Mancos Shale in northwestern New Mexico and in the equivalent calcareous shale unit in the Mancos in the west-central part. Limestone concretions near the top of the Mancos Shale in the Fence Lake area and near Truth or Consequences also contain *M. nodosoides*. Farther southeast, near El Paso, Texas, the species has been found in limestone concretions in a shale unit like that of the Mancos in the Truth or Consequences area but were included in the Boquillas Formation. Paralleling this northwest-trending shale belt is a near-shore sandstone belt that also contains *M. nodosoides* (e.g., in the Cooke Range).

In southern Utah, *M. nodosoides* has been recorded from the middle of the Tropic Shale as far west as the Glendale area (Lawrence and Stokes, 1965). Just east of Cedar City, about 60 km northwest of Glendale, a shaly unit in the dominantly sandstone sequence contains the bivalve *Mytiloides* of the *mytiloides-duplicostatus* group which suggests a *M. nodosoides* age. Stanton (1893, p. 37) noted the occurrence of marine and brackish-water fossils 30 km west of Cedar City. Inasmuch as the entire Cretaceous sequence is nonmarine 70 km southwest of Cedar City (C.M. Molenaar, pers. commun., 1981), the *nodosoides* shoreline was between these localities. The early Turonian seems to have been the time of maximum transgression in southern Utah.

Much farther northeast in Utah near Thistle, *Mammites* has been found in nearshore sandstone near the base of the Sanpete Formation. A northeast trend of the shoreline between the Cedar City area and Thistle is apparent.

Aside from the bivalve *Mytiloides mytiloides* (Mantell), fossil molluscs are scarce in the large area of carbonate deposition that covered Colorado, much of New Mexico, and parts of Arizona and Utah. The belt of noncalcareous shale bordering the west edge of the carbonate area contains many fossiliferous limestone concretions especially in western New Mexico. Here the bivalves *Phelopteria gastrodes* (Meek), *Plicatula ferryi* Coquand, *Pleuriocardia pauperculum* (Meek), and *Veniella mortoni* Meek and Hayden are abundant as well as thin-shelled oysters and the gastropods *Gyrodes conradi* Meek, *Turritella whitei* Stanton, and *Pyropsis coloradoensis* Stanton. Nine genera of ammonites are present including the Tethyan forms *Neoptychites cephalotus* (Courtiller) and *Fagesia superstes* (Kossmat). Large and varied bivalve assemblages are locally present in the near-shore sandstone beds, such as in the Sanpete Formation in central Utah.

Range Zone of *Collignoniceras Woollgari*

The ammonite for this zone was described from the Middle Chalk of England (Mantell, 1822, p. 197, Pl. 21, Fig. 16; Pl. 22,

Fig. 7). A middle Turonian age is usually accepted. The species has been found at many localities in the Four Corners States (Fig. 5). In places, an early and a late form of the species can be distinguished (Cobban and Hook, 1979) but in the present report, no separation is made.

In the eastern part of the area, *Collignoniceras woollgari* occurs rarely in limestone beds at or near the top of the Bridge Creek Limestone Member of the Greenhorn Limestone and as impressions in the overlying Fairport Member of the Carlile Shale. Farther west in the area of the San Juan Basin, Black

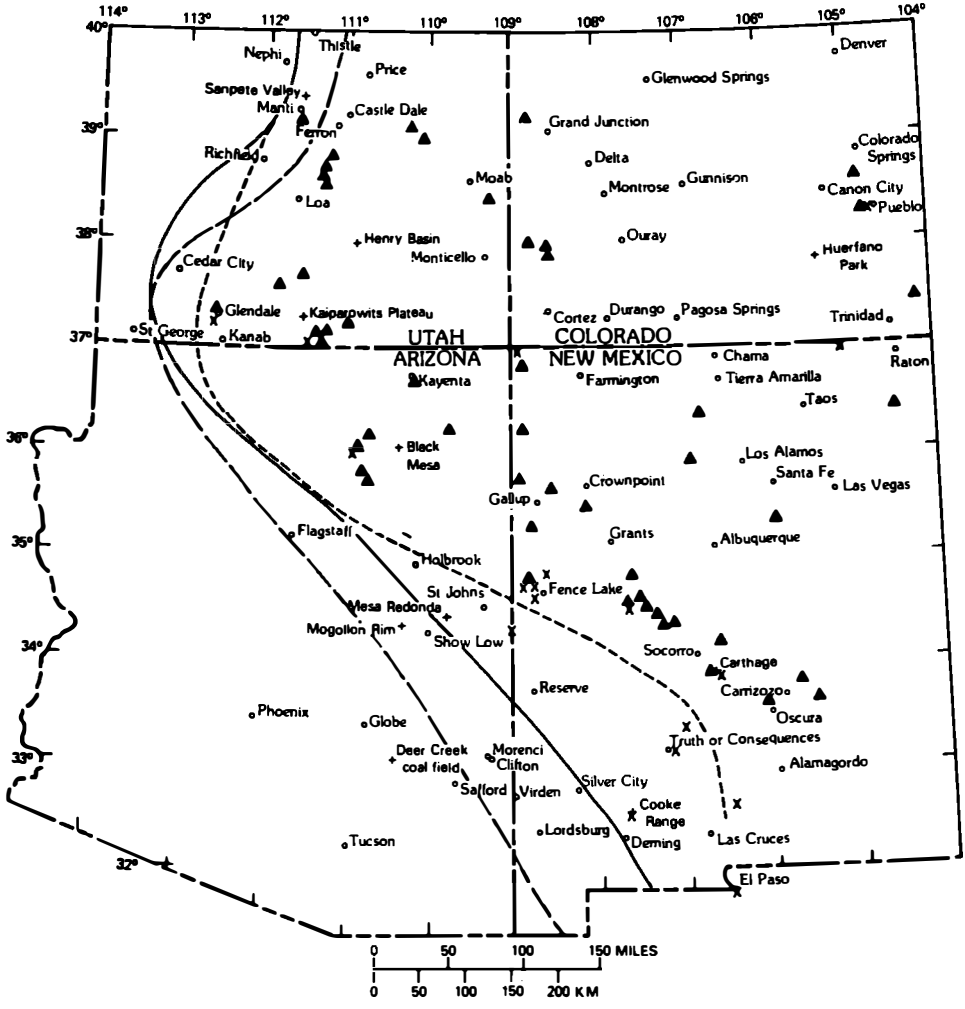

Figure 5. Map of parts of the Four Corners States showing localities (X) where *Mammites nodosoides* (Schlüter) has been found. Solid line shows the general position of the shoreline. Solid triangles (▲) mark localities where *Collignoniceras woollgari* (Mantell) has been found, and the general position of the shoreline of that time is marked by short dashes. The approximate position of the shoreline during the time of *Sciponoceras gracile* (Shumard) is shown by the long dashes.

Mesa, Kaiparowits Plateau, and Henry basin. *C. woollgari* is abundant as impressions in shale or as small internal molds in thin olive-grey siltstone lenses in the Mancos and Tropic Shales and in the Tununk Member of the Mancos Shale. In west-central New Mexico, the species is found in sandstone concretions in the basal regressive sandstone unit (Atarque Member) of the Tres Hermanos Formation as well as in limestone concretions in the upper part of the underlying Rio Salado Tongue of Mancos Shale.

The distribution of *C. woollgari* in New Mexico and the presence of this species in the basal regressive sandstone unit of the Tres Hermanos reveals a general regression of the epeiric sea in a northeastward direction in Arizona and New Mexico. The Salt Lake coal field in the Fence Lake area may have formed marginal to the shoreline during this time.

In southwest Utah, the shoreline seems to have remained nearly where it was in *nodosoides* time. The *Prionotropis* sp., recorded by Richardson (1927, p. 473) in the Glendale area, may be *C. woollgari*. If this interpretation is correct, the *woollgari* shoreline was somewhere between Glendale and Cedar City. A westward transgression of the sea in central Utah is suggested by the Allen Valley Shale, a 180 to 240 m thick unit of chiefly grey marine shale that overlies the nearshore sandstones of the lower Turonian Sanpete Formation.

Aside from *Mytiloides* of the *mytiloides-hercynicus* groups, small thin-shelled oysters, and *C. woollgari*, molluscan fossils are scarce in the calcareous shaly beds in eastern Colorado and northeastern New Mexico. In areas of noncalcareous shale deposition farther west and southwest, as many as nine genera of ammonites are present, but there is very little else (Cobban and Hook, 1979, p. 11). A much larger fauna of bivalves and gastropods and a few ammonites are present in nearshore sandstones in west-central New Mexico (basal regressive sandstone unit of Tres Hermanos Formation), northeastern Arizona (Toreva Formation, J.I. Kirkland, pers. commun., 1981), and western Colorado (unnamed sandy unit in Mancos Shale west of Grand Junction). Nineteen genera of bivalves, seven genera of gastropods, and six genera of ammonites have been recorded from the basal part of the Tres Hermanos Formation in west-central New Mexico (Cobban and Hook, 1979, p. 11). Bivalves usually found in these sandstone units include *Pinna petrina* White, *Pleuriocardia* aff. *pauperculum* (Meek), and *Veniella mortoni* Meek and Hayden. Common gastropods are *Pugnellus* (*Gymnarus*) *fusiformis* Meek, *Gyrodes conradi* Meek, *G.* aff. *depressa* Meek, *Pyropsis coloradoensis* Stanton, and *Carota* cf. *dalli* (Stanton). Ammonite diversity is low in the northern part of the area but greatly increases southward in New Mexico where some Tethyan forms (e.g., *Hoplitoides* ex gr. *koeneni-wohlmanni, Spathites rioensis* Powell, and *Neoptychites*? sp.) have been recorded (Cobban and Hook, 1979, p. 11).

Range Zone of *Prionocyclus Hyatti*

Prionocyclus hyatti (Stanton) was based on specimens from the Codell Sandstone Member of the Carlile Shale in Huerfano Park, Colorado (Stanton, 1893, p. 176, Pl. 42, Figs. 5-8). The species is transitional from *Collignoniceras* to *Prionocyclus*. A late middle Turonian age is usually assigned.

Prionocyclus hyatti has been found at many localities in the Four Corners States (Fig. 6). Specimens occur in concretions in the Blue Hill Member and Codell Sandstone Member of the Carlile shale in southeastern Colorado and northeastern New Mexico, in the Semilla Sandstone Member of the Mancos Shale in west-central New Mexico, and in the Tres Hermanos Formation farther south. The species also occurs in silty beds in the upper part of the Tununk Member of the Mancos in southern Utah and in the upper part of the Mancos Shale beneath the Ferron Sandstone Member much farther north near Price. Probably part of the Ferron Member and its coal beds in the Emery coal field were formed during this time.

At Carthage in south-central New Mexico, the middle non-marine part of the Tres Hermanos Formation (Carthage Member) is of *hyatti* age inasmuch as *Collignoniceras woollgari* has been collected from the basal regressive sandstone unit, and *Prionocyclus macombi* Meek of post-*hyatti* age has been found in the top of the member. *Prionocyclus hyatti*, however, has been found in a nearshore sandstone bed in the Tres Hermanos Formation near Oscura about 75 km southeast of Carthage and the shoreline was somewhere between these localities.

During the time of *P. hyatti*, the sea regressed northeastward in New Mexico. Possibly some of the coal beds in the Salt Lake coal field along the Arizona border were formed during this time. The shoreline probably trended northwest across the northeastern part of Arizona. *Prionocyclus hyatti* has not been identified for certain in the Black Mesa area, although *Inoceramus howelli* White of this age has been found on the north side of the mesa.

In Utah an eastward regression of the sea is indicated by a shift in fossil localities eastward compared to those of *woollgari* time and by the presence of *P. hyatti* in the lower regressive marine sandstone part of the Ferron Sandstone Member of the Mancos Shale as well as in the underlying transition beds to the Mancos Shale. Some of the coal beds in the Emery and Henry Mountains coal fields may have been formed late in *hyatti* time.

Over much of the area of the Four Corners States, molluscan fossils are rather sparse in rocks of *hyatti* age. Two exceptions are the Codell Sandstone Member of the Carlile Shale in Huerfano Park in south-central Colorado and the Semilla Sandstone Member of the Mancos Shale in the Rio Puerco valley northwest of Albuquerque, New Mexico. The beds now named the Codell Sandstone Member in Huerfano Park were referred to by Stanton (1893, p. 28) as the Pugnellus sandstone for the abundance of the gastropod *Pugnellus fusiformis* Stanton. Stanton (1893, p. 29) listed some 23 kinds of bivalves and 17 forms of gastropods from this unit. The Semilla Sandstone Member does not have as varied a fauna, but at least 20 kinds of bivalves and a few species of gastropods were listed from the type section (Dane *et al.*, 1968, p. F17-F19).

Bivalves that are useful guides to the range zone of *Prionocyclus hyatti* include *Inoceramus howelli* White, *I. flaccidus* White, *Exogyra suborbiculata* (Lamarck), *Ostrea malachitensis* Stanton, and *Lopha bellaplicata novamexicana* Kauffman. The Tethyan ammonites *Coilopoceras springeri* Hyatt, *Herrickiceras costatum* (Herrick and Johnson), and *Spathites puercoensis* (Herrick and Johnson) are found in this zone in New Mexico.

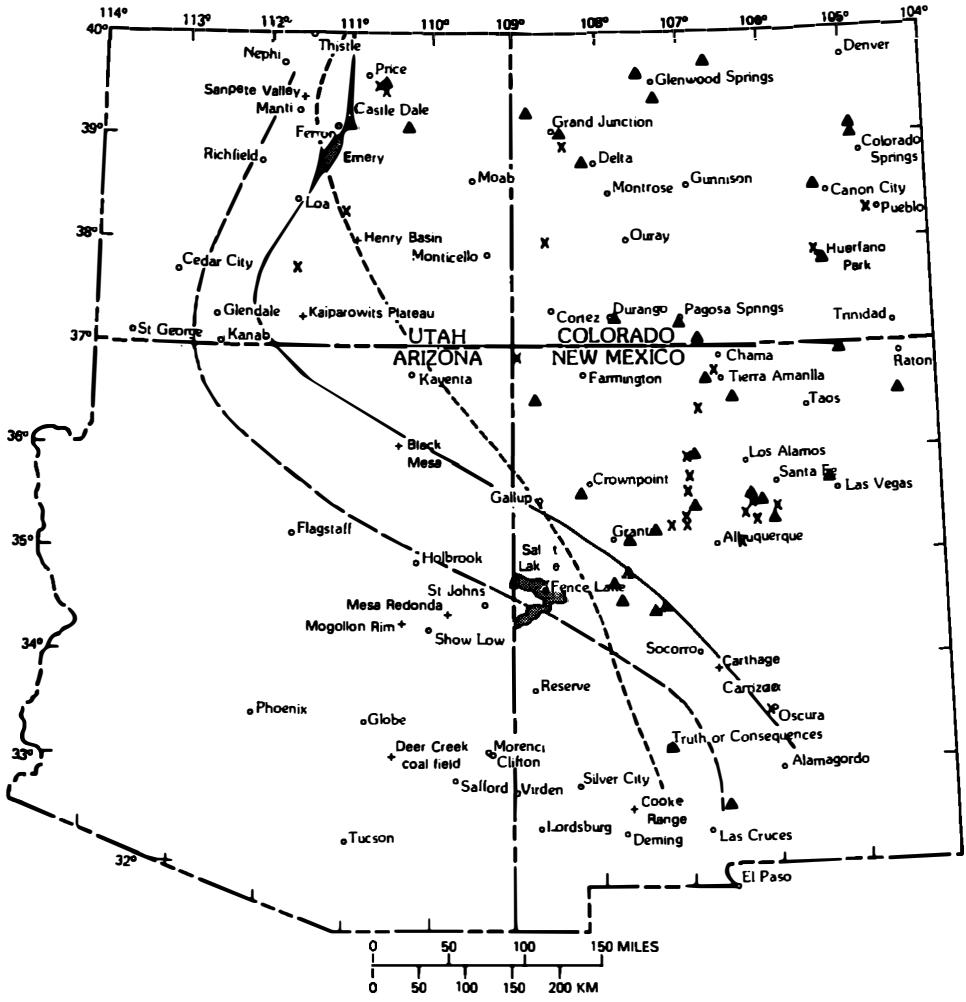

Figure 6. Map of parts of the Four Corners States showing localities (X) where *Prionocyclus hyatti* (Stanton) has been found. Solid line shows the general position of the shoreline. Solid triangles (▲) mark localities where *Scaphites whitfieldi* Cobban has been found, and the general position of the shoreline of that time is marked by short dashes. The approximate position of the shoreline during the time of *Collignoniceras woollgari* (Mantell) is shown by the long dashes.

Range Zone of *Scaphites Whitfieldi*

Cobban (1951b, p. 24, Pl. 4, Figs. 30-40; Pl. 5, Figs. 1-4) described the guide fossil to this late Turonian zone from the Turner Sandy Member of the Carlile Shale of the Black Hills. Many localities are known for this species in Colorado, Utah, and New Mexico (Fig. 6).

A southwestward transgression of the sea in western New Mexico occurred during the time of *Scaphites whitfieldi* when the D-Cross Tongue of the Mancos Shale was deposited over the Tres Hermanos Formation. *Scaphites whitfieldi* has been collected from nearshore sandstone in the Truth or Consequences area. Inasmuch as rocks of this age are nonmarine in the

Cooke Range near Deming, a shore position between these localities is indicated. Molenaar (1973, Fig. 7) pointed out that the strike of the shoreline in western New Mexico during this time was north-northwest. This trend probably continued across the northeastern corner of Arizona and on to central Utah where scaphites closely related to *S. whitfieldi* have been found near Ferronjust above the Ferron Sandstone Member of the Mancos Shale (Cobban, 1976, p. 124, Pl. 1, Fig. 4). From central Utah, the shoreline curved northeastward and entered Wyoming at some point east of its southwestern corner. Over much of the western two-thirds of Colorado and the north half of New Mexico, the uppermost part of the Juana Lopez Member of the Carlile and of the Mancos Shales was deposited during this time.

Molluscan fossils had little diversity during the time of *S. whitfieldi*. *Inoceramus perplexus* Whitfield, *Lopha lugubris* (Conrad), *Baculites yokoyamai* Tokunaga and Shimizu, *Scaphites whitfieldi* Cobban, and *Prionocyclus novimexicanus* (Marcou) are the usual forms. A rarity in the Western Interior is the ammonite *Reesideites* cf. *minimus* (Hayasaka and Fukada).

REFERENCES

Adkins, W.S., 1928, Handbook of Texas Cretaceous Fossils: Texas University Bulletin 2838, 385 p.

Averitt, Paul, and Threet, R.L., 1973, Geologic Map of the Cedar City Quadrangle, Iron County, Utah: United States Geological Survey Quadrangle Map GQ-1120, Scale 1:24,000.

Campbell, M.R., 1904, The Deer Creek Coal Field, Arizona: United States Geological Survey Bulletin 225, p. 240-258.

Cashion, W.B., 1973, Geologic and Structure Map of the Grand Junction Quadrangle, Colorado and Utah: United States Geological Survey Miscellaneous Investigations Series Map I-736, Scale 1:250,000 (reprinted 1979).

Cobban, W.A., 1951a, Colorado Shale of Central and Northwestern Montana and Equivalent Rocks of Black Hills: American Association of Petroleum Geologists Bulletin, v. 35, p. 2170-2198.

———, 1951b, Scaphitoid Cephalopods of the Colorado Group: United States Geological Survey Professional Paper 239, 42 p.

———, 1953, Cenomanian Ammonite Fauna from the Mosby Sandstone of Central Montana: United States Geological Survey Professional Paper 243-D, p. 45-55.

———, 1976, Ammonite Record from the Mancos Shale of the Castle Valley-Price-Woodside Area, East-Central Utah: Brigham Young University, Geology Studies, v. 22, p. 117-126.

———, 1977, Characteristic Marine Molluscan Fossils from the Dakota Sandstone and Intertongued Mancos Shale, West-Central New Mexico: United States Geological Survey Professional Paper 1009, 30 p.

Cobban, W.A., and Hook, S.C., 1979, *Collignoniceras woollgari woollgari* (Mantell) Ammonite Fauna from Upper Cretaceous of Western Interior, United States: New Mexico Bureau of Mines and Mineral Resources Memoir 37, 51 p.

Cobban, W.A., and Reeside, J.B., Jr., 1952, Correlation of the Cretaceous Formations of the Western Interior of the United States: Geological Society of America Bulletin, v. 63, p. 1011-1043.

Cobban, W.A., and Scott, G.R., 1972, Stratigraphy and Ammonite Fauna of the Graneros Shale and Greenhorn Limestone Near Pueblo, Colorado: United States Geological Survey Professional Paper 645, 108 p.

Cunningham, J.E., 1974, Geologic Map and Sections of Silver City Quadrangle, New Mexico: New Mexico Bureau Mines and Mineral Resources, Geologic Map 30, Scale 1:24,000.

Dane, C.H., Kauffman, E.G., and Cobban, W.A., 1968, Semilla Sandstone, A New Member of the Mancos Shale in the Southeastern Part of the San Juan Basin, New Mexico: United States Geological Survey Bulletin 1254-F, 21 p.

Darton, N.H., 1916, Geology and Underground Water of Luna County, New Mexico: United States Geological Survey Bulletin 618, 188 p.

Elston, W.E., 1960, Reconnaissance Geologic Map of Virden Thirty-Minute Quadrange (N. Mex.): New Mexico Institute Mining Technology Geological Map 15, Scale 1:126,720.

Finnell, T.L., 1966, Geologic Map of the Chediske Peak Quadrangle, Navaho County, Arizona: United States Geological Survey Quadrangle Map GQ-544, Scale 1:62,500.

Fisher, D.J., Erdmann, C.E., and Reeside, J.B., Jr., 1960, Cretaceous and Tertiary Formations of the Book Cliffs, Carbon, Emery, and Grand Counties, Utah, and Garfield and Mesa Counties, Colorado: United States Geological Survey Professional Paper 332, 80 p.

Gregory, H.E., 1951, The Geology and Geography of the Paunsaugunt Region, Utah: United States Geological Survey Professional Paper 226, 116 p.

Gregory, H.E., and Moore, R.C., 1931, The Kaiparowits Region, a Geographic and Geologic Reconnaissance of Parts of Utah and Arizona: United States Geological Survey Professional Paper 164, 161 p.

Grossouvre, Albert de, 1901, Recherches Sur la Craie Supérieur, Part 1, No. 2, Stratigraphie Générale: Mémoires pour Servir a L'explication La Carte Geologique Détaillée de la France, p. 561-1013.

Haas, Otto, 1949, Acanthoceratid Ammonoidea from Near Greybull, Wyoming: American Museum of Natural History Bulletin, v. 93, art. 1, 39 p.

Haynes, D.D., Vogel, J.D., and Wyant, D.G., 1972, Geology, Structure and Uranium Deposits of the Cortez Quadrangle, Colorado and Utah: United States GeologicalSurvey Miscellaneous Investigations Series Map I-629, Scale 1:250,000.

Hook, S.C., and Cobban, W.A., 1977, *Pycnodonte newberryi* (Stanton) - Common Guide Fossil in Upper Cretaceous of New Mexico: in Kottlowski, F.E., *et al.*: New Mexico Bureau of Mines and Mineral Resources Annual Report 1976-77, p. 48-54.

———, 1979, *Prionocyclus novimexicanus* (Marcou) - Common Upper Cretaceous guide fossil in New Mexico: *in* Kottlowski, F.E., *et al.*: New Mexico Bureau of Mines and Mineral Resources Annual Report 1977-78, p. 35-42.

———, 1980, Some Guide Fossils in Upper Cretaceous Juana Lopez Member of Mancos and Carlile Shales, New Mexico: in Kottlowski, F.E., *et al.*: New Mexico Bureau of Mines and Mineral Resources Annual Report 1978-79, p. 38-49.

———, 1981, Late Greenhorn (Mid-Cretaceous) Discontinuity Surfaces, Southwest New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 180, p. 5-21.

Hook, S.C., Cobban, W.A., and Landis, E.R., 1980, Extension of the Intertongued Dakota Sandstone-Mancos Shale Terminology into the Southern Zuni Basin: New Mexico Geology, v. 2, p. 42-44, 46.

Hook, S.C., Molenaar, C.M., and Cobban, W.A., 1983, Stratigraphy and Revision of Nomenclature of Upper Cenomanian to Turonian (Upper Cretaceous) Rocks of West-Central New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 185, p. 7-28.

Jones, W.R., Hernon, R.M., and Moore, S.L., 1967, General Geology

of Santa Rita Quadrangle, Grant County, New Mexico: United Geological Survey Professional Paper 555, 144 p.

Kirkland, J.I., 1982, Reassessment of the Age of the Late Cretaceous Section at Mesa Redonda, Apache County, Arizona: Journal of Paleontology, v. 56, p. 547-550.

Kottlowski, F.E., Flower, R.H., Thompson, M.L., and Foster, R.W., 1956, Stratigraphic Studies of the San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 1, 132 p.

Landis, E.R., Dane, C.H., and Cobban, W.A., 1973, Stratigraphic Terminology of the Dakota Sandstone and Mancos Shale, West-Central New Mexico: United States Geological Survey Bulletin 1372-J, 44 p.

Lawrence, J.C., 1965, Stratigraphy of the Dakota and Tropic Formations of Cretaceous Age in Southern Utah: in Geology and Resources of South-Central Utah - Resources for Power: Utah Geological Society Guidebook to Geology of Utah, no. 19, p. 71-91.

Lawrence, J.C., and Stokes, W.L., 1965, *Mammites* Zone in the Tropic Shale of Late Cretaceous Age in Southern Utah [abst.]: Utah Academy Science, Arts, and Letters, Proceedings, v. 42, pt. 1, p. 168-169.

Lawrence, J.C., Herman, George, and Elison, J.H., 1966, North American Distribution of the Turonian (Late Cretaceous) Ammonite *Mammites Nodosoides* (Schlotheim): in Abstracts for 1965: Geological Society of America Special Paper 87, p. 293.

Lawyer, G.R., 1972, Sedimentary Features and Paleoenvironment of the Dakota Sandstone (Early Upper Cretaceous) Near Hanksville, Utah: Brigham Young University Geology Studies, v. 19, p. 89-120.

Lindgren, Waldemar, 1905a, Description of the Clifton Quadrangle [Ariz.]: United States Geological Survey Geologic Atlas, Folio 129, 13 p.

———, 1905b, The Copper Deposits of the Clifton-Morenci District, Arizona: United States Geological Survey Professional Paper 43, 375 p.

Mantell, Gideon, 1822, The Fossils of the South Downs, or Illustrations of the Geology of Sussex: London, Lupton Relfe, 327 p.

McKay, E.J., 1972, Geologic Map of the Show Low Quadrangle, Navajo County, Arizona: United States Geological Survey Quadrangle Map GQ-973, Scale 1:62,500.

Miller, H.W., Jr., and Breed, W.J., 1963, Lower Turonian (Cretaceous) Ammonite from Mesa Redonda, Arizona: Plateau, v. 35, p. 123-130.

Molenaar, C.M., 1973, Sedimentary Facies and Correlation of the Gallup Sandstone and Associated Formations, Northwestern New Mexico: in Cretaceous and Tertiary Rocks of the Southern Colorado Plateau: Four Corners Geological Society Memoir, p. 85-110.

Moreman, W.L., 1942, Paleontology of the Eagle Ford Group of North and Central Texas: Journal of Paleontology, v. 16, p. 192-220.

Morrison, R.B., 1965, Geologic Map of the Duncan and Canador Peak Quadrangles, Arizona and New Mexico: United States Geological Survey Miscellaneous Geologic Investigations Map I-442, Scale 1:48,000, Separate Text.

Morrow, A.L., 1935, Cephalopods from the Upper Cretaceous of Kansas: Journal of Paleontology, v. 9, p. 463-473.

O'Brien, B.R., 1956, Geology of Cienega Amarilla Area, Catron County, New Mexico, and Apache County, Arizona: Unpub. M.A. Thesis, University Texas, Austin.

O'Sullivan, R.B., Repenning, C.A., Beaumont, E.C., and Page, H.C., 1972, Stratigraphy of the Cretaceous Rocks and the Tertiary Ojo Alamo Sandstone, Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: United States Geological Survey Professional Paper 521-E, 65 p.

Peterson, Fred, and Kirk, A.R., 1977, Correlation of the Cretaceous Rocks in the San Juan, Black Mesa, Kaiparowits and Henry Basins, Southern Colorado Plateau: in New Mexico Geological Society Guidebook, 28th Field Conference, San Juan Basin III: p. 167-178.

Peterson, Fred, and Waldrop, H.A., 1965, Jurassic and Cretaceous Stratigraphy of South-Central Kaiparowits Plateau, Utah: in Geology and Resources of South-Central Utah - Resources for Power: Utah Geological Society and Intermountain Association of Petroleum Geologists Guidebook to the Geology of Utah, No. 19, p. 47-69.

Pillmore, C.L., and Eicher, D.L., 1976, Lower Part of the Marine Cretaceous at Gold Creek, Vermejo Park, New Mexico: New Mexico Geological Society Guidebook 27th Field Conference, p. 171-176.

Reagan, A.B., 1924, Cretacic Mollusca of Pacific Slope: Pan-American Geologist, v. 41, p. 179-190.

Repenning, C.A., and Page, H.G., 1956, Late Cretaceous stratigraphy of Black Mesa, Navajo and Hopi Indian Reservations, Arizona: American Association of Petroleum Geologists Bulletin, v. 40, p. 255-294.

Richardson, G.B., 1927, The Upper Cretaceous Section in the Colob Plateau, Southwest Utah: Washington Academy of Science Journal, v. 17, p. 464-475.

Rigby, J.K., Hintze, L.F., and Welsh, S.L., 1974, Geologic Guide to the Northwestern Colorado Plateau, Pt. 1, Thistle to Green River, Utah, via U.S. Highway 50-6; Pt. 2, Green River to Salina, via Interstate 70; Pt. 3, Salina to Thistle, via U.S. Highway 89: Brigham Young University Geology Studies, v. 21, pt. 2, Studies for Students No. 9, 119 p.

Ross, C.P., 1925, Geology and Ore deposits of the Aravaipa and Stanley Mining Districts, Graham County, Arizona: United States Geological Survey Bulletin 763, 120 p.

Scott, G.R., 1969, General and Engineering Geology of the Northern Part of Pueblo, Colorado: United States Geological Survey Bulletin 1262, 131 p.

Shumard, B.J., 1860, Descriptions of New Cretaceous fossils from Texas: Academy of Science of St. Louis, Transactions, v. 1, p. 590-610.

Sohl, N.F., 1967, Upper Cretaceous Gastropod Assemblages of the Western Interior of the United States: in A Symposium on Paleoenvironments of the Cretaceous Seaway in the Western Interior: Geological Society America, Rocky Mountain Section, 20th Annual Meeting: Golden, Colorado, Colorado School of Mines, p. 1-37.

Spencer, A.C., and Paige, Sidney, 1935, Geology of the Santa Rita Mining Area, New Mexico: United States Geological Survey Bulletin 859, 78 p.

Spieker, E.M., 1946, Late Mesozoic and Early Cenozoic History of Central Utah: United States Geological Survey Professional Paper 205-D, p. 117-161.

Stanton, T.W., 1893, The Colorado Formation and Its Invertebrate Fauna: United States Geological Survey Bulletin 106, 288 p.

Stark, J.T., Johnson, J.H., Behre, C.H., Jr., Powers, W.E., Howland, A.L., Gould, D.B., and others, 1949, Geology and Origin of South Park, Colorado: Geological Society of America Memoir 33, 188 p.

Steven, T.A., Lipman, P.W., Hail, W.J., Jr., Barker, Fred, and

Luedke, R.G., 1974, Geologic Map of the Durango Quadrangle, Southwestern Colorado: United States Geological Survey Miscellaneous Investigations Map I-764, Scale 1:250,000.

Strain, W.S., 1968, Cerro de Muleros (Cerro de Cristo Rey): in Delaware Basin Exploration, 1968 Guidebook: West Texas Geological Society Publication 68-55, p. 82.

———, 1976, New Formation Names in the Cretaceous at Cerro de Cristo Rey, Dona Ana County, New Mexico: in Lovejoy, E.M.P., Geology of Cerro de Cristo Rey Uplift, Chihuahua and New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 31, p. 77-82.

Wright, C.W., and Kennedy, W.J., 1981, The Ammonoidea of the Plenus Marls and the Middle Chalk: Palaeontographical Society (Monograph), 148 p.

Young, Keith, 1957, Cretaceous Ammonites from Eastern Apache County, Arizona: Journal of Paleontology, v. 31, p. 1167-1174.