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ALBIAN-CENOMANIAN DEPOSITIONAL CYCLES TRANSGRESSED FROM CHIHUAHUA TROUGH TO WESTERN INTERIOR

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Abstract.—The Upper Albian to Lower Cenomanian stratigraphic record in the Chihuahua Trough at El Paso, Texas is more than 250 m thick and records six depositional cycles averaging 1.6 million years in duration. Five of these cycles are identified in the much thinner Albian-Lower Cenomanian stratigraphic sections of northeastern New Mexico, Colorado, Kansas, and Wyoming, and the cycle of the Mesilla Valley Formation correlates into the regional unconformity between the Glencairn and Mesa Rica Formations.

Three transgressive-progradational cycles were deposited continuously from Texas north to Wyoming and Montana and the associated seaways provided opportunities for south to north biotic exchange. The first early Late Albian connection is represented by correlation of the two cycles of the Del Norte and Smeltertown formations at El Paso with the Tucumcari/Purgatoire/Kiowa/Skull Creek formations in New Mexico, Colorado, and Kansas, and the Thermopolis Formation in Wyoming and Montana. Part of the third cycle represented by the Muleros Formation may be partly represented locally in Kansas-Colorado, but its record is absent in most places.

The second potential connection is represented by the Anapra Formation at El Paso, the Pajarito Formation in New Mexico and the Van Bibber Member of the Muddy Formation in eastern Colorado. The Anapra correlates with the Pawpaw and Main Street formations in north Texas, which includes the range of the uppermost Albian oyster in the Pajarito, *Peilinia levicostata* Kues [formerly *Rastellum quadriplicata* (Shumard)]. But the Van Bibber contains a sparse non-marine biota indicating that little northward exchange occurred across the Transcontinental Arch with deposition of the Mowry Formation in Wyoming and Montana. The third connection in the Early Cenomanian is indicated by the Del Rio/Buda formations in El Paso and the lower part of the Graneros Shale northward. However, during this time little biotic exchange occurred, and the foraminiferal faunas are quite different. Full and open exchange was resumed during the Middle Cenomanian when the Thatcher Member of the Graneros was deposited.

The geographic pathways of the ancestors of the endemic ammonites and inoceramids of the Mowry Formation in Wyoming and Montana are as yet unclear. It is possible that these species are relics of the earlier Late Albian connection between the Caribbean and North Temperate Provinces. The geographic range of one of the ammonites is expanded by a new occurrence in the basal Cenomanian section in northwestern France (Cobban and Amedro, personal commun., 2001). Most of the benthic foraminifers in the Mowry are from the northern area, but a sparse planktic foraminiferal assemblage indicates a filtered connection with the Tethyan Realm. This connection was not necessarily southward with the Gulf Coast Caribbean Province.

INTRODUCTION

Traditional sequence models of the mid-Cretaceous North American Western Interior Seaway recognize that the first north-south connection between the Boreal and Caribbean Provinces was made during the early part of the Late Albian (about 103 to 99 Ma) (Kauffman, 1984; Scott et al., 1998). During the latest Albian these biotic provinces became separated. This seaway was opened again in the Middle Cenomanian about 94 Ma. These two continental-wide transgressions correspond to sequences Al 8 and Ce 3 of Hardenbol et al. (1998), respectively; the timing of maximum flooding of these sequences is 101.06 Ma and 95.23 Ma. New stratigraphic field evidence supports the hypothesis that an additional major (3rd-order) transgressive/regressive episode between these two floodings spanned the Early/Late Cretaceous boundary in the Western Interior Basin. The evidence further suggests that transgression was sufficient to reconnect the Tethyan and Boreal seas for at least a brief period. The regional scale, timing, and mechanics of this proposed seaway connection are very poorly constrained. This cycle has not been incorporated into the existing stratigraphic framework of major transgressive/regressive Western Interior cycles.

The suggestion of an intermediate connection during the Albian/Cenomanian interval was made by Cobban and Kennedy (1989) to account for the dispersal of Caribbean engonocerid ammonites into the Boreal Mowry seaway. They also suggested that the correlative Albian/Cenomanian boundary defined in Europe was low in the Mowry Formation below the well-dated Clay Spur bentonite and close to the Arrow Creek bentonite dated at 98.52+/-0.41 Ma (Obradovich, 1993). The result of this suggestion was to increase the age of the Albian/ Cenomanian boundary nearly 2 my. However, this suggested correlation has yet to be tested utilizing other fossil groups such as dinoflagellates, foraminifers and radiolaria.

Here, we propose tentative stratigraphic correlations of Albian/ Cenomanian strata from the Chihuahua Trough at the Texas-Chihuahua border to New Mexico, Kansas and Colorado based on preliminary data. We are in the process of testing the hypothesis that an additional extensive transgressive/regressive cycle near the Early/Late Cretaceous boundary connected the southern and northern basins.

An age model of the fossils and depositional cycles of middle Cretaceous strata has been developed based on more than 40 outcrop and core data from around the world and calibrated to the time scale of Harland et al. (1990) (Scott et al., 2000). Ranges of more than 1100 bioevents, planktic and benthic foraminifers, nannofossils, dinoflagellates, ammonites, bivalves, echinoids, calcareous algae, magnetochrons, geochemical events, and sequence stratigraphic markers have been integrated by the technique of graphic correlation. Albian depositional cycles were defined in the Washita Group of north Texas and labeled WA1-6 (Scott et al., 1994; Scott et al. 2000). This data set includes the core of Cretaceous strata in the Amoco Bounds well at the Kansas-Colorado state line (Scott et al., 1994, 1998). Foraminiferal data from the

Mowry and Graneros formations in Kansas and Colorado have been graphed to this data set so that the ages of Western Interior marker fossils and depositional cycles can constrain regional correlations. This new data set and age model is the MIDK4 composite standard, which will be used to make preliminary estimates of the ages of mid-Cretaceous depositional sequences from the U.S.-Mexico border to northern Colorado.

STRATIGRAPHIC DATA

Biostratigraphy

Fossils that have biostratigraphic utility in these strata in Colorado, New Mexico, and Kansas are uncommon and not diverse. Benthic foraminiferal zones were used by Eicher (1962, 1965, 1967) to correlate the Mowry and Belle Fourche formations from Colorado to Montana. These zones in the Canadian Plains region are conceptually bodies "...of strata distinguished by a particular foraminiferal fauna that empirically is distinctive enough to have at least local biostratigraphic value" (Caldwell et al., 1978, p. 501). These assemblage zones are defined by the composite group rather than by first or last occurrences. The *Miliammina manitobensis* Zone consists of at least 14 principal taxa and extends from the Interior Plains of Canada to Colorado (McNeil and Caldwell, 1981). It characterizes strata above the Viking Sandstone and up to the Fish Scale Beds in Canada and the Shell Creek and Mowry Formations in the U.S. This zone occurs with the ammonites *Neogastroplites haasi* Reeside and Cobban, *N. cornutus* (Whiteaves), and *N. muelleri* Reeside and Cobban (Caldwell et al., 1978), which were originally correlated with Upper Albian ammonites in Europe. But Cobban and Kennedy (1989) reinterpreted these zones as Lower Cenomanian because the metengonocerid species are similar to Cenomanian species. However, additional data are needed to evaluate and clarify this new correlation. Our new data from the Mowry and basal Graneros formations in the sections at the I-70 roadcut west of Denver and at Turkey Creek near Morrison establish the presence of the *M. manitobensis* Zone across the Mowry-Graneros contact supporting correlation of this contact with the top of the Mowry in Wyoming.

The Graneros Shale in Colorado and southern Wyoming is divided into two foraminiferal zones characterized by low diversity of Boreal agglutinated foraminifera: the lower *Trochammina mellariolum* Zone and the upper *Evolutinella apricarius* Zone (Eicher, 1962, 1965, 1967; Caldwell et al., 1993). Both zones are used mainly in the U.S. part of the Western Interior, where the *T. mellariolum* Zone encompasses the Lower Cenomanian part of the Graneros and the *E. apricarius* zone spans from below the Middle Cenomanian Thatcher bed to the top of the Graneros (Caldwell et al., 1993). Both zones contain sparse numbers of cosmopolitan, shallow-dwelling planktic foraminifers; however the Thatcher is evidence that the seaway opened to Caribbean waters introducing Tethyan biota, including nannofossils into the Western Interior (Cobban and Scott, 1972; Scott et al., 1994, 1998).

Ammonite zones are not well developed in most of the section, however the Graneros Shale has four zones in ascending order: *Conlinoceras tarrantense* (Adkins), *Acanthoceras granerosense* Cobban and Scott, *Acanthoceras muldoonense* Cobban and Scott, and *Acanthoceras amphibolum* Morrow (Cobban and Scott, 1972; Cobban, 1990). In the Thatcher Member at Pueblo the *C. tarrantense* Zone is represented by *Conlinoceras gilberti* Cobban and Scott with *Borissiakoceras compressum* Cobban and *Inoceramus eulessanus* Stephenson. This zone is also present in the uppermost Woodbine Formation in north Texas and the basal Boquillas Formation at Cerro de Cristo Rey, and is correlated with the Middle Cenomanian. The *A. granerosense* and *A. amphibolum* zones span from just above the Thatcher to the top of the Graneros and are correlated with the Middle Cenomanian. The age span of these three zones in the MIDK4 composite standard is from 93.43 to 92.62 Ma.

Three Gulf Coast Upper Albian ammonite zones are known in this region below the Graneros: *Craginites serratescens* (Cragin), *Eopachydiscus marcianus* (Shumard), and *Mortoniceras equidistans* (Cragin). These three species define successively younger range zones in the lower Upper Albian Duck Creek Formation in Texas (Young, 1986; Kauffman et al., 1993), where they occur just above the top of *Hysteroceras* sp. cf. *varicosum* (Sowerby), which defines a zone in the lower Upper Albian in Europe, so the *E. marcianus* Zone is correlated with the *Callihoplites auritus* Zone in Europe (Hancock et al., 1993; Kennedy et al., 1999). Both *E. marcianus* and *M. equidistans* occur in the upper parts of the Tucumcari Formation and basal part of the Mesa Rica Sandstone, and *E. marcianus* is in the Glencairn Formation in northeastern New Mexico and southeastern Colorado with *Inoceramus comancheanus* Cragin and/or *Inoceramus bellvuensis* Reeside (Cobban, 1985, 1987a; Kues et al., 1985; Kues and Lucas, 1987). Both inoceramids occur in the Glencairn as far north as Bellvue, Colorado near the Northern Front Range section (Reeside, 1923), so the *M. equidistans* Zone can be correlated to this section. The *M. equidistans* Zone also occurs in the Smeltertown Formation at Cerro de Cristo Rey (Cobban, 1985), where it characterizes depositional cycle Washita (WA) 2 of the middle-upper Duck Creek Formation. Consequently, we correlate cycle WA2 in the upper part of the Smeltertown with the Glencairn in New Mexico and Colorado. In the MIDK4 composite standard the age of *E. marcianus* is 101.39-101.32 Ma, *M. equidistans* is 101.01-100.55 Ma, *I. comancheanus* is 101.48-101.39 Ma, and *I. bellvuensis* is 101.47-101.39 Ma. Note, however, that Cobban (1985) reports that ranges of *E. marcianus* and *M. equidistans* overlap and *M. equidistans* ranges higher.

Two of the Western Interior Cretaceous palynomorph biozones (Nichols et al., 1982) can be recognized by our preliminary data. The dinocyst, *Ovoidinium verrucosus* (Cookson and Hughes) of the *Spinidinium vestitum* Assemblage Zone occurs in the basal Graneros Shale in the Tollgate Canyon section in the Dry Cimarron Canyon. This zone spans the Bear River Formation and Aspen Shale in western Wyoming and it is found in the Thermopolis Shale, Skull Creek Shale, and Mowry Formation (Nichols et al., 1982). Several spore and pollen taxa suggest the presence of the nonmarine *Appendicisporites unicus* Interval Zone (Nichols et al., 1982) in the Van Bibber Shale Member in the Interstate 70 roadcut and in sections of the Pajarito and Dry Creek Canyon members in the Dry Cimarron Valley. Albian pollen were found in the Pajarito Formation at Romeroville Gap, New Mexico (Lucas, 1990).

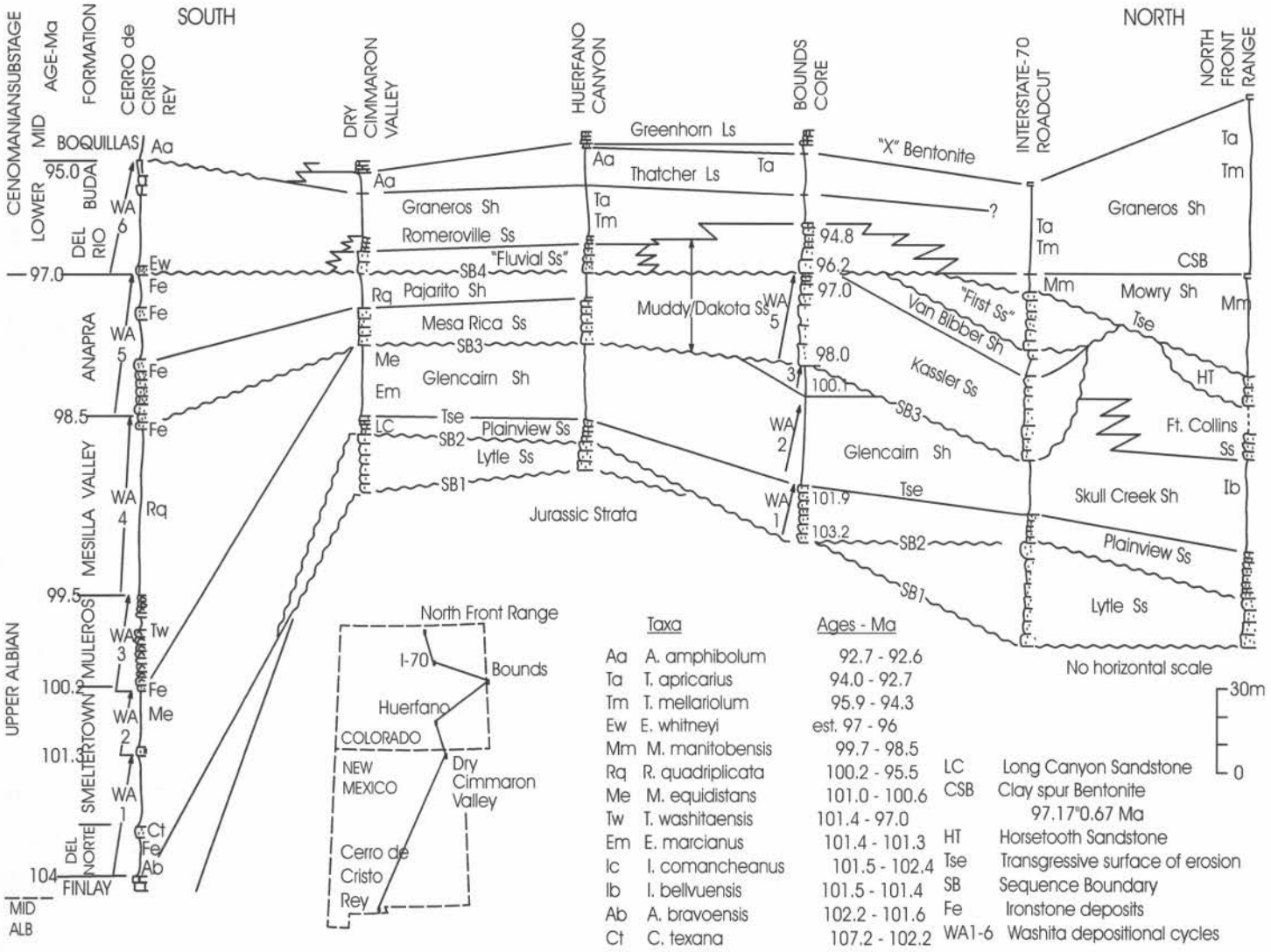


FIGURE 1. Regional north-south stratigraphic cross section on the datum of the Albian-Cenomanian boundary placed at SB4 and the Clay Spur Bentonite bed. Long arrows indicate generalized shoaling up depositional cycles. No horizontal scale.

Cerro de Cristo Rey, New Mexico Section

The Upper Albian-Lower Cenomanian reference section of the Chihuahua Trough is documented at Cerro de Cristo Rey uplift on the border between Doña Ana County, New Mexico and Ciudad Juarez, due west of El Paso, Texas (Lovejoy, 1976). This section is approximately 265 m thick and composed of seven lithostratigraphic units that yield age-diagnostic ammonites and bivalves that enable correlation of the section with the Trinity River Valley section near Fort Worth (Scott et al., 1994, 1996, 2000) and with the eastern New Mexico sections (Cobban, 1985, 1987a, b; Kues, 1986, 1997; Kues and Lucas, 1993; Lucas, 1991; Lucas and Estep, 1998). Six depositional cycles are distinguished by shale to ferruginous sandstone successions from about 20 to nearly 100 m thick (Fig.1). The ferruginous sandstones tend to contain taphonomically mixed assemblages suggesting transportation and depositional bypassing. These cycles appear to represent deepening to shoaling base levels. Diagnostic ammonites and oysters indicate biostratigraphic correlations with depositional cycles of shale to limestone in north Texas (Scott et al., 2000) and in northern New Mexico (Kues and Lucas, 1987; Cobban, 1985). We correlate the formations at Cerro de Cristo Rey with those in the Trinity River Valley generally in the same way as did Strain (1976).

Dry Cimarron Valley, New Mexico Section

The Dry Cimarron Valley in Union County, northeastern New Mexico and the panhandle of Oklahoma, exposes Albian-Cenomanian sandstones, mudstones, and shales of the Lytle Sandstone, the Glencairn Formation including the basal Long Canyon Sandstone Bed, the Mesa Rica Sandstone, the Pajarito Formation, and the Romeroville Sandstone overlain by the Graneros Shale (Kues and Lucas, 1987; Lucas, 1990). These lithostratigraphic units are separated into genetic sets by four regional unconformities that are well exposed at Tollgate Pass (Holbrook, 1992; Holbrook and Wright Dunbar, 1992; Holbrook and White, 1998). The basal unconformity sequence boundary (SB) 1 separates the Lower Cretaceous Lytle Formation from underlying Jurassic

rocks, unconformity K-0 of Lucas et al. (1998). The Lytle ranges up to 20 m thick in this region and represents mainly fluviatile deposition. It is overlain by a regional unconformity designated SB 2 by Holbrook (1992) at the base of the Long Canyon Sandstone Member of the Glencairn, which is up to about 3 m thick. The Long Canyon is in the same stratal position as the Planiview Sandstone but is not physically continuous with it. The contact of the Long Canyon with the overlying Glencairn is a transgressive surface. The remaining Glencairn consists of paralic and nearshore marine shelf facies and is up to 20-25 m thick. The Glencairn here and in southeastern Colorado and its equivalent unit in east-central New Mexico, the Tucumcari Formation, yield age-diagnostic ammonites and bivalves (Scott, 1970; Cobban, 1985; Kues et al., 1985). Many of the taxa in the Tucumcari are also found in the Smeltertown Formation at Cristo Rey and in the Duck Creek Formation in north Texas, depositional cycle WA2.

In the Dry Cimarron Valley the Glencairn Formation is disconformably separated by SB 3 from overlying fluviatile strata of the Mesa Rica Sandstone, which represent the lowstand and transgressive deposits of a depositional cycle that includes the overlying Pajarito Shale. Westward at Romeroville SB3 merges with SB1 and SB2 where it is the K-0 unconformity of Lucas et al. (1998). Here the Mesa Rica is up to 10-12 m thick and the Pajarito is 12 m thick. In the Dry Cimarron Valley the Mesa Rica is unfossiliferous, however, southward in the Tucumcari Basin correlative Mesa Rica marine strata yield sparse ammonites, including *Mortoniceras equidistans*, which characterizes the Duck Creek Formation in north Texas. Also southern outcrops of the Pajarito yield the Upper Albian oyster, *Peilinia levicostata* (Kues, 1997). A closely related oyster, *Rastellum quadriplicata* (Shumard), is found in the Mesilla Valley Formation, depositional cycle WA4 at Cristo Rey, and in the Denton through Main Street formations in north Texas, depositional cycles WA3-WA5. The basal Pajarito is overlain disconformably at SB 4 by an unnamed upper Pajarito fluviatile sandstone up to about 8 m thick.

The overlying Romeroville Sandstone is up to 5 m thick and represents transgressive paralic deposition grading up into the Graneros Shale, which is up to 20-30 m thick in the region. In the upper part of the Graneros a thin limestone unit, Thatcher Limestone Member, contains Middle Cenomanian ammonites correlative with the uppermost part of the Woodbine Formation in north Texas (Cobban and Scott, 1972).

Huerfano Canyon, Colorado Section

The section at Huerfano Canyon is about 40 km southeast of Pueblo, Colorado, where the pre-Graneros section is well exposed (Long, 1966; Taylor, 1974; Holbrook and White, 1998). The section of the Graneros Shale, however, is a composite based on several measured sections of Cobban and Scott (1972) at the Rock Canyon area near Pueblo, the Old Hatchet Ranch and the Model anticline. The base of the Lytle is a regional unconformity (SB1) that locally cuts into red mudstone and white sandstone of the Morrison Formation below. The Lytle is 10-20 m thick. The base of the overlying Plainview Sandstone is a sharp surface of valley incision. The Plainview is about 8 m thick and dominantly estuarine fill. The Glencairn Formation is about 25 m thick and consists of interbedded sandstone, shale and mudstone. Besides shallow shelf trace fossils, *Inoceramus bellvuensis* is present. The Glencairn correlates with Washita Group depositional cycle WA2 in north Texas. The unconformity between the Lytle and Plainview is extremely widespread and marks fluvial incision. SB2 probably records a separate major regression.

The overlying Muddy Sandstone at Huerfano Canyon consists of a lower, thick-bedded, medium grained, cross-bedded sandstone about 15 m thick, the Dry Creek Canyon Member up to 10 m thick, an upper thick-bedded sandstone about 12 m thick, and a 3-m-thick sandstone with trace fossils indicating transgression. We place SB3 at the Glencairn-Muddy contact and SB4 between the Dry Creek Canyon and the upper Muddy units. We suggest that SB4 correlates with the same contact between the lower and upper Dakota units in the Amoco No. 1 Bounds core, and thus, is the Albian-Cenomanian boundary. The overlying Graneros Shale at Huerfano Canyon consists of a lower shale unit about 21 m thick, the Thatcher Limestone Member 0.5 m thick, and an upper shale unit 13 m thick. The 1-m-thick "X" Bentonite is at the top of this upper unit. The basal Graneros contact is a transgressive lag contact, and the upper contact with the Greenhorn Formation is abruptly gradational. In the Pueblo section, Eicher (1965) identified the *Trochammina mellariolum* Zone in the lower shale and the *Evolutinella apricarius* Zone at the top of the Graneros.

Amoco No. 1 Bounds, Kansas Section

The Amoco No. 1 Bounds core near the Kansas-Colorado border presents a complete section of the Plainview-Graneros interval (Hamilton, 1989, 1994; Scott et al., 1994; Scott et al.,1998). The Plainview Formation is the 20-m-thick basal sandstone-shale interval that disconformably overlies the Upper Jurassic Morrison Formation. It is a nearshore paralic facies with two transgressive contacts within it, and its top is a transgressive contact with the Glencairn Formation, which is 44 m thick. The maximum flooding interval in the Glencairn is about 1400-1410 ft depth, where *Adkinsites bravoensis* (Böse) and *Inoceramus comancheanus* Cragin occur. These fossils occur in north Texas in the Kiamichi-Duck Creek formations. The contact between the Glencairn and Dakota formations is an erosional disconformity (SB3).

The Dakota Formation consists of two intervals separated by a regional erosional disconformity, SB4. This contact separates nonmarine beds below from bioturbated transgressive sandstone above. The lower interval is 33 m thick, and the upper interval is 17 m thick. Graphic correlation postulates that the lower interval correlates with the Pawpaw-Mainstreet formations depositional cycle WA5 in north Texas, and the upper unit with either the Grayson-Buda formations or the basal Woodbine Formation, both of Cenomanian age (Scott et al., 1994).

The Graneros Shale is divided into a lower interval about 10 m thick capped by a very thin Thatcher Member, and an upper interval about 17 m thick. The "X" Bentonite is within 2.4 m of the contact between the Graneros and the Greenhorn Limestone. The *Evolutinella apricarius* Zone is represented by two species at a depth of 1050 ft in the upper Graneros interval about 2.4

m below the "X" Bentonite. The first nannofossils in the Graneros at a depth of 1084.75 ft and the first planktic foraminifers at 1080 ft indicate connection between the Caribbean and Boreal seas (Scott et al., 1998).

Interstate-70 Roadcut, Colorado Section

The Lower Cretaceous section exposed along the I-70 roadcut west of Denver is one of the most informative along the Front Range. It has been described carefully by Waage (1955) and Weimer and Land (1972), and our sampling of the Mowry has added a few details. The base of the section is the contact between the Jurassic Morrison Formation and the Lytle Formation, which is characterized by red mudstone below and tan sandstone above. The Lytle is 36.5 m thick and represents fluvial deposition. The basal South Platte Formation consists of the Plainview Sandstone, 10.1 m thick. The Glencairn Member is 18.9 m thick, and shallow water trace fossils occur in sandstone interbedded with mudstone. It is disconformably overlain by the Kassler Sandstone Member, which is 29.5 m thick and is characterized by trough cross bedding. The Van Bibber Shale Member is 8.8 m thick and did not yield foraminifers. The upper sandstone member is 20.9 m thick and consists of cross-bedded sandstone with clay clasts at the base, which is in sharp contact with bioturbated sandstone of the Van Bibber. Waage (1961) referred to this unit as the "First sandstone" of the South Platte Formation, and Weimer (1984) combines this unit with the Van Bibber and Kassler in the "J" sand unit. The sharp contact with the overlying Mowry is marked by a lamina of ferruginous sandstone, and it appears to be a transgressive disconformity. The Mowry is 5.6 m thick and yields foraminfers of the *Miliammina manitobensis* Zone, which extends into the overlying Graneros Shale at least 2 m. A thin sandstone bed marks the conformable Mowry/Graneros contact. Although bentonitic laminae are common in both units, the Clay Spur Bentonite is absent. Rojas (1980) measured more than 29 m of Graneros at this roadcut. Eicher measured about 33 m of Graneros up to the "X" Bentonite at the Alameda roadcut section about 3 km south of the I-70 roadcut, and that measurement is used here. His data also show that the Upper Albian-Lower Cenomanian *M. manitobensis* Zone spans the Mowry-Graneros contact; the Lower Cenomanian *Trochammina mellariolum* Zone is from 7.3 to 13.4 m above the base of the Graneros, and the mainly Middle Cenomanian *Evolutinella apricarius* Zone is from 13.4 to at least 31.7 m. The Thatcher bed is not recognized here.

Northern Front Range, Colorado Section

The thickest Mowry section along the Front Range, measured by Eicher (1965, section 11), is in Larimer County. The Mowry Formation is 34.8 m thick, and the Clay Spur Bentonite is about 0.9 m thick. The Graneros Shale is 62.5 m thick, and the 0.8-m-thick "X" Bentonite is at the top. The Thatcher Member is not identified here. The *M. manitobensis* Zone is present in the Mowry, the *T. mellariolum* Zone is in the lower part of the Graneros, and the *E. apricarius* Zone is in the upper part.

The lithologic succession and thicknesses of the pre-Graneros interval are based on cross sections by Eicher (1962), Dolson et al. (1991), and Dubois (1996). The Lytle Formation is estimated to be about 18 m thick; the Plainview Formation is about 16 m thick; the Skull Creek Formation is about 33 m thick; the Fort Collins Sandstone is about 19 m thick; and the Horsetooth Sandstone is about 10 m thick. *Inoceramus bellvuensis* occurs in the shale and sandstone interval of the Skull Creek (Reeside, 1923). This section needs to be re-examined for details about the contacts, but it is assumed that the features seen near Bellvue and at Spring Canyon Dam at Horsetooth Reservoir (MacKenzie, 1965) also characterize the contacts here.

CONCLUSIONS

Depositional Cycles

In the U.S. Western Interior Basin, the middle Cretaceous stratigraphic section consists of two long-term transgressive-regressive depositional cycles, the Kiowa-Skull Creek Cycle and the Greenhorn Cycle (Kauffman, 1977) and four short-term cycles. The Kiowa-Skull Creek Cycle as defined by Kauffman incorporates the Lytle, Plainview, and Glencairn formations and is bounded by SB1 at the base and SB3 at the top. Although the Lytle is part of the Kiowa-Skull Creek, the regional incision marked by SB2 suggests a major episode of regional incision between Lytle and Plainview. It seems more reasonable that the Lytle records an earlier event, older than the Plainview-Glencairn-Skull Creek. The Greenhorn Cycle includes the Muddy Sandstone and the Mesa Rica Sandstone/Pajarito Shale/Romeroville Sandstone succession at its base overlain by the Graneros and Greenhorn formations. Additional unconformities in this section bound short-term depositional sequences (Holbrook and Wright Dunbar, 1992). Sequence 1 is bounded by sequence boundary 1 (SB1) at the base of the Lytle and by SB2 at the top of the Lytle. Sequence 2 is bounded by SB2 at the base of the Plainview/Long Canyon Sandstone Bed/Campana Sandstone Bed and by SB3 at the top of the Glencairn. Sequence 3 is bounded by SB3 at the base of the Muddy Sandstone and by SB4 at the base of either the Romeroville Sandstone or local fluvial sandstone lenses filling channels incised into the upper Pajarito Formation. The Romeroville grades upward into Upper Cretaceous marine strata in the Dry Cimarron Valley (Lucas, 1990; Lucas et al., 1998; Holbrook, 1996). Westward of the Dry Cimarron SB1, SB2, and SB3 merge into a single unconformity, K-0, between the Morrison and Mesa Rica (Lucas et al., 1998). They label the Pajarito/Romeroville unconformity K-1, which we name SB4.

Sequence 1

The basal Cretaceous sequence 1 consists of the Lytle Formation in New Mexico and Colorado, and the localized incised channel fill of the Cheyenne Sandstone in southern Kansas. The Lytle has been correlated with basal Cretaceous sandstone units in Wyoming (Cloverly Formation), South Dakota (Lakota Formation), and Montana (Kootenai Formation). These basal sandstones consist of fluvial channel complexes that represent lowstand deposits, but, successive systems tracts of a complete sequence are absent. In Colorado, the Lytle is overlain by transgressive bio-

turbated facies of the Plainview, and the age of the Lytle is indeterminate because age-diagnostic fossils have not been recovered. The Lytle may be a truncated part of an older separate sequence, if the Lytle is coeval with a more complete sequence to the north. Alternatively the Lytle may be the lowstand facies tract of the Plainview-Glencairn sequence 2.

Sequence 2

At the base of this sequence in Colorado and western Kansas are transgressive paralic facies of the Plainview Sandstone. In northeastern New Mexico lenticular Campana and Long Canyon sandstones represent fluvial, estuarine and lagoonal facies in topographic depressions (Holbrook and Wright Dunbar, 1992). The Glencairn and Tucumcari shales and nearshore sandstones represent the deeper shelf deposits of maximum transgression of the early Late Albian Kiowa-Skull Creek seaway (Scott, 1970; Holbrook and Wright Dunbar, 1992). A localized shoreface sand at the top of the Glencairn on the northern Front Range is mapped as the Fort Collins Sandstone (MacKenzie, 1965; Dubois, 1996). This sequence correlates with depositional cycles WA1 and WA2 and part of WA3 at the base of the Washita Group in north Texas (Scott et al, 1978; Scott et al., 1994), which are also developed in the Cerro de Cristo Rey section. These cycles were renumbered Al 4, 5, and 6, and the bases of these cycles are dated at 104.00 Ma, 101.30 Ma, and 100.2 Ma (Scott et al., 2000).

Sequence 3

The regional unconformity within the Mesa Rica Sandstone between the lower marine facies and the upper fluviatile facies in northeastern New Mexico correlates into western Kansas with the basal unconformity of the Dakota Formation in the Bounds core. The lower Dakota here is dated as 98.2 to 96.0 Ma by correlating it with the north Texas depositional cycle WA5, Pawpaw and Main Street formations (Scott et al., 1994, 1998). Consequently, the Mesa Rica correlates with the Anapra Formation at Cerro de Cristo Rey. Southward in the Tucumcari Basin Holbrook and Wright Dunbar (1992) did not recognize SB3 below deltaic facies of the Mesa Rica. Northward the Mesa Rica correlates with the lower Muddy sandstone at Pueblo and in the Bounds core, and with the Kassler Sandstone at the I-70 road cut. The Van Bibber Shale is in the stratigraphic position of a transgressive unit above the Kassler as is the Pajarito above the Mesa Rica.

The Kassler Sandstone pinches out northward between the I-70 roadcut and the Horsetooth Reservoir, where the Horsetooth Sandstone, a localized incised valley-fill up to 38 km wide in a north-south direction (MacKenzie, 1965; Weimer, 1984; Mateer, 1987; Dolson et al., 1991; Dubois, 1996), disconformably overlies SB3 and the underlying Fort Collins Sandstone. The Fort Collins is a nearshore facies grading down into the Skull Creek. Because the Horsetooth is overlain by the Mowry Shale and the *M. manitobensis* Zone, it is older than the 97 Ma-old Clay Spur Bentonite Bed. Between the southern pinchout of the Horsetooth and the northern pinchout of the Muddy Sandstone/"J" sand, the Fort Collins underlies the basal Mowry transgressive disconformity (Weimer, 1984, fig. 15). The upper sandstone of Weimer's "J" sand in the I-70 section unconformably overlies the Van Bibber Shale and underlies the Mowry Formation at a transgressive contact and the *M. manitobensis* Zone. The Horsetooth Sandstone is correlated with the upper sandstone of the Muddy Sandstone in the I-70 section because they both are overlain by and in transgressive contact with the Mowry. The upper one meter of the Horsetooth has shallow-water burrows indicating encroaching marine conditions and is overlain by a lag pebble lamina of phosphate and shark teeth (MacKenzie, 1965). MacKenzie's isopach map indicates northeast transport into the Denver Basin. It is clear that both the Horsetooth and the upper Muddy sandstone at the I-70 cut are part of an incised valley cycle younger than Van Bibber and older than the top of the Mowry and the basal contact is amalgamated SB3 and SB4. Both sequence 3 and the Horsetooth sandstones are paralic facies of the Mowry basin to the north. The Muddy extends eastward and northeastward into the Denver Basin where it is overlain by the Huntsman Shale, which is correlated as a tongue of the Graneros Shale and overlain by the "D" sandstone. South of the I-70 section the Van Bibber and part of the Kassler are, in turn, cut out by the transgressive sandstones of sequence 4. The Pajarito Shale is also dominantly nonmarine except in one southernmost exposure where it has oysters.

If the environments in which the Van Bibber and Pajarito shales were deposited were connected, a limited, filtered exchange of southern and northern biota could have occurred during the transgressive cycle of sequence 3, thus permitting shallow-dwelling planktic foraminifers and perhaps larvae of engonocerid ammonites to enter Mowry waters. However the Van Bibber in the I-70 section yields non-marine spores and pollen and no benthic foraminifers.

Sequence 4

The base of sequence 4 is SB4 in New Mexico, and in some sections it is at the base an upper fluvial sandstone bed filling a channel incised into the Pajarito, and elsewhere it lies at the base of the Romeroville Sandstone. The sandstones above SB4 in places are lowstand incised fluvial sands. Generally these sands are overlain by marine sands of the Romeroville, which are nearshore transgressive facies tracts grading into the Graneros Shale in northeastern New Mexico, Colorado, and Kansas. In some sections, such as near Pueblo, Colorado, and in the Bounds core, the channel sandstone in the upper part of the Pajarito is missing and the transitional sandstone interval directly overlies SB4 amalgamated with TSE. Sequence 4 is correlated with the north Texas cycle WA6 of the Grayson and Buda formations (Scott et al., 1994, 1998). Thus, the strata above SB4 are younger than the Clay Spur Bentonite in Wyoming at the top of the Mowry Formation. Finally by Middle Cenomanian time when the Thatcher Member was deposited the Caribbean and Boreal seas were connected and biota freely exchanged.

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