BIOSTRATIGRAPHY OF THE MANCOS SHALE IN WESTERN NEW MEXICO AND WESTERN AND CENTRAL COLORADO

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ABSTRACT OF THE THESIS

Biostratigraphy of the Mancos Shale in Western New Mexico and Western and Central Colorado

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The study of Foraminifera from three sections of the Cretaceous Mancos Shale in Colorado and New Mexico has established: 1. correlation among the three sections and correlation with the Standard Sections of the Gulf Coastal Plain and the Western Interior; 2. a biostratigraphic zonation of the Mancos Shale which may be applicable to other Western Interior Sections; and, 3. a paleoenvironmental interpretation of the microfauna.

Sixty species of Foraminifera are described from the Mancos Shale. The Mancos includes Coloradoan and Montanan strata. Faunal diversity is low. Calcareous shales of the Mancos Shale are dominated by a few planktonic species. The number of benthonic genera and species is low. Noncalcareous shales generally contain a limited agglutinated microfauna or are barren. Species of *Gavelinella*, although more abundant in the calcareous

shales of the Mancos Shale, also occur in the noncalcareous shales.

The specific composition of the microfauna shows a similarity to microfaunas previously described from the Western Interior, particularly those from the Greenhorn and Niobrara Formations and their equivalents in the Great Plains, the northern Western Interior of the United States, Alberta, and the north slope of Alaska. Similarity to the Gulf Coastal Plain microfaunas is also apparent.

Biostratigraphic analysis of the foraminiferal faunas in the Mancos Shales has established four Assemblage Zones, the Gavelinella dakotensis Assemblage Zone, the Gavelinella kansasensis Assemblage Zone, the Gavelinella henbesti Assemblage Zone, and the Haplophragmoides rota Assemblage Zone. Correlation of these four Assemblage Zones to the Standard Section of the Western Interior is made. The Gavelinella Assemblage Zones are suggested to be of correlative value throughout the Western Interior, whereas the Haplophragmoides rota Assemblage Zone is probably a facies zone.

The noncalcareous parts of the Mancos Shale yield a sparse agglutinated microfauna or are barren. The evidence suggests an analogue to modern delta front areas where one of the major ecological restrictions is variable salinity and abundance is determined by sedimentation rates. Barren parts of the section are interpreted as

representing above mean high water sediments on a delta margin.

Foraminiferal faunas from the calcareous parts of the Mancos Shale are analyzed. Microfaunas are dominated by species of *Heterohelix* and *Hedbergella*. Faunal diversity of benthonic species, morphoecological analogues of benthonic species, and dominance values of planktonic species suggest inner shelf depths for the deposition of calcareous Mancos Shale. It is suggested that some species of *Heterohelix* may have been neritopelagic or benthonic rather than true oceanic. Species of *Hedbergella* were probably restricted to an upper thin column of water. The use of planktonic-benthonic ratios including species of *Heterohelix* and *Hedbergella* results in high ratios that do not yield valid paleobathymetric interpretations. Productivity at the sediment interface is considered the factor limiting benthonic diversity.

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To my wife, Karin, for whom the task of completion seemed endless.

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INTRODUCTION

The Mancos Shale is the thickest marine Cretaceous sedimentary unit west of the Front Range Uplift in Colorado and New Mexico. Its thickness varies from less than 1000 feet in western New Mexico to more than 5000 feet in Colorado. It includes all of the Coloradoan strata and, in areas where it is thickest, most of the Montanan strata. Stratigraphic analysis of sections reveals a gross similarity of lithology to the Standard Section of the Western Interior in the Great Plains states.

Three sections of Mancos Shale were measured and samples collected in New Mexico and Colorado (Figure 1). The section in western New Mexico was chosen because its location is near the southwestern-most extent of the formation. The section in western Colorado was chosen because through most of Mancos Shale deposition the shoreline was far to the west. The section in central Colorado was chosen because it is the eastern-most location where the name Mancos is applied to Upper Cretaceous marine shale.

The collected samples were analyzed for their foraminiferal content. The objectives of the study were to identify the species, to determine their geographic and geologic extent, and to interpret the fauna paleo-ecologically. Systematic description of the Foraminifera, their occurrence, and correlation with the Standard Section of the Western Interior is made. Biostratigraphic relationships among the three sections and Assemblage Zones have been established based on microfaunal and lithologic studies.

METHODS OF STUDY

Field Study

Three stratigraphic sections of the Mancos Shale, located in northwestern New Mexico, west central Colorado, and central Colorado were measured and sampled during the summers of 1959 and 1961 (Figure 1). The sections were measured with aid of a tape measure, hand level, and in central Colorado with a plane table and telescopic alidade. Because the Mancos Shale is largely undifferentiated with few stratigraphic markers, samples were nearly always collected at intervals of ten feet. Channel samples were collected whenever possible. Where thickness of weathered material exceeded approximately two feet, spot samples were taken.

Laboratory Study

Two hundred eighty-two samples were processed for their foraminiferal content. Five hundred grams of each sample was processed by the following methods: The sample was boiled in a weak solution of sodium carbonate for a minimum of one hour. The mud was decanted over a 62 micron sieve and the residue dried and bottled.

Many of the samples did not respond to the above method. These samples were dried, placed into a weak solution of sodium carbonate and boiled again until broken down or for a maximum of eight hours. Those samples that still had not broken down were dried, heated, and immersed in kerosene overnight. Subsequently, they were again boiled in a weak solution of sodium carbonate, decanted, dried, and bottled. Numerous samples that still did not break down were dried and immersed in a hot saturated solution of sodium thiosulphate.

Each disaggregated sample was examined for its foraminiferal content. A representative fauna from each sample was picked and provisionally identified. In most cases all of the specimens of Foraminifera were picked. In those samples where dominant species were extremely abundant, approximately thirty were picked and their great abundance noted.

Foraminiferal counts of species, planktonic-benthonic ratios, and foram number were determined for many of the samples from the lower part of the section at Gallup in the hope that these counts would enhance the study. It became apparent that the data of these counts did not change conclusions reached prior to the counts. Consequently, these counts are not reported nor were further counts made on other samples.

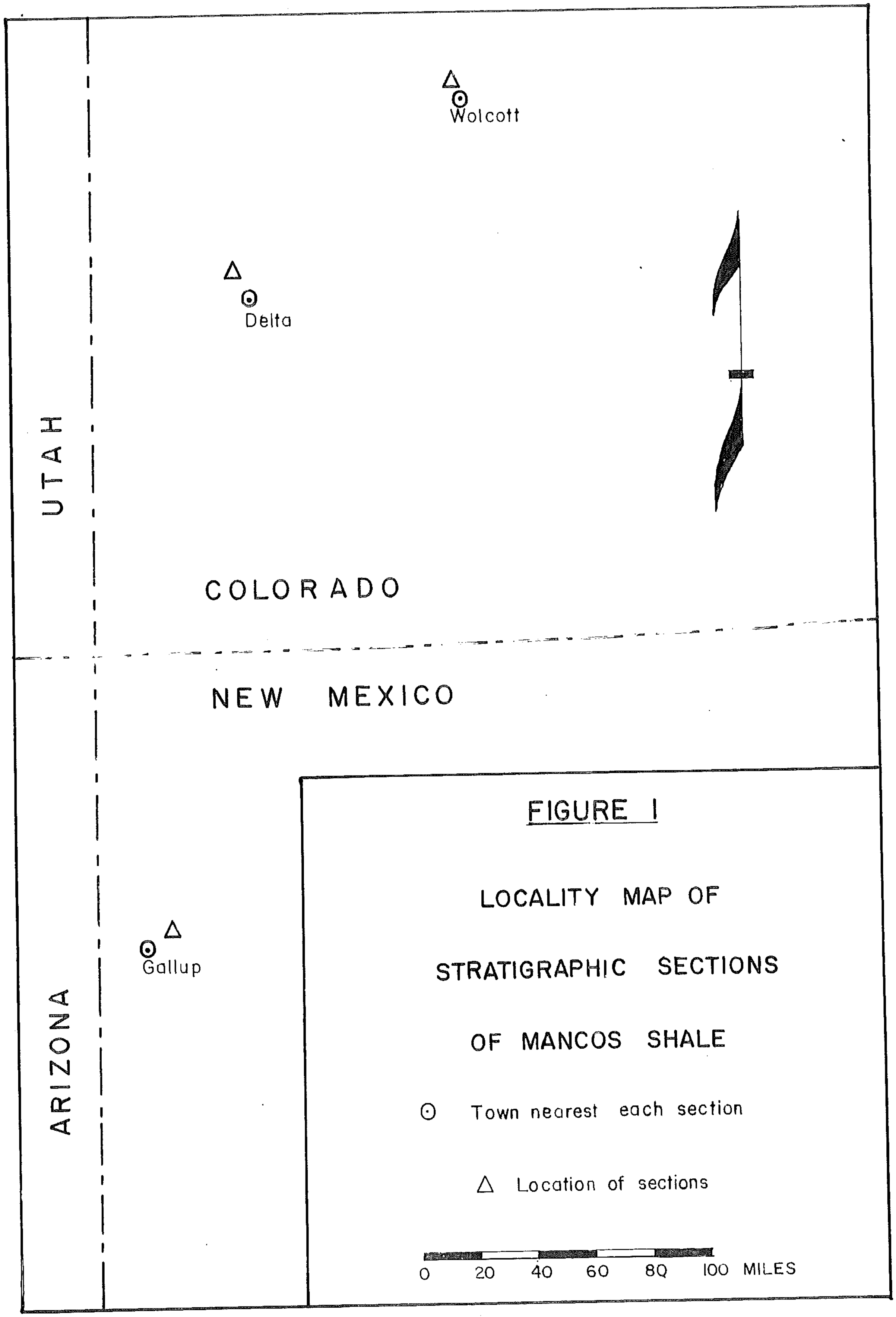

FIGURE I

LOCALITY MAP OF STRATIGRAPHIC SECTIONS OF MANCOS SHALE

STRATIGRAPHY

Stratigraphy - General

The Mancos Shale was named by Cross (1899a) for a section of 1200 feet of dark marine shales cropping out near the town of Mancos in southwestern Colorado. In this area the Mancos Shale conformably overlies the Dakota Sandstone and is unconformably overlain by the Eocene San Miquel Formation. Fossiliferous horizons near the base and near the top of the formation were correlated with the Benton and Pierre Formations, respectively (Cross, 1899a).

In an adjacent area east of the type locality Cross (1899b, p. 4) described the formation as ".... an almost homogeneous body of soft, dark gray or nearly black, carbonaceous clay shale..... It is limited below by the Dakota Sandstone and above by the lowest of the Mesaverde formation of alternating sandstones and shales." Faunas correlative with the Benton and Pierre Formations were collected and described (Cross, 1899b). These two areas are considered by the writer as the combined type area of the Mancos Shale.

Subsequent to its original description the name "Mancos" was applied by a number of workers to the thick grey marine shale unit overlying the Dakota Sandstone and overlain by the Mesaverde Formation. Thus the name "Mancos" spread through Colorado west of the Front Range Uplift, eastern Utah, northern New Mexico, and northeastern Arizona.

For approximately two decades after its original description, however, the Mancos Shale received little detailed attention. General geology reports of areas within the outcrop belts of the Mancos Shale were, for the most part, reconnaissance in nature or concerned primarily with investigations of coal beds within the overlying Mesaverde Group or underlying Dakota Sandstone. Consequently, the Mancos Shale was largely ignored except for general descriptions and somewhat more detailed descriptions of parts of the formation near the lower and upper contacts.

Reeside (1924) studied the Upper Cretaceous stratigraphy of the northern San Juan Basin, which included the type area of the Mancos Shale. He was the first to recognize the complexity of facies relations within Cretaceous strata in the northern San Juan Basin. Moreover, he recognized the stratigraphic drop of the top of the Mancos Formation southward and westward and a corresponding rise eastward and northward.

Stratigraphy - Gallup Area

The name, Mancos Shale, was applied by several workers in reconnaissance surveys or coal investigations to the lowermost marine shale of the Upper Cretaceous in the southern part of the San Juan Basin early in the twentieth century (Shaler, 1907; Schrader, 1906; Gardner, 1909, 1910). Because of the nature of the investigations little was added to the knowledge of the Mancos Shale. In fact, because of the facies relations involved, correlations from the type area southward were later proven to be incorrect.

Sears (1925) was the first investigator to recognize the complexity of the upper Cretaceous facies in the Gallup-Zuni Basin. Sears, et al. (1941) showed that the top of the main body of the Mancos Shale was stratigraphically as much as 1000 feet lower in the type area in the northern San Juan Basin than in the Gallup area to the southwest.

The Gallup Section

A stratigraphic section of the Mancos Shale was measured in Sec. 16, T16N, R17W, McKinley County, New Mexico (Figure 1). The section is located approximately eight miles northeast of Gallup, New Mexico and shall be herein referred to as the "Gallup section."

The Mancos Shale crops out in a strike valley between the cuesta cliffs of the Dakota Sandstone and the First Gallup Sandstone Member of the Mesaverde Group. The Gallup section is located in the southwestern edge of the San Juan Basin north of the Zuni Uplift. This location was chosen because it is located near the southwesternmost site of Late Cretaceous marine deposition in the Western Interior.

In the Gallup area the lower part of the Mancos

Shale is poorly exposed except in the hogback just east of Gallup, New Mexico. Samples of the lower Mancos Shale were collected for the writer from the Phillips Company mine shaft located in the previously named section. The upper part of the Mancos Shale immediately north of the mine shaft was measured and samples were collected.

An abbreviated description of the Gallup section follows. Each of the sections measured is subdivided into informal lithologic units. In most cases the units correlate with formations of the standard reference section (Figure 2).

Mesaverde Group:

First Gallup Sandstone - massive white to grey quartz sandstone, crossbedded, one foot conglomerate bed near base.

Mancos Shale:

Unit G2

Dark grey thinly bedded shale and siltstone with some thin sandstone beds decreasing in abundance downward, siltstone beds more abundant near top, limonite stained throughout, selenite crystals in vertical joints. *Inoceramus* fragments. 50 feet

Dark grey shale with few siltstone beds, thin beds of calcareous sandstone, two limestone beds less than 1/2 foot thick near base of unit. 143 feet

Tan fine grained limonite stained sandstone, carbonaceous fragments, cliff-forming.	37 feet
Grey fine grained sandstone, irregular lenses of carbonaceous shale, limonite stained, selenite.	23 feet
Dark grey to black shale, limonite stained, selenite crystals, Prionocyclus hyatti (Stanton) molds.	67 feet
Alternating black shale and thin siltstone beds, limonite stained, secondary selenite, Prionocyclus hyatti (Stanton) molds.	30 feet
Covered interval.	168 feet
Unit G1	
Phillips mine shaft samples - all samples collected for the writer were grey calcareous shale. 302 feet below the collar of the mine a sample of Dakota Sandstone.	302 feet
Total Mancos Shale	700 feet

Dakota Sandstone

The Gallup Section is located near the southwestern edge of the San Juan Basin. Lamb (1968) subdivided the Lower Mancos Shale into the Graneros, Greenhorn, Carlile, and Niobrara Members in the northern part of the San Juan Basin. He defined the Graneros Member as the strata between the Dakota Sandstone and the calcareous shale bed containing Gryphaea newberryi Stanton. This bed is considered to be the lowermost bed of the Greenhorn Member (Lamb, 1968). North of the Gallup section near Red Wash, New Mexico the Graneros Member is 30 feet thick (Lamb, 1968). Because the lowest sample from the mine shaft is 50 feet above the top of the Dakota Sandstone, the presence of the Graneros Member in the Gallup section could not be verified.

The samples from the mine shaft are all calcareous grey shales (Unit G1). They contain a characteristic upper Greenhorn foraminiferal fauna (Gavelinella dakotensis Assemblage Zone).

The transition to the Carlile Shale occurs in the stratigraphic interval between the uppermost sample in the mine shaft and the lowermost outcrop. The lowermost bed in outcrop is a black shale containing molds of Prionocyclus hyatti (Stanton) indicating a probable correlation with the Blue Hill Shale Member of the Carlile Formation.

The section above the mine shaft becomes essentially coarser with an increase in silt beds, sand beds, and beds containing plant debris, although shale remains the dominant lithology. The tan cliff-forming sandstone may be correlative with the Codell Sandstone Member of the Carlile Formation. Lamb (1968) notes a sandstone, which he correlated with the Codell Sandstone in a stratigraphically similar position in the northern San Juan Basin.

The top of the Mancos Shale is the base of the cliff-forming massive cross-bedded sandstone and conglomerate, the First Gallup Sandstone. Above the sandstone the Mulatto Tongue of the Mancos Shale occurs. It consists predominantly of siltstone but in addition beds of carbonaceous shale and cross-bedded sandstones occur. The tongue is largely nonmarine, pinches out a few miles to the Southwest, and represents the distal part of a marine tongue in the Gallup section.

There are no marine beds above the Gallup Sandstone in the southwest edge of the San Juan Basin. The Mancos Shale here records one transgression correlative with the type Greenhorn Formation (Unit G1) and one regression correlative with the Carlile Formation (Unit G2). Further to the north and east marine Mancos Shale correlative with the Niobrara is found (Pike, 1947; Lamb, 1968). Thus, a clastic source to the southwest and a northwest-southeast shoreline is indicated for post-Carlile deposition in the San Juan Basin.

Stratigraphy - Delta Area

The Cretaceous stratigraphy of the Grand Mesa area south of Grand Junction, Colorado was first studied by Lee (1912). His study emphasized the distribution of coal beds within the Dakota Formation and the Meseverde Group. Lee estimated a thickness of 3000 feet for the

Mancos Shale south of Grand Junction. Fossil collections were made near the base and top of the formation.

Erdmann (1934) corrected Lee's estimate of the thickness of the formation. On the basis of measured sections and well logs the Mancos Shale was shown to be 4020 ± 50 feet thick in the vicinity of Grand Mesa. Erdmann also noted the complex facies relations between the upper Mancos Shale and the lower part of the Mesaverde Group. He was the first to show a stratigraphic rise of the top of the Mancos Shale in a west to east direction along the Book Cliffs from Utah to Colorado and southeast from Grand Junction, Colorado along the flanks of Grand Mesa. Recent detailed stratigraphic analysis has clarified the complex facies relationships in the Book Cliffs (Spieker, 1947; Young, 1950; Fisher, et al., 1960).

The Delta Section

A stratigraphic section of the Mancos Shale was measured in T4S, R3E Ute. Mer., Delta County, Colorado. The section was measured approximately eight miles northwest of Delta, Colorado and shall herein be called the "Delta section" (Figure 2).

The Mancos Shale crops out on the flanks of the southern part of Grand Mesa between the valley of the Gunnison River and the mesa to the North. The Mancos Shale is almost completely exposed beneath a thin veneer of clay on the dissected pediment slopes north of the river.

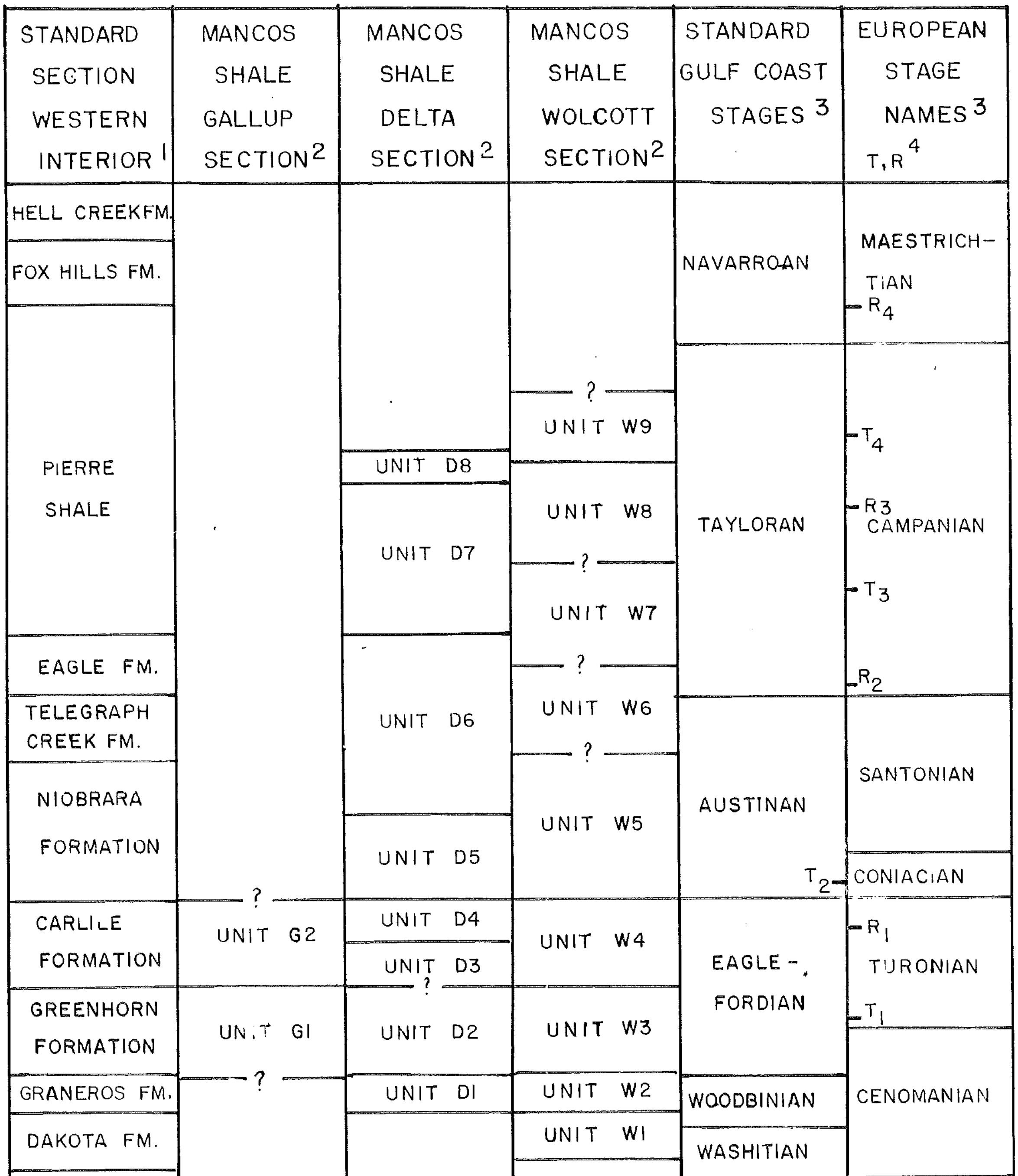

FIGURE 2 — CORRELATION OF THE MANCOS SHALE WITH EUROPEAN STAGES AND STANDARDS OF WESTERN INTERIOR AND GULF COAST

1 — Cobban & Reeside, 1952
2 — This report
3 — after Pessagno, 1967
4 — (T) Transgressions, (R) Regressions Weimer, 1960

The Delta section is located in the southwestern part of the Piceance Basin near the eastern end of the Book Cliffs. The section was measured in this area because the shoreline was far to the west throughout the main part of the Mancos Shale deposition (Spieker, 1946). Consequently, foraminiferal distribution was not effected by near shore conditions except during the initial transgression and the final regression.

An abbreviated description of the Delta section follows:

Mesaverde Group - Mount Garfield Formation

Rollins Sandstone Member

White crossbedded sandstone, massive, slightly calcareous, plant debris present.

Mancos Shale

Unit D8

Highly weathered grey silty shale with sandstone beds becoming more abundant near the upper contact, limestone bed 40 feet below contact.	31 feet
Covered interval.	360 feet
Shale, fine grained, dark, limonite stained, with silty shale beds, gypiferous, limestone concretions.	210 feet
Covered interval.	301 feet

Shale, dark grey, weathered, limonite stained, siltstone beds becoming more abundant toward top, 10 foot shaly siltstone at top of 122 foot interval. 122 feet

Unit D7

Grey shale, calcareous in lower part of unit decreasing upward in unit becoming more silty, 2 foot brown limestone at bottom of unit, two one foot limestone beds 180 and 184 feet above base of unit, 1 foot brown silty limestone at top of unit. 852 feet

Unit D6

Grey calcareous shale grading upward to non-calcareous shales, discontinuous siltstone beds less than 2 inches thick in upper half of unit. 796 feet

Unit D5

Light grey calcareous shale with high carbonate content, shales thickly bedded, shaly limestones common, some siltstone bed near base of unit, 40 shaly limestone bed at top of unit. 972 feet

Unit D4

Black shale, weathered, limonite stained, silty, 3 foot platy calcareous sandstone bed 27 feet above base of unit, 4 foot limestone at base of unit. 79 feet

Unit D3

Black weathered carbonaceous shale, silty beds, limonite stained, gypiferous, unit largely covered. 279 feet

Unit D2

Calcareous black shale, limonite stained. 10 feet

Unit D1

Carbonaceous black fissile shale with siltstone beds, some sandstone beds, highly weathered, limonite stained throughout, concretions. 30 feet

Total Mancos Shale 4042 feet

Dakota Sandstone - white crossbedded sandstone with shale and coal interbeds.

The boundaries among the eight units are somewhat subjective because few sharp lithologic boundaries occur within the main body of the Mancos Shale in the Delta section. The units do show, however, a subtle but definite correlation with the Western Interior reference section (Figure 2).

The boundary between the Dakota Sandstone and Unit D1 is gradational. The base of the Mancos Shale was chosen as being the top of the highest massive sandstone in the valley of the Gunnison River. Below the contact the Dakota Sandstone consists of alternating beds of massive sandstone, carbonaceous thinly bedded shales and siltstones, and coal beds.

Unit D1 has not yielded a microfauna nor has there been a report of a macrofauna (Fisher, et al., 1960). The correlation of this unit is conjectural but by stratigraphic position it is correlative with the Graneros Formation.

Above Unit 1 ten feet of platy sandstones with calcareous shales (Unit D2) are exposed containing a Greenhorn planktonic fauna. Although not collected, Gryphaea newberryi has been reported from this horizon (Fisher, et al., 1960). Gryphaea newberryi is generally considered to be of early Turonian age (upper Greenhorn). The upper contact of Unit D2 is questionable because above the ten foot outcrop the Mancos Shale is covered for some stratigraphic distance. The Dakota Sandstone and Units D1 and D2 stratigraphically represent the initial transgression of the Late Cretaceous epicontinental sea.

Unit D3 consists of poorly exposed and highly weathered black carbonaceous shale with some platy sandstones. The upper contact is the base of the 4 foot limestone bed of the overlying unit. The rare occurrence of Prionocyclus hyatti establishes a correlation with the Lower Carlile Formation.

Unit D4 consists essentially of sandy shales somewhat calcareous with some limestone interbeds. The unit grades upward into the grey calcareous shales of the overlying unit. The upper boundary is the base of the grey calcareous shale sequence. Middle Carlile ammonites have been reported from this part of the section (Fisher, et al., 1960). The upper part of this unit stratigraphically marks the beginning of the second transgression of the sea. Consequently Unit D3 and Unit D4 represent the first regression of the sea.

Units D5 and D6 are correlative with the Niobrara Formation. Unit D5 is a monotonous grey calcareous shale which grades up to Unit D6, a calcareous silty shale. The contact between the two units is at the top of the four foot limestone 1370 feet above the base of the Mancos Shale. Above this limestone the formation becomes progressively more silty. Discontinuous thin sandstone beds occur between 1800 and 1950 feet above the base of the formation. Above 1950 feet Unit D6 becomes noncalcareous. Fisher et al. (1960) reports a Niobrara and Eagle macrofauna from this part of the Mancos section. Microfaunally the two units are distinctly different reflecting the second transgressive-regressive cycle in the Western Interior. The Eagle correlative (noncalcareous part of Unit D6) is not microfaunally distinctive.

Unit D7 in the Delta section is a repetitive sequence of Units D5 and D6, but the calcareous lower part of the unit is approximately only 250 feet thick. The bottom of Unit D7 is the base of the two foot limestone bed 2168 feet above the base of the formation. The transitional change from predominantly calcareous shale to predominantly noncalcareous shale is gradational over many feet and no convenient bed occurs which could serve to divide the unit into two. The upper contact is also gradational. It is considered to be the top of the one foot ton limestone 3018 feet above the base of the Mancos Shale. Stratigraphically, Unit D7 represents the third transgressive-regressive cycle in the Western Interior correlative with the lower part of the type Pierre Shale.

Unit D8 is predominantly a grey to black shale sequence with silt- and sandstone beds becoming more abundant upward in the unit. The top of the Mancos Shale is the base of the white massive sandstone (Rollins Sandstone Member). Fisher et al. (1960) report a lower Pierre fauna from Unit D8. Unit D8 represents the continuation of the third and final regression of the Late Cretaceous sea in the Delta area.

The Wolcott Section

The Mancos Shale was measured and sampled in Secs. 4 and 9, T4S, R83W and Sec. 15, 21, and 32, T3S, R83W, Eagle County, Colorado (Figure 1). The base of the section is located approximately one mile northwest of Wolcott, Colorado and shall herein be called the "Wolcott section."

The Wolcott section is located near the southern border of the North Park Basin west of the Front Range Uplift. The section was chosen because it is the eastern most area where the name "Mancos" is applied to Upper Cretaceous marine shales. Sixty miles to the East the Cretaceous strata are exposed in the foothills of the northern Front Range where stratigraphic terminology is similar to the Western Interior reference section (Figure 2).

In the foothills of the northern Front Ranges the Cretaceous sediments above the Dakota Sandstone are collectively termed the Benton Formation. However, it is possible to divide the Benton Formation lithologically into the Mowry, Graneros, and Greenhorn Members (Eicher, 1965). The Mowry Formation is a northern Western Interior formation occurring stratigraphically between the Dakota and Graneros Formations.

The Mancos Shale was measured and sampled on the southeast flank of a northward plunging syncline. The lower part is exposed along the north valley wall of the Eagle River and a small southward flowing tributary. The upper part of the Mancos is exposed on the scarp slopes of cuesta ridges held up by either sandstone or limestone. The Mesaverde(?) Group occurs only as an erosional remnant in the trough of the plunging syncline.

The Wolcott section is lithologically more similar to the Denver Basin stratigraphy than the Piceance Basin stratigraphy. The section can be subdivided into lithologic units which are easily correlated with the stratigraphic sequence east of the Front Range Uplift.

An abbreviated description of the Wolcott section follows. Stratigraphic correlation of each unit is indicated in parentheses.

Mesaverde Group (?)

Tan crossbedded platy sandstone with asymmetrical ripples, siltstone and some shale, lignitic or calcareous.

Mancos Shale

Unit W9

Grey siltstone with some shale beds, silt decreasing downward in unit; one foot fossiliferous limestone 34 feet below top of unit, top 41 feet cliff-forming, weathered with limonite staining. (Pierre correlative) 321 feet

Unit W8

Thinly bedded fine grained quartz five foot sandstone on top of unit forming prominent cuesta, becoming siltstone downward in section, 27 foot thinly bedded sandstone with mold of fossils 46 feet below top of unit, dary grey noncalcareous shale with few thin limestone and siltstone beds, bottom 62 feet of unit alternating beds of calcareous and noncalcareous siltstones containing leaf impressions and molds of bivalves. (Pierre correlative) 689 feet

Covered interval. 290 feet

Unit W7

Black shale, several small tan limestone beds, 1 foot concretion bed 548 feet above base of unit. (Pierre correlative) 638 feet

Unit W6

Dark grey to black calcareous shale. (Pierre correlative) 752 feet

Unit W5

Alternating dark grey calcareous shales, thin limestone beds, and shaly limestones. (Niobrara correlative) 260 feet

Unit W4

Siltstone, calcareous and noncalcareous, thinly bedded with black shale interbeds, 12 foot black shale bed at base, 1 inch bentonite at base. (Carlile correlative) 46 feet

Unit W3

Dark grey calcareous shale and limy mudstones, some limestone beds. (Greenhorn correlative) 104 feet

Unit W2

Black shale with numerous limonite stained thinly bedded siltstones, highly weathered. (Graneros Member of Eicher, 1965) 150 feet

Unit W1

Alternating dark grey siliceous siltstone and shale, fish scales on some bedding plains. (Mowry Shale Member of Eicher, 1965) 40 feet

Total Mancos Shale 3270 feet

Dakota Sandstone

The section measured may not be a complete section of the Mancos Shale. The platy sandstone above Unit W8 is not typical Mesaverde lithology. Normally even the basal sandstones of the Mesaverde Group are massive. Also, the Wolcott section above the Niobrara correlative (Unit W5) is 2695 feet thick. Lovering (1934) reports the Pierre Shale to be 3975 feet thick in an area about 20 miles to the East.

Stratigraphic correlation of the three sections

The three sections of this study can be correlated lithologically and faunally (Figure 2). Although these specific sections have never been correlated previously, correlations have been made by numerous workers on other Mancos sections. The general depositional history of the Western Interior during the Cretaceous has been outlined (Reeside, 1924, 1944, 1957; Cobban and Reeside, 1952; Weimer, 1960).

The Mancos Shale was deposited on the Dakota Sandstone marking the initial deposition of marine shale during the Late Cretaceous. In the south these sediments are correlative with the Graneros Shale of the Great Plains (Unit D1 at Delta and the Graneros Shale member of Lamb (1968) in the San Juan Basin). At Wolcott the Graneros (Unit W2) is underlain by the Mowry Shale correlative (Unit W1 at Wolcott), a northern Western Interior Formation. In all three sections evidence for a decrease in clastic sedimentation rates is shown by the Greenhorn correlative (Units D2 and D3 at Delta; Unit W2 at Wolcott; Unit G1 at Gallup). The lithologies above the Dakota

Sandstone represent the Upper Cenomanian - Lower Turonian transgression (T_1 of Weimer, 1960) (see Figure 2).

The Carlile correlatives (Unit D4 at Delta and Wolcott and Unit G2 at Gallup) represent the Middle Turonian regression of the Western Interior sea (R_1 of Weimer, 1960). At Gallup the shoreline retreated east of the Gallup section (Sears, et al., 1941; Pike, 1947). No marine sediments above the Gallup Sandstone are present in the Gallup section. The Delta and Wolcott area are marked only by an increase in clastic sedimentation with no evidence of a nearby shoreline (Fisher, 1960).

Marine correlatives of the Niobrara Formation are present only in the Delta (Units D5 and D6) and Wolcott (Unit W5) sections. The Niobrara correlative at Delta comprises just under half of the section whereas in Wolcott only 260 feet are correlative with the Niobrara Formation. The thickness of the Niobrara correlative at Wolcott is similar to the Great Plains sequences whereas the Delta area must have been an area of greater basinal subsidence. The Niobrara represents the second transgression (T_2 of Weimer, 1960) occurring during the Coniacian. The lower Campanian regression (R_2 of Weimer, 1960) is represented by the upper part of Unit D6 at Delta and the lower part of Unit W6 at Wolcott.

The lower Pierre Shale (lower-middle Campanian) marks the third transgressive sequence of sediments in the Western Interior. This transgression (T_3 of Weimer,

1960) is represented by Unit D7 at Delta. At Wolcott Units W7, W8, and W9 are repetitive cycles of shale to siltstone to sandstone. They probably represent local sediment supply from a nearby source area masking the fundamental third regression of the Western Interior. The upper part of Unit D7 and all of Unit D8 at Delta is correlative with the middle Pierre upper Campanian regression (T_3 of Weimer, 1960) of the Western Interior sea. At Delta Unit D8 marks the final regression of the sea. The relationship of Units W7, W8, and W9 at Wolcott with the general history of the Western Interior is not well known, but the three units probably represent a single regression correlative to the third regressive sequence at Delta.

PALEONTOLOGY

General Statement

Sixty species of Foraminifera are present in the three sections measured by the writer. The species are not evenly distributed among the three sections or within each of the sections. Of the three sections, the Wolcott section contains the fewest number of species; only twenty-nine are reported. Thirty-one and thirty-five species are reported from the Gallup and Delta sections, respectively. The Gallup section is stratigraphically the thinnest. However it contains a varyed microfauna.

Within each section the calcareous shale beds yielded the most abundant microfaunas. Foraminifera are scarce or absent in the noncalcareous shale and silty shale beds of the Mancos Shale. The microfaunas from the calcareous shale beds are dominated by species of *Hedbergella* and species of *Heterohelix*. Species of Marginotruncanidae occur only in a few tens of feet of section at Delta and Wolcott. Species of *Gavelinella* are more widely distributed stratigraphically than all other species and are less restricted to specific lithologies than planktonic species.

Faunas from correlative strata among the three sections are dissimilar. For example, the benthonic fauna from the Gallup section is more similar to correlative faunas described by Fox (1954) from Wyoming and Young (1951) from Montana than the Delta or Wolcott correlatives and the fauna described by Lamb (1968) from the northern San Juan Basin.

Faunal diversity is low in all samples from the three sections. Faunal diversity is ideally a measure of the number of species occurring on one stratigraphic horizon, a bedding plane. However, most of the samples are ten-foot channel samples. Consequently, faunal diversity in this study refers to the number of species found in a single 500 gram sample. It is thus possible that the faunal diversity of a sample, however low, exceeds the faunal diversity of any bedding plane contained within that sample and is in every case a maximum value.

Faunal dominance is high in all fossiliferous samples of the Mancos Shale. This is expected in faunas showing low faunal diversity (Walton, 1964). The faunal dominance value of a single sample must be a maximum value for any single bedding plane. Because those species that dominate a fauna in one sample occur consistently in many samples, it is reasonable to assume that faunal dominance of a sample is, however, representative.

The Gallup Section

Unit G1 at Gallup contains an abundant foraminiferal fauna. Thirty-one species belonging to eight Families are present in the formation 130 to 300 feet above the base of the formation (Figure 3). Of the thirty-one species, seven are planktonic. The planktonic species dominate the foraminiferal fauna in most samples and swell the foram number to above 500 in several samples. Benthonic species approached equality in abundance only in those samples where Neobulimina canadensis Cushman and Wickenden is present.

Benthonic species are dominated by Neobulimina canadensis and Gavelinella dakotensis (Fox). Gavelinella dakotensis is present in all samples of Unit G1. Its abundance varies from less than one per gram of sample to five per gram of sample. The abundance of all other species of benthonic foraminifera is less than one per gram of sample.

Nodosariidae are the most diverse Family in Unit G1 at Gallup. Thirteen species are recorded but none are common. Lenticulina gaultina (Reuss) occurs throughout Unit G1. Marginulina gallupina n. sp. Hirsch, Frondicularia frontierensis Young, Marginulinopsis amplaspira Young, Saracenaria reesidei Fox, and F. inversa Reuss are present in the lower part of Unit G1. Lenticulina gaultina (Reuss), L. muensteri (Roemer), Dentalina communis (d'Orbigny), D. cf. D. consobrina, Frondicularia inversa Reuss, and Lenticulina muensteri (Roemer) occur rarely at the bottom and near the top of Unit G1.

Species of the Family Anomalinidae are common

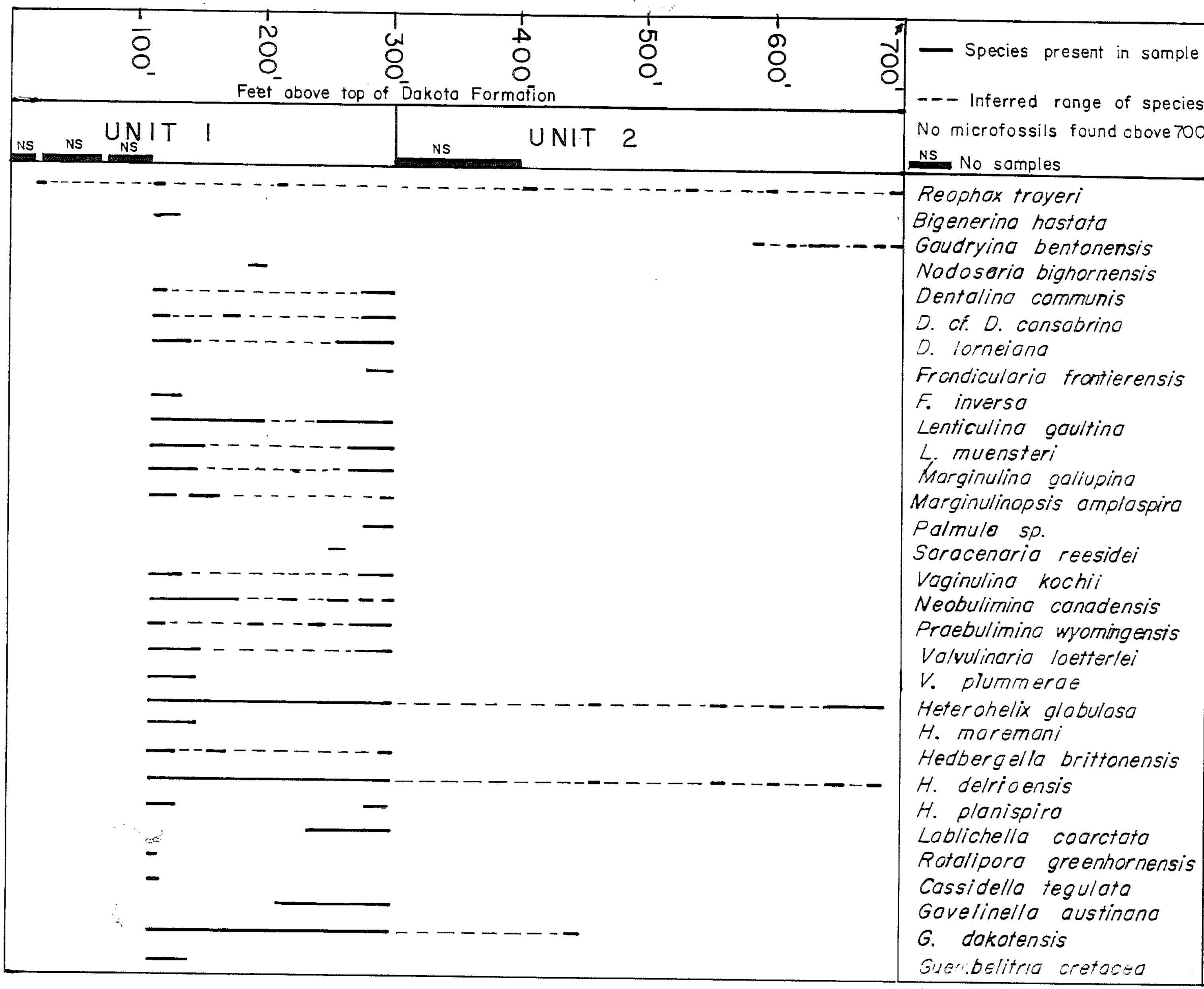

FIGURE 3 STRATIGRAPHIC DISTRIBUTION OF FORAMINIFERA AT GALLUP

throughout Unit G1 at Gallup. Gavelinella bighornensis (Young) occurs rarely but G. dakotensis and G. austinana (Cushman) are common in Unit G1. Gavelinella dakotensis ranges through the unit, whereas G. austinana is common only in the upper part of Unit G1.

Species belonging to the Discorbidae are present only in the lower part of Unit 1. Valvulinaria plummerae Loetterle is restricted to the lower part of Unit 1, whereas V. loetterlei Plummer ranges throughout Unit 1.

When they are present, species belonging to the Turrilinidae dominate the benthonic fauna. Neobulimina canadensis (Cushman and Wickenden) is particularly abundant in the lower part of Unit 1 where it comprises up to forty-two per cent of the foraminiferal fauna. Although the abundance of N. canadensis decreases upward in section, it is restricted to samples containing Heterohelix globulosa. The presence of N. canadensis is not, however, concomitant with every occurrence of Heterohelix globulosa.

The planktonic fauna of Unit 1 at Gallup is dominated by species of Hedbergella, including H. delrioensis (Carsey), H. brittonensis Loeblich and Tappan, H. planispira (Tappan); and species of Heterohelix, including Heterohelix globulosa (Ehrenberg), and H. moremani (Cushman). Hedbergella brittonensis and H. planispira occur near the bottom and near the top of Unit 1 but are absent in the section 180 to 240 feet above the base of the formation. Rotalipora greenhornensis (Morrow) is represented by two specimens in one sample 130 feet above the base of the formation. Loeblichella coarctata Pessagno occurs rarely in the upper part of Unit G1.

Heterohelix globulosa and Hedbergella delrioensis are the most abundant of the planktonic species. Both species are extremely abundant (foram number exceeding 500) in samples from the bottom and the top of the Unit. In the center of Unit G1, 180 to 240 feet above the base of the formation, Foraminifera are reduced in abundance. In this part of the section Heterohelix globulosa dominates the faunas.

Unit G2 at Gallup is distinguishable from Unit G1 both stratigraphically and microfaunally. Unit 2 is essentially devoid of a microfauna. Only a few scattered specimens of Reophax troyeri Tappan, Gaudryina bentonensis (Carman) G. dakotensis and molds of H. cf. H. delrioensis and Heterohelix globulosa are present. In addition there are many distorted, generally flattened, unidentifiable tests that are either crushed rotaloid agglutinated species or crushed molds of rotaloid calcareous species. The abrupt change in character of the microfauna from Unit G1 to Unit G2 is probably due to both an ecological change upward in section and diagenetic destruction of foraminiferal tests.

Unit G2 was measured and samples collected from the cuesta north of the mineshaft. The occurrence of gypsum in vertical joints and along bedding planes mitigates against the occurrence of either a calcareous micro- or macrofauna. In fact, ammonite specimens occurred as molds. Updip outcrop samples of Unit G1 were barren of Foraminifera, whereas the mineshaft samples were all fossiliferous.

Although the absence of a calcareous microfauna in Unit G2 may in part be due to leaching, agglutinated faunas tend to be less effected by leaching. The sparsity of agglutinated Foraminifera is due either to extreme dilution of Foraminifera by rapid sedimentation, to the destruction of the tests during the diagenesis of the Mancos Shale in the Gallup area, or to original paucity of a fauna.

Correlation of the Mancos Shale at Gallup

Because of the diverse benthonic foraminiferal faunas and the occurrence of several planktonic species, the correlation of Unit G1 with the standard section of the Western Interior and the Gulf Coastal Plain standard section is readily determined. The age of Unit G2 must necessarily be inferred by stratigraphic position and macrofaunal correlation.

Floods of *Hedbergella delrioensis*, which occur in samples from Unit G1 at Gallup, is a characteristic feature of the Greenhorn Formation and correlative strata throughout the Western Interior (Morrow, 1934; Loetterle, 1937; Fox, 1954; Loeblich and Tappan, 1961; Eicher, 1965, 1966). The range of H. delrioensis in the Gulf Coast is Cenomanian to Campanian (Pessagno, 1967).

The occurrence of a few specimens of Rotalipora greenhornensis 130 feet above the base of the formation in Unit 1 is significant. The range of R. greenhornensis is restricted to Cenomanian strata in the Gulf Coast (Pessagno, 1967). The species has also been reported from the Greenhorn Formation in Kansas (Loeblich and Tappan, 1961).

The benthonic foraminiferal fauna of Unit G1 indicates a late Cenomanian to early Turonian age for Unit G1. Valvulineria plummerae, Dentalina lorneiana, Frondicularia inversa, and Gavelinella austinana do not occur in strata older than Turonian in the Gulf Coast (Frizzell, 1954). Conversely, Lenticulina gaultina, Vaginulina kochii and Valvulineria loetterlei have not been reported in strata younger than Cenomanian in the Gulf Coast (Frizzell, 1954).

The Delta Section

General Statement

Thirty-five species of Foraminifera are reported from the Delta Section (Figure 4). The distribution of the species among the Units of the section is not uniform. Units D1, D3 and part of D8 are devoid of a microfauna. These three units are silty- and sandy- noncalcareous shales. The calcareous shales (Units D2, D5, D7) of the Delta section contain a microfauna varying in abundance.

Planktonic species, particularly Hedbergella spp. and Heterohelix spp., dominate the faunas. However, planktonic Foraminifera are rare above 2,166 feet. Species of the Genus Gavelinella are the only benthonic foraminifera that consistently occur throughout most of the fossiliferous section. In the uppermost part of the section (Unit D8), agglutinated faunas are common.

The most striking feature of the benthonic fauna is the extremely low faunal diversity in individual samples. Of the twenty-six benthonic species, thirteen are calcareous. The greatest faunal diversity of calcareous benthonic species in a single sample is five near the base of Unit D5. The faunal diversity of agglutinated species is maximum near the top of Unit D8 where six species are recorded from one sample. Generally, the fauna contained in any one sample is dominated by two to three species.

The lowest fossiliferous sample in the Delta section occurs in Unit D2 (Figure 4). Hedbergella delrioensis and Heterohelix globulosa occur abundantly in the calcareous shales of Unit D2. The abundant occurrence of these species in conjunction with its stratigraphic position in section establishes a correlation with the Greenhorn Formation and its correlatives. In addition to the above species a few specimens of the following are recorded:

Reophax troyeri Tappan

Dentalina reflexa Morrow

Gavelinella dakotensis (Fox)

Gavelinella dakotensis and *D. reflexa* are typical Greenhorn species and, although rare, corroborate a correlation with the Greenhorn Formation (Figure 2).

Unit D4 contains a microfauna dominated by crushed agglutinated Foraminifera. Although relatively abundant, the specific identification of these forms is impossible, and generic identification can be questioned. The writer identified them as *Reophax* ? *sp.*, *Ammobaculites* ? *sp.* and *Trochammina* ? *sp.* In the upper part of Unit D4, a few specimens of *Gavelinella kansasensis* (Loetterle) and *Lenticulina kansasensis* (Morrow) were found. Correlation of this Unit on the basis of the microfauna is not justifiable; however, by stratigraphic position and macro-faunal correlation, a Carlile correlation is indicated (Fisher, *et.al.*, 1960).

Unit D5 contains a typical Niobrara fauna dominated by the planktonic species *Hedbergella delrioensis* and *Heterohelix globulosa*. *Hedbergella delrioensis* is not as abundant as it is in the Greenhorn equivalents. From 900 to 980 feet above the base of the formation *Marginorenzi* (Gandolfi), *Archaeoglobigerina bosquiensis* (Pessagno), and *A. cretacea* (d'Orbigny) occur. The occurrence of *M. renzi* and *A. cretacea* is significant because the ranges of these species overlap in the Gulf Coast (Pessagno, 1967).

Pessagno reports the latest occurrence of *M. renzi* to be the top of the Santonian, which is the earliest occurrence of *A. cretacea*.

The occurrence of six of the planktonic species in one sample 900 feet above the base of the formation marks the greatest faunal diversity of planktonic species at Delta. Moreover, the appearance of the species is sudden. Upward in this part of the section the abundance decreases gradually with the disappearance of *M. renzi* above 950 feet.

The following species are restricted to Unit D5.

Dentalina lorneiana d'Orbigny

Lenticulina sublaevis Morrow

Hedbergella planispira (Tappan)

Loeblichella coarctata (Bolli)

Marginotruncana renzi (Gandolfi)

Archaeoglobigerina bosquensis (Pessagno)

Archaeoglobigerina cretacea (d'Orbigny)

Gavelinella kansasensis (Morrow)

The following species occur in Unit 5 but are not restricted to it.

Dentalina lorneiana d'Orbigny

Heterohelix globulosa (Ehrenberg)

Hedbergella delrioensis (Carsey)

Unit 6 contains a unique fauna dominated by *Heterohelix striata*. *Hedbergella delrioensis* occurs rarely throughout the Unit. *Heterohelix globulosa* occurs rarely at the base of the Unit. The occurrence of Heterohelix striata as the dominant species in Unit 6 marks the only occurrence of this species in the sections studied.

Unit 7 at Delta marks a change in the microfauna from a dominantly calcareous to a dominantly agglutinated fauna. Planktonic species occur only at the bottom of the unit and do not appear above 2,166 feet. A few molds of H. globulosa occur in the upper part of Unit 6, but their occurrence along with well preserved G. henbesti suggests the possibility that they were washed into the area rather than be an indigenous part of the fauna. The occurrence of a more varied agglutinated fauna in the upper part of Unit 7 (Figure 4) substantiates this possibility.

Gavelinella henbesti occurs in nearly every sample and is the dominant species. Although the agglutinated fauna is similar to that of Unit 8, species number is extremely low.

The following species are restricted to Unit 7 at Delta (Figure 5).

Bullopora laevis (Solas)
Globogerinelloides prairiehillensis Pessagno
Loxostomum clavatum (Cushman)
Gavelinella henbesti (Plummer)

All of the species except G. prairiehillensis and G. henbesti are long ranging. The oldest reported occurrence of each of these species is Campanian. Therefore, a lower Pierre correlation (Figure 2) is indicated.

With the exception of *Anomalinoides sp.* in one sample, Unit 8 contains an agglutinated fauna.

The following species are restricted to Unit 8.

Haphophragmoides bonanzaensis Stelck and Wall

Thalmannammina sp.

Ammobaculites coprolitheforme (Schwager)

Dorothia bulleta (Carsey)

Anomalinoides sp.

Haplophagnoides rota and *H. bonanzaensis* have been reported by Tappan (1962) from Alaska where they range in age from Turonian to Campanian. Mello (1969) reports them from the upper Pierre Formation (Campanian). The fauna is difficult to correlate because the ranges of all the species are long.

The Wolcott Section

The microfauna contained in the samples from the Wolcott Section is restricted to a few Units of the Section (Figure 5). Units W2, W8 and W9 are barren of Foraminifera. Unit W1 is a silica cemented shale containing fish scales typical of the Mowry Shale further to the north. The samples did not break down and, thus, the presence or absence of Foraminifera could not be determined. Unit W2 was almost completely covered. The samples collected from Unit W2 were highly weathered and yielded no microfossils. Unit 7 contained only a few specimens of Foraminifera. Kent (1967) reports that correlative strata approximately 50 miles west of the Wolcott Section are essentially barren of a microfauna. The only units yielding an abundant foraminiferal fauna at Wolcott are Units W3 and W5, stratigraphically correlative of the Greenhorn and Niobrara Formations, respectively.

Unit W3 yielded a microfauna, typical of the Greenhorn, dominated by *Hedbergella delrioensis* and *Heterohelix globulosa*. *Gavelinella dakotensis* occurs throughout most of the Unit, is the most abundant element of the impoverished benthonic fauna (Figure 5).

The following species are restricted to Unit W3 at Wolcott.

Gavelinella dakotensis (Fox)

Lenticulina gaultina (Berthelin)

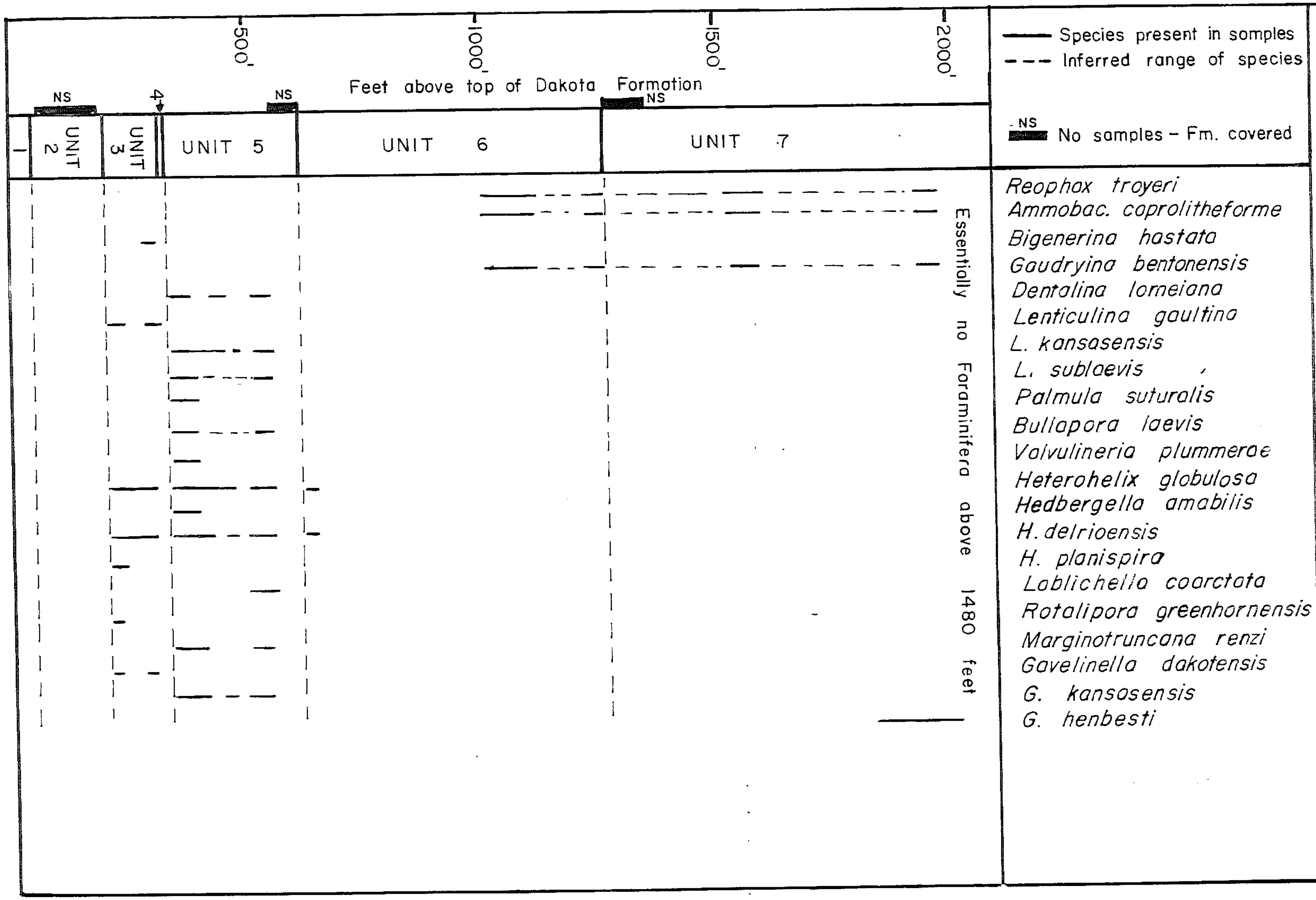

FIGURE 5 STRATIGRAPHIC DISTRIBUTION OF FORAMINIFERA AT WOLCOTT

Hedbergella brittonensis Loeblich and Tappan

Hedbergella planispira (Tappan)

Rotalipora greenhornensis (Morrow)

The following species occur in Unit W2, but are not restricted to the Unit at Wolcott.

Hedbergella delrioensis (Carsey)

Heterohelix globulosa (Ehrenberg)

The species restricted to Unit W3 are typical of Greenhorn faunas reported elsewhere (Figure 2).

Unit W4 yielded a sparse microfauna consisting of a few specimens of Gaudryina bentonensis and Bigenerina hastata. Distorted and crushed, unidentifiable specimens were numerous. By stratigraphic position and lithology, the Unit is correlated with the Carlile Shale (Figure 2).

Unit W5 contains the most diverse foraminiferal fauna and is correlated with the Niobrara Formation.

The species restricted to Unit W5 at Wolcott follow:

Lenticulina muensteri (Romer)

L. sublaevis Morrow

Palmula suturalis (Cushman)

Loeblichella coarctata (Bolli)

Gavelinella kansasensis (Morrow)

With the exception of a few specimens of Foraminifera in Unit W6 (Figure 5), the entire formation above Unit W5 is essentially barren of Foraminifera. Unit W6 contains the following species.

Lenticulina kansasensis Morrow

Bullopora laevis (Solas)

Heterohelix globulosa (Ehrenberg)

Gavelinella henbesti (Plummer)

The occurrence of *G. henbesti* is, however, significant and suggests a correlation with Unit W6 at Delta and the lower Pierre Formation.

Microfaunal Zones

The marine Cretaceous sediments of the Western Interior are characterized by containing a microfauna that is extremely variable. Very often the dominant elements of a fauna are few long ranging species of planktonic Foraminifera, particularly in the Greenhorn and Niobrara equivalent strata. Short-ranging species, such as species of *Rotalipora* are restricted to the southern part of the Western Interior. Species of Marginotruncanidae are likewise restricted (Kent, 1967) and occur in only limited parts of the stratigraphic section.

The only species with a relatively short range that have been reported to occur throughout much of late Cretaceous marine strata are species of *Gavelinella* (Morrow, 1934; Loetterle, 1937; Nauss, 1947; Young, 1950; Fox, 1954; Eicher, 1966; Kent, 1967, 1969; Lamb, 1968; Mello, 1969; this study). Although, it is obviously less desirable to attempt zonation of marine sediments on the basis of benthonic species, the limited occurrence of short-ranging planktonic species necessitates this procedure. Kent (1967) recognized this problem and suggested a Gavelinella Interval for part of the lower Niobrara equivalent in northwestern Colorado.

Five species of Gavelinella have been described in strata from the Western Interior. They are G. dakotensis, G. austinana, G. kansasensis, G. henbesti and G. talaria (Nauss). Although their abundance varies they have been reported in faunas from a variety of lithologies over a large part of the Western Interior.

The difficulty in appraising their value as zone species is the differing opinion of paleontologists of the taxonomic status of these species. Thus Mello (1969) considers G. dakotensis a junior synonym of G. kansasensis. Lamb (1968) considers G. dakotensis a junior synonym of G. austinana. The writer strongly suspects that G. talaria (Nauss) is a junior synonym of G. henbesti. Because primary types of G. talaria were unavailable to the writer, the species is considered valid although its range is similar to G. henbesti. The two species are reported to occur together in the same samples (Kent, 1967). The other four species described in this report have been compared to primary types and are considered valid.

The confusion of their taxonomic status is, in part, due to their morphological similarity. This similarity along with stratigraphic occurrence suggests the possibility that they represent an evolutionary lineage.

In the Mancos Shale the order of stratigraphic occurrence is *G. dakotensis*, *G. austinana*, *G. kansasensis*, *G. henbesti*. Elsewhere, in the Western Interior the previously reported first appearance of each of the species is similar and given below.

Species	Formation or Standard Section equivalent (=)	Author
G. dakotensis	upper Greenhorn (=)	Fox, 1954
G. austinana	upper Greenhorn (=)	Lamb, 1968
G. kansasensis	lower Niobrara	Morrow, 1934
G. henbesti	upper Niobrara (=)	Kent, 1967

The last occurrence of these species reported elsewhere in the Western Interior is given below.

Species	Formation or Standard Section equivalent (=)	Author
G. dakotensis	lower Carlile	Eicher, 1966
G. austinana	upper Greenhorn	Lamb, 1968
*G. kansasensis**	upper Pierre	Mello, 1969
G. henbesti	upper Niobrara	Kent, 1967

*the writer believes *G. kansasensis* Mello not Morrow is *G. henbesti*.

Although this stratigraphic succession and morphological similarity suggest a lineage, the ranges of these species in the Western Interior is still uncertain. Consequently, the writer believes that inclusion into Assemblage Zones rather than Range Zones is warranted.

Gavelinella dakotensis Assemblage Zone

The earliest zone proposed by the writer is the *Gavelinella dakotensis* Assemblage Zone (Table 1). In the sections studied for this report it is best developed in the Gallup section where it comprises all of Unit G1.

The guide fossils for this Assemblage Zone include:

Gavelinella dakotensis (Fox)
Nodosaria bighornensis Young
Frondicularia frontierensis Young
Lenticulina gaultina (Berthelin)
Marginulinopsis amplaspira Young
Saracenaria reesidei Fox
Praebulimina wyomingensis (Fox)
Rotalipora greenhornensis (Morrow)

Hedbergella brittonensis
Gavelinella austinana

All of these species have been reported from Greenhorn equivalent strata elsewhere in the Western Interior (Morrow, 1934; Young, 1950; Fox, 1954; Loeblich and Tappan, 1961; Lamb, 1968). *Gavelinella dakotensis* has been reported to occur in the overlying Carlile Formation (Eicher, 1966). The range of *G. dakotensis* must be considered greater than the limits of the presently defined Assemblage Zone. *Hedbergella brittonensis* has not been reported from elsewhere in the Western Interior because most of the published reports of Greenhorn equivalents predate the

TABLE 1 - SIGNIFICANT SPECIES OF FORAMINIFERA FROM THE ASSEMBLAGE ZONES IN THE MANCOS SHALE

Gd - *Gavelinella dakotensis* Assemblage Zone
Gk - *Gavelinella kansasensis* Assemblage Zone
Gh - *Gavelinella henbesti* Assemblage Zone
Hr - *Haplophragmoides rota* Assemblage Zone

G, D, and W - Occurrence of species in Gallup, Delta, and Wolcott sections, respectively.

E - species reported elsewhere in correlative strata from Western Interior.

Assemblage Zones				
Gd	Gk	Gh	Hr	Significant species
GDWE				*Gavelinella dakotensis*
GE				*Nodosaria bighornensis*
GWE				*Lenticulina gaultina*
GE				*Praebulimina wyominensis*
GWE				*Rotalipora greenhornensis*
GE				*Hedbergella brittonensis*
G				*Gavelinella austinana*
GWDE	WDE			*Hedbergella delrioensis*
GDE	D			*Hedbergella amabilis*
GDE				*Hedbergella planispira*
GDWE	DWE	DWE	E	*Heterohelix globulosa*
GE				*Neobulimina canadensis*
GE	E			*Valvulineria loeterlei*
GE	E			*Valvulineria plummerae*
GE	DE			*Dentalina lorneiana*
	DWE			*Gavelinella kansasensis*
	DW			*Marginotruncana renzi*
	W			*Archaeoglobigerina bosquensis*
	DW			*Archaeoglobigerina cretacea*
	DWE			*Lenticulina kansasensis*
	DWE			*Palmula suturalis*
	DW			*Loblichella coarctata*
		D	D	*Saccammina difflugiformis*
			D	*Ammodiscus cretaceus*
		DWE	DE	*Haplophragmoides rota*
		DWE	DE	*H. bonanzensis*
	DWE	DWE		*Gaudryina bentonensis*
		D		*Praebulimina carseyae*
	D	D		*Heterohelix striata*
		D		*Globo. prariehillensis*
	WE	D		*Gyroidinoides subconicus*
			D	*Coscinophragma codyensis*
	D	D	D	*Spiroplectammina lalickeri*
		DE		*Bullopora laevis*
G			DW	*Reophax troyeri*

recognition of the species.

Gavelinella kansasensis Assemblage Zone

The Gavelinella kansasensis Assemblage Zone is proposed for the lower part of the Niobrara equivalent of the Mancos Shale. It is best developed at the Delta Section where the Assemblage Zone comprises all of Unit D5. Gavelinella kansasensis, Lenticulina kansasensis, Marginotruncana renzi, and Archaeoglobigerina cretacea, are guide species for the Assemblage Zone.

Gavelinella henbesti Assemblage Zone

In the sections studied Gavelinella henbesti is restricted to upper Niobrara and lower Pierre equivalents. It is named for its occurrence in the upper part at Unit D6 and all of Unit D7 at Delta. The species is abundant at Delta and Wolcott where it is the only benthonic species in many samples.

Haplophragnoides rota Assemblage Zone

The Haplophragnoides rota Assemblage Zone is named for the microfauna of Unit D8 at Delta. The zone does not occur at Wolcott.

The naming of an Assemblage Zone that in the present study occurs only in one locality is somewhat risky. Because the species characteristic of this zone are long-ranging, agglutinated species the zone is considered a facies assemblage. The validity of this zone must await further study to verify its usefulness.

EUROPEAN STAGES [a]	GULF COAST STAGES [a]	ASSEMBLAGE ZONES [a]	SUBZONES [a]	MANCOS SHALE ASSEMBLAGE ZONES
NAVARROAN	MAESTRICHTIAN			?
CAMPANIAN	TAYLORAN	*Globotruncana fornicata* — *stuarfiformis*	*Globotruncana elevata*	*Haplophrag. rota* ?
			Archaeoglobigerina blowi	*Gavelinella henbesti*
SANTONIAN	AUSTINAN	*Globotruncana bulloides*	*Globotruncana fornicata*	
			Marginotruncana concavata	*Gavelinella kansasensis*
CONIACIAN		*Marginotrancana renzi*		
TURONIAN	EAGLEFORDIAN	*Marginotruncana helvetica*	*Whiteinella archaeocretacea*	
			Marginotruncana sigali	*Gavelinella dakotensis*
CENOMANIAN		*Rotalipora s.s.*	*Rotalipora cushmani* — *greenhornensis*	
	WOODBINIAN		*Rotalipora evoluta*	

a — after Pessagno, 1967

FIGURE 6 CORRELATION OF ASSEMBLAGE ZONES OF THE MANCOS SHALE WITH ASSEMBLAGE ZONES IN THE GULF COAST

PALEOECOLOGY

The transgressive-regressive nature of Upper Cretaceous strata in the Western Interior is well known. In a more recent review of the stratigraphy, Weimer (1960) shows evidence for four transgressions occurring during the Late Cretaceous. Each of the transgressions is followed by a regression. Stratigraphically, each transgression is represented by a marine shale tongue extending westward between deltaic and non-marine sediments of the Mesa Verde Group. The increase in carbonate content, particularly during Greenhorn and Niobrara equivalent deposition, suggests a decrease in the rate of terrigenous sediment supply. Each regression is marked by an eastward intertongue of Mesa Verde lithology into shale (e.g., the Mancos Shale). Each cycle (transgression-regression) represents a westward then eastward migration of the shoreline (Weimer, 1960).

The foraminiferal faunas of the Mancos Shale and other Western Interior stratigraphic units are different from the faunas of the well known Coastal Plains of the Atlantic and Gulf Coast regions. The features requiring explanation include: 1. the dominance of agglutinated species in parts of each section; 2. the tens of feet of one or more parts of each section barren of Foraminifera;

3. the large number of samples containing a monospecific fauna; 4. the swarms of planktonic Foraminifera in several samples of each section; and 5. the relatively few feet of each section that contain a diversified fauna. These features point to a temporal and spatial complex interrelationship between fauna and environment. The variability of faunal characteristics both between correlative stratigraphic sections and within each section indicate local geographic ecological differences that were rapidly changing with respect to time.

Interpretations of ancient marine environments as old as the Cretaceous have been made by comparison of ancient foraminiferal faunas with modern ones. The environmental control of foraminiferal distribution has been studied in many modern marine environments (Phleger, 1960). Recently, the very comprehensive study of Foraminifera on the Gulf Coast continental shelf has furthered knowledge of foraminiferal ecology (Walton, 1965). Paleoecological interpretation of the foraminiferal faunas from the Mancos Shale must, however, be consistent with stratigraphic interpretation of environment of deposition and depositional history.

Paleoecology of Noncalcareous Shales

Samples containing agglutinated foraminiferal faunas are most abundant in Units D7 and D8 at Delta. Units D1, D3, and D4 at Delta, Unit W6 at Wolcott, and Unit G2 at Gallup contain a sparse agglutinated fauna.

Abundance of Foraminifera and faunal diversity is low in these samples. Generally, the fauna is dominated by one species. The greatest faunal diversity of agglutinated faunas occurs in the upper part of Unit D8 at Delta where one sample contains six agglutinated species and one calcareous species. They are species of the Genera Gaudryina, Ammobaculites, Trochammina, Saccammina, and Haplophragmoides. Species of Gaudryina and Haplophragmoides dominate the fauna. Planktonic Foraminifera are essentially absent in all these samples, although occasional tests occur. The planktonic tests were probably carried into the area and not indigenous to the fauna.

A modern analogue of similar foraminiferal distribution occurs on the continental shelf of the Gulf Coast. At the present time agglutinated faunas are restricted to shallow generally brackish water (Bandy, 1956; Lankford, 1959; Bandy, 1964; Walton, 1964). The general character of the agglutinanted faunas in the Mancos Shale is similar to the Ammobaculites fauna described by Walton (1964) with respect to the faunal diversity of an agglutinated fauna and the dominance of one or two agglutinated species. The Ammobaculites fauna occurs in less than 12 feet of water extending upward to the base of the littoral zone. Significantly, the Ammobaculites fauna is the dominant fauna at the proximal part of the Mississippi delta front on the east, in addition to Mobile Bay and the western half of Chandeleur Sound (Walton, 1964). These are areas of rapid sedimentation. The analogue of deltaic sedimentation, delta front sedimentation, and rapid sedimentation on the continental shelf is identical to the Mesa Verde and Mancos depositional relationships.

Barren samples in the noncalcareous shales are found in all three sections of the Mancos between occurrences of agglutinated faunas. The absence of Foraminifera in these samples can be attributed either to original absence in the sediment or to postdepositional destruction of foraminiferal tests. There is no physical evidence that weathering is any different between fossiliferous and barren strata. The lack of microfossils in some Cretaceous Western Interior shales is common in outcrop as well as in the subsurface (Tappan, 1962). Ammonites have been found by the writer in strata barren of Foraminifera and have been reported from correlative parts of the section (Reeside, 1924; Sears, et.al., 1941; Pike, 1947; Cobban and Reeside, 1952; Fisher, et.al., 1960).

The Units in which samples are commonly barren of Foraminifera but in agglutinated species in other samples are listed below:

Section	Unit
Gallup	G2
Delta	D1, D3, D4, D7, D8
Wolcott	W4, W6, W7

An original absence is suggested for these barren samples. The cause for an original absence could have been ecological controls in a marine environment. Variable temperature and salinity are not likely to have been limiting factors because of the known tolerance of agglutinated species to these factors. Sediment type and sedimentation rates, although effecting the specific composition of a fauna and its abundance must also be discounted (Walton, 1964). Unfavorable water chemistry is also unlikely because macroinvertebrates are well developed in the sandy shales of the Western Interior (Kauffman, 1967; Sohl, 1967). The Mancos Shale contains no pyrite, nor has any been reported elsewhere in the Western Interior. It appears unlikely that the lack of oxygen was a limiting factor. Thus, no ecological cause for the occurrence of these barren samples in the Mancos is apparent.

A common feature of those parts of the sections containing barren samples and agglutinated faunas is the occurrence of plant debris. Although plant debris could have been washed into below sea level sediment the possibility exists that the shale barren of Foraminifera was deposited above mean high water in a coastal marsh. Moreover, if the analogue of the associated agglutinated faunas to a maximum depth of a few fathoms is valid then shallow areas would rapidly be filled to sea level and above, because deltaic deposition must have exceeded subsidence rates where deposition was most rapid.

Subsequent to above mean high water shale deposition a change in depositional patterns in the deltas, perhaps a shift of distributaries, would locally produce an area in which sedimentation rates decreased. Compaction of sediments and basinal subsidence would have lowered the area below mean high water and agglutinated faunas would have become re-established. Atchafalaya Bay, Breton Sound, and Chandeleur Sound on the eastern and western margins of the Mississippi delta were above sea level previously and an analogue to the Mancos appears likely.

Because distributaries could again have shifted back to the same area, as is the case of the present Mississippi delta, rapid sedimentation could again have filled the area to above mean high water. The occurrence of barren samples among samples containing agglutinated faunas is more readily explained by delta and delta margin sedimentation than by imposition of some unexplainable ecological control. Storms accompanied by abnormal high tides could easily have carried ammonites shells and other macroinvertebrates to an above mean high tide elevation.

In some parts of the sections surface weathering has clearly affected some samples high in the Mancos section. Gypsum occurs in vertical joints in the upper parts of Unit G2 at Gallup and Units W6, W7, W8, and W9 at Wolcott. Because weathering is evident here a calcareous microfauna, if originally present, would have been destroyed and an agglutinated fauna would have been less effected. Because of their stratigraphic position high in the Mancos just below the deltaic sands of the Mesa

Verde, their interpretation as in part above sea level sediments is reasonable.

Paleoecology of Calcareous Shales

Parts of the Mancos Shale between the noncalcareous shales are characteristically calcareous with a few limestone beds or lenses. These parts of the sections basically reflect a decrease in rate of terrigenous sedimentation. They are correlative with the Greenhorn, the Niobrara, and to a lesser extent the Lower Pierre Formations (Figure 2). The Greenhorn equivalents include Unit D2 at Delta, Unit G1 at Gallup, and Unit W3 at Wolcott. The Niobrara equivalents include Units D5 and D6 at Delta and Unit W5 at Wolcott. The lower Pierre equivalents include D7 at Delta.

Microfaunally the calcareous shales of the Mancos contain faunas that show maximum diversity of calcareous benthonic species for the Mancos and faunas that are mostly or entirely planktonic. These faunas are typical of foraminiferal faunas in Greenhorn and Niobrara correlatives in the Western Interior (Morrow, 1934; Loetterle, 1937; Fox, 1954; Eicher, 1967; Lamb, 1968). The increase in faunal diversity upward in section from near shore sediments indicates a transgression of the sea (Walton, 1964). Conversely, a decrease of faunal diversity and planktonic Foraminifera upward in section indicates a regression of the sea (Walton, 1964). On the basis of a change from agglutinated faunas or barren shale to diversified calcareous faunas with planktonic transgression of the sea is microfaunally evident in the Greenhorn correlative of the Mancos at Delta, Gallup, and Wolcott; the Niobrara equivalent at Delta and Wolcott; and the lower Pierre correlative at Delta.

The planktonic ratios are high for most samples in the calcareous parts of the Mancos Shale. Many samples in the Greenhorn and Niobrara equivalents contain only planktonic Foraminifera. The ratio decreases to a minimum of approximately one when species of Buliminacea are abundant. Neobulimina canadensis comprises 42% of the fauna in one sample of Greenhorn equivalent at Gallup. Praebulimina carseyae comprises 52% of the fauna in one sample of the Niobrara correlative at Delta. A modern foraminiferal analogue based upon planktonic benthonic ratios occurs on the upper continental slope (Phleger, 1960).

Faunal diversity of planktonic species is low in the Mancos. Planktonic faunas are dominated by Hedbergella, primarily H. delrioensis, and Heterohelix, primarily H. globulosa. Rotalipora greenhornensis is rare in the Greenhorn correlative at Gallup and absent at Delta and Wolcott. Marginotruncanidae and Globotruncanidae are restricted to a few feet of section in the Niobrara equivalent at Delta and Wolcott. An abundance and diversity of planktonic Foraminifera similar to the Mancos has been recorded elsewhere in the Western Interior

(Morrow, 1934; Loetterle, 1937; Fox, 1954; Eicher, 1965).

The abundance of modern planktonic Foraminifera in sediments is dependent upon the amount of sediment dilution on the continental shelf and slope of the Gulf of Mexico and is independent of the depth of water (Walton, 1964). The Holocene species _Globigernoides ruber_ appears in sediments as shallow as 70 feet and is the dominant species to the edge of the continental shelf (Bandy, 1956). Phleger (1960) shows that _G. ruber_ is the dominant planktonic species in depths less than 300 feet on the western continental shelf of the Gulf of Mexico. Thus the faunal dominance of planktonic species in the Mancos Shale suggests shallow shelf conditions irrespective of abundance rather than deep water as concluded from planktonic - benthonic ratios.

The largest number of benthonic species occurring in one sample (faunal diversity) of Mancos Shale is thirteen in the Greenhorn equivalent at Gallup, nine in the Niobrara equivalent at Delta, and six in the Pierre equivalent at Delta. Furthermore, faunal dominance is high. At Gallup _Gavelinella dakotensis_ and _Neobulimina canadensis_ are the dominant species. _Gavelinella kansasensis_ and _Praebulimina carseyae_, if present, are dominant benthonic calcareous species in the Niobrara correlative. _Gavelinella henbesti_ is dominant in the Pierre equivalent at Delta.

Faunal diversity of benthonic species in the Mancos Shale is not significantly different from correlative sections in other areas. Fox (1954) shows a maximum diversity of 14 and 13 species from the Greenhorn and Niobrara equivalents of the Cody Shale, respectively. Kent (1967) shows a maximum of 21 species from the Niobrara equivalent in northwestern Colorado. Lamb (1968) shows a maximum of 16 species from the Greenhorn member and 14 species from the Niobrara member in the northern San Juan Basin. Morrow (1934) found only one benthonic species in the Greenhorn Formation in Kansas. Six species are most common in the Fort Hays Member of the Niobrara Formation in Kansas (Loetterle, 1937). Foraminiferal faunas consisting of less than thirty species are restricted to a depth of less than 120 feet (Walton, 1964). Benthonic faunal diversity suggests inner neritic depths.

The strict application of these uniformatarian analogues of modern foraminiferal faunas to Mancos Shale faunas yields conflicting interpretations of the paleobathymetry of the transgressive phases of the Mancos Shale. Planktonic-benthonic ratios suggests a minimum depth of 300 feet. Benthonic faunal diversity and dominance suggests depth of water of less than 120 feet. Planktonic faunal diversity and dominance suggest a depth of water between 120 and 300 feet.

The planktonic-benthonic ratios have been made on the basis that the Heterohelicidae are planktonic. The Heterohelicidae are extinct and some species may have been benthonic or were neritopelagic mostly rather than true oceanic. If this is the case, then planktonic-benthonic ratios determined by the writer and others (Eicher, 1969; Kent, 1967, 1969) are too high and the interpreted depths too great. In many samples in Unit G1 at Gallup, Units D3, D5, D6, and D7 at Delta, and Units W3 and W5 at Wolcott specimens of Heterohelicidae are more abundant than specimens of species of Hedbergella. Thus the minimum depth of water based upon planktonic-benthonic ratios would be less than a minimum of 300 feet.

Bandy (1964) has shown a correlation between the environment in which modern Foraminifera live and their morphology. The dominant calcareous benthonic species occurring in the Mancos Shale are species of Gavelinella, Neobulimina canadensis, and Praebulimina carseyae. All other species of calcareous benthonic species, excepting the Heterohelicidae, are rare.

The species of Gavelinella all have compressed tests with angled peripheries. Bandy (1964) shows rotalid species with sharp edges to be characteristic of the Reuss shelf environment. The typical Genus is Hanzawaia. Hanzawaia strattoni comprises 55 per cent of the benthonic fauna in Mobile Bay at a depth of less than 80 feet (Bandy, 1956, chart 3). In all five sampling transverses on the eastern shelf of the Gulf of Mexico H. strattoni and H. concentrica are most abundant at depths above 120 feet and decrease markedly below that depth (Bandy, 1956). The analogue of species of Gavelinella in the Mancos

Shale suggests inner shelf depths.

Neobulimina canadensis and *P. carseyae* are extremely small, smooth-walled species. Small unornamented buliminids characteristically occur in bay and the inner shelf (Bandy, 1964). Bandy considers buliminid morphology to be an excellent indicator of environment. The abundant occurrence of *N. canadensis* in the Greenhorn equivalent and *P. carseyae* in the Niobrara equivalent strongly suggest inner shelf depths as the maximum depth of water for the Mancos Shale.

The abundant occurrence of planktonic Foraminifera in the calcareous parts of the Mancos Shale is difficult to assess in terms of inner shelf depths. However, except for a few specimens of *Rotalipora greenhornensis* in the Greenhorn equivalent and a few tens of feet of section in which Marginotruncanidae occur in the lower part of the Niobrara equivalent at Delta and Wolcott, planktonic Foraminifera are limited in diversity. Species of *Hedbergella* dominate the planktonic fauna if the Heterohelicidae are considered benthonic. The limited diversity of planktonic species suggest shelf depths.

The paleoecology of Cretaceous planktonic Foraminifera is not known very well. Olsson (1969) considers the secondary thickening of tests of Cenozoic Globigerinacea to be an adaptation for a more efficient use of the water column. Thus, thin-walled Cretaceous planktonic species of *Hedbergella* may have been restricted to an upper, thin column of water and have been more abundant in shelf waters than modern planktonic species.

The diversity of benthonic species is less than the diversity of Foraminifera reported from the Gulf Coast. The low diversity of benthonic Foraminifera is similar to the diversity of Western Interior macroinvertebrate faunas. The only common invertebrates are epifaunal gastropods and bivalves and ammonites (Cobban and Reeside, 1952; Kauffman, 1967; Sohl, 1967). Other invertebrate groups commonly associated with Cretaceous mollusks in the Gulf Coast are essentially absent. The benthonic mollusks are themselves restricted faunas (Kauffman, 1967; Sohl, 1967), whereas planktonic ammonites are abundant and varied, a situation crudely analogous to benthonic and planktonic foraminiferal faunas from the Mancos.

The cause of low diversity invertebrate faunas in the calcareous shales is perplexing. Variable salinity of the water is probably not the cause, because planktonic species were probably as stenohyaline in the Cretaceous as they are today. Unfavorable water chemistry would have effected planktonic species as well as benthonic species. Abundant inoceramid prisms throughout the Western Interior infer a pH above seven. The lack of pyrite within the Mancos Shale suggests sufficient oxygen at the water-sediment interface. Low water temperature may have restricted the geographic distribution of some species of planktonic Foraminifera (Kent, 1969; Eicher, verbal communication) but the low diversity of benthonic species cannot be attributed to cool water. Restricted benthonic macroinvertebrate assemblages have been attributed to a soft smothering substrate by Hattin (1965), Kauffman (1967), and Sohl (1967). The effect on foraminiferal assemblages is difficult to evaluate because modern Foraminifera are not known to be restricted by soft substrate.

Because the bivalves and benthonic Foraminifera are primary consumers, the reason for the restriction of the benthonic biota is probably the same for all groups. Gastropods are not as abundant as they are on the Gulf Coast but most taxonomic groups are represented in the Western Interior (Sohl, 1967). The single exception is the Archaeogastropoda which are essentially absent throughout the Western Interior (Sohl, 1967). The near absence of this group may be significant because Archaeogastropoda are the only group of gastropods that are typically algal grazers and a scarcity of bottom algae is inferred. If bottom algae were indeed scarse then all of the benthonic biota, including Foraminifera, would be restricted and probably show a low faunal diversity. On the other hand, abundant planktonic Foraminifera are dependent upon floating algae and their abundance would not be restricted by low productivity near the bottom of the sea.

In summary, morphoecological comparisons of the abundant benthonic species, the benthonic faunal diversity, and planktonic foraminiferal abundance suggest a depth of less than 200 feet. The assumptions that the Heterohelicidae are benthonic or only partially planktonic and that planktonic Foraminifera could thrive in a thin column of water are consistent with this interpretation. Paleoecological analysis of gastropods (Sohl, 1967) and bivalve (Kauffman, 1967) also agree with the interpretation of the paleobathymmetry.

Lithologic analysis of the calcareous facies of the Western Interior corroborates a shallow depth. The origin of calcite in the Mancos, as well as correlative sediments, could have been calcareous algae or comminuted pelecypod valves, probably inoceramids. Inoceramids are all considered to be shelf bivalves (Kauffman, 1967). Sand-size inoceramid prisms were recognized in residues and have been reported by others. Furthermore, discontinuous calcarenite lenses occur in the Niobrara equivalent at Delta and Wolcott. The comminutation of inoceramid valves or the growth of algae is limited to shallow water. Subsequent to destruction of the inoderamids at or above the general wave base and the death of algae, traction currents or wave action dispersed them. There is no evidence of transport by turbidity currents. The depth to which sand-sized calcite could be dispersed by currents and storm waves is the maximum depth of water in the Mancos sea. In the Gulf of Mexico sand dispersal is essentially restricted to the shelf (Curray, 1960). The effect of the surge of hurricane waves is reworking of sediments unless unidirectional currents are superimposed, in which case, short-distance net transport occurs (Curray, 1960).

Furthermore, lithologic evidence from the Greenhorn Formation in Kansas corroborates shallow shelf conditions during carbonate deposition. Hattin (1965) reports the presence of cross-bedded calcarenite lenses, isolated *Inoceramus* fragments, and overturned adult *Inoceramus* specimens with epifaunal *Ostrea* attached to both valves, which he attributes overturning by storm waves. It is doubtful whether storm waves could overturn 100 mm bivalves or fragment bivalves at depths below 200 feet. Hattin (1965) suggests shallow shelf depths for the Greenhorn Formation in Kansas.

SUMMARY

Three sections of Mancos Shale in Colorado and New Mexico were measured and correlated with the Standard Section in the Western Interior. Samples collected from these sections were examined for their foraminiferal content. The faunal diversity of the fauna is low in all parts of the measured sections. The noncalcareous shale units within the three sections are either barren or contain a sparse agglutinated microfauna with few, if any, calcareous benthonic species. The calcareous shale units within the three sections contain a foraminiferal fauna consisting of a low number of calcareous species and are often dominated by a few species of planktonic Foraminifera, Hedbergella delrioensis and Heterohelix globulosa. Other planktonic species are restricted to limited parts of the section. Species of Gavelinella are most widespread of all species both stratigraphically and geographically.

The foraminiferal faunas within the three sections are similar to microfaunas previously described from the Western Interior, Alberta, the North Slope of Alaska, and the Gulf Coast. Correlation of the Greenhorn and Niobrara equivalents of the Mancos Shale is made and augments the study of Foraminifera through the Western Interior.

Because the noncalcareous shales of the Mancos Formation are less fossiliferous and, in addition, contain a dominant, generally long-ranging, agglutinated microfauna, foraminiferal correlation with the Graneros, Carlile, and Pierre equivalents is less certain.

The writer proposes four biostratigraphic zones. In order of stratigraphic occurrence they are the *Gavelinella dakotensis* Assemblage Zone, the *Gavelinella kansasensis* Assemblage Zone, the *Gavelinella henbesti* Assemblage Zone, and the *Haplophragmoides rota* Assemblage Zone. Among the three sections, *Gavelinella dakotensis* Assemblage Zone is recognized in all sections of the Mancos Shale. The *Gavelinella kansasensis* and the *Gavelinella henbesti* Assemblage Zones are recognized only at Delta and Wolcott because the top of the formation at Gallup is older than the *Gavelinella kansasensis* Assemblage Zone. The *Haplophragmoides rota* Assemblage Zone is recognized only at Delta and is probably a facies zone. The correlation of these zones has been made with the Standard Sections of the Western Interior and the Gulf Coast. The *Gavelinella* zones are probably of correlative value within the Western Interior.

Valid environmental analysis of a marine formation is dependent upon interpretation of the physical stratigraphy as well as the contained macro- and microfaunas. Paleoecological conclusions in this report are based primarily upon foraminiferal, lithologic, and stratigraphic analysis. Interpretations of bivalve and gastropod paleoecology are also considered.

In all three sections the Mancos Shale conformably overlies the Dakota Formation and is in turn conformably overlain by the Mesa Verde Formation. The Dakota and Mesa Verde Formations are marginal marine deposits. Within the Mancos Shale changes in texture and composition (calcareous and noncalcareous) reflect the lithologies of the Western Interior Standard and the transgressions and regressions occurring during the Late Cretaceous.

The noncalcareous shales and sandy shales of the Mancos Formation yield sparse agglutinated faunas or are barren. The evidence suggests the faunas to have a modern analogue in delta front areas. Moreover, the occurrence of these faunas in the regressive parts of the Mancos Shale and the facies relationship of this formation with the deltaic Mesa Verde Formation corroborates this conclusion. The faunal diversity and composition of the agglutinated faunas suggest a depth of water of less than twenty feet and variable, severely limiting environmental conditions associated with modern deltas. Variable salinity is considered the limiting factor most responsible for the lack of an appreciable number of calcareous species.

The occurrence of barren samples among those containing agglutinated faunas suggest that parts of the Mancos Shale were deposited above mean high water on a deltaic plain. This interpretation is consistent with the Mississippi delta analogue where sedimentation rates exceed subsidence rates in parts of the delta front.

The calcareous shale Greenhorn and Niobrara equivalents of the Mancos Shale lithologically represent times of maximum extent of the Late Cretaceous seas; times of minimum influx of terrigenous sediments; and times of greatest depth. The analogue of faunal diversity of the benthonic species suggest an inner shelf depths for the Mancos sea similar to Chandeleur Sound east of the Mississippi delta. The abundant benthonic species of the Genera, Gavelinella, Neobulimina, and Praebulimina are morphologically similar to inner shelf species living today. Species of living Hanzawaia are similar to species of Gavelinella from the Mancos Shale. Mancos Shale buliminids are small, unornamented species similar to those found in modern shelves in shallow water.

It is suggested that some species of Heterohelix may have been benthonic or neritoplanktonic rather than true oceanic. If this is the case then planktonic-benthonic ratios would also be consistent with a shelf interpretation. Furthermore, the abundant thin-shell species of Hedbergella may have required only a thin upper column of water.

Paleoecologic interpretation is consistent with the paleoenvironmental analysis of the bivalves (Kauffman, 1967) and gastropods (Sohl, 1967). The low diversity of macro- and microinvertebrate benthonic assemblages is considered to be caused by low productivity at the bottom.

Lithologic analysis of the calcareous shales of the Mancos Formation and correlative units in the Great Plains is consistent with a shelf interpretation for the Mancos Shale.

SYSTEMATIC PALEONTOLOGY

Species of foraminifera described in this paper follow the classification of Loeblich and Tappan (1964) except for planktonic Foraminifera. Planktonic foraminifera are classified according to the classification of planktonic Foraminifera proposed by Pessagno (1967).

Figured specimens are in the writer's personal collection.

Order	FORAMINIFERIDA	Eichwald, 1839
Suborder	TEXTULARINNA	Delage and Herouard, 1896
Family	SACCAMMINIDAE	Brady, 1884
Genus	SACCAMMINA	M. Sars, 1869

Saccammina difflugiformis (Brady)

Plate 1, figure 12.

Reophax difflugiformis Brady, 1879, Quart. Jour. Micro. Sci., new. ser., vol. 19, p. 51, pl. 4, figs. 3a-b.

Proteonina difflugiformis Brady - Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 15, pl. 1, figs. 1,2.

Remarks. - *Saccammina difflugiformis* is characterized by an inflated pyriform test with a distinct neck. It differs from *S. lathrami* Tappan which is flattened.

Figured hypotype: Maximum Diameter 0.53 mm; length 0.88.

Occurrence. - Cushman reports the restriction of S. difflugiformis to Navarroan strata. Saccammina difflugiformis occurs rarely in the upper part of Unit D7 and throughout D8 at Delta. The presence of the species in the Haplophragmoides rota Assemblage Zone at Delta indicates an earlier appearance of the species in the Western Interior than has been reported from the Gulf Coast.

Family AMMODISCIDAE Reuss, 1862

Genus AMMODISCUS Reuss, 1862

Ammodiscus cretaceus (Reuss)

Plate 1, figure 14.

Operculina cretacea Reuss, 1845, Versteinerung boehm. Kreideformation, pt. 1, p. 35, pl. 13, figs. 64,65.

Ammodiscus cretaceus Reuss - Cushman, 1934, Cush. Lab. Foram. Res. Contr., vol. 20, pt. 2, p. 2, pl. 1, fig. 2.

Cushman, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 17, pl. 1, fig. 35.

Tappan, 1962, U. S. Geol. Survey, Prof. Paper 236-C, p. 130, pl. 30, figs. 1-2.

Remarks. - Ammodiscus cretaceus is characterized by a large number of volutions each of which overlap previous volutions.

Figured hypotype: Diameter 0.80 mm.

Occurrence. - Ammodiscus cretaceus is a long ranging species in the Cretaceous. The species ranges through the Upper Cretaceous strata in the Gulf Coast but perhaps more significantly it has been found only in Campanian strata in Canada (Wickenden, 1945) and Alaska (Tappan, 1962). In the Mancos Shale A. cretaceus occurs only in Unit D8 at Delta in the Haplophragmoides rota Assemblage Zone. This suggests that it may be of limited correlative value in this area.

Family HORMOSINIDAE Haeckel, 1894

Genus REOPHAX Montfort, 1808

Reophax troyeri Tappan

Plate 1, figures 1,8.

Reophax troyeri Tappan, 1960, Amer. Assoc. Petroleum Geol. Bull., vol. 44, no. 3, p. 291, pl. 1, figs. 10-12.

________, 1962, U. S. Geol. Survey Prof. Paper 236-C, p. 133, pl. 30, figs. 11-13.

Remarks. - Reophax troyeri is characterized by spherical chambers and an aperture produced on a short neck. Crushed specimens identical to those figured by Tappan (1962) occur sporadically throughout the Mancos Shale at Gallup, Delta, and Wolcott. The few uncrushed specimens are identical to the primary types.

Reophax troyeri differs from R. texanus Cushman and Waters by having a short neck.

Figured hypotype: (Plate 1, figure 1), Length 1.10 mm; Diameter of last chamber 0.32 mm. (Plate 1, figure 8), Length 0.53 mm; Diameter of last chamber 0.17 mm.

Occurrence. - Tappan (1960) described the species from the lower Cretaceous of Alaska. Reophax troyeri occurs rarely in Units D1, D3, D7, and D8 at Delta and Units W6 and W7 at Wolcott. The occurrence of R. troyeri in the Haplophragmoides rota Assemblage Zone extends the range to Campanian.

Family LITUOLIDAE de Bainville, 1825

Genus HAPLOPHRAGMOIDES Cushman, 1910

Haplophragmoides bonanzaensis Stelck and Wall

Plate 3, figures 6-7.

Haplophragmoides bonanzaensis Stelck and Wall, 1954, Res. Council Alberta Rept. 68, p. 24, pl. 2, fig. 10.

Haplophragmoides bonanzaensis Stelck and Wall - Tappan, 1962, U. S. Geol. Survey Prof. Paper 236-C, p. 133, figs. 16-19.

Remarks. - Haplophragmoides bonanzaensis is characterized by 6-7 chambers in the final whorl and by wide chambers resulting in a broadly rounded inflated test.

Haplophragmoides bonanzaensis differs from H. rota Nauss, with which it is associated, by the fewer number of chambers in the final whorl, its smaller size, and by the absence of an angled periphery. Crushed specimens of *H. rota* and *H. bonanzaensis* are difficult to distinguish from one another. The writer differentiated them on a basis of the number of chambers in the final whorl.

Figured hypotype: Greatest diameter 0.40 mm; thickness 0.28 mm.

Occurrence. - *Haplophragmoides bonanzaensis* occurs in the *Haplophragmoides rota* Assemblage Zone Unit D8 at Delta. It is not so abundant as *H. rota* nor does it occur in as many samples. Originally it was described from the Turonian in Alberta (Stelck and Wall, 1954). Tappan (1962) reports the range to be Turonian through Campanian on the Alaskan Coastal Plain.

Haplophragmoides rota Nauss

Plate 1, figures 6-7, 10, 15-16.

Haplophragmoides rota Nauss, 1947, Jour. Paleon., vol. 21, no. 4, p. 339, pl. 49, figs. 1a-b.

Tappan, 1962, U. S. Geol. Survey Prof. Paper 236-C, p. 134, pl. 31, figs. 16-18.

Remarks. - *Haplophragmoides rota* is characterized by a compressed test with slightly angled periphery, seven to nine chambers in the last whorl, and a small shallow umbilicus on both sides.

Haplophragmoides rota differs from *H. bonanzaensis* Stelck and Wall by its larger size and more compressed test.

Figured hypotypes: (Plate 1, figures 6-7), Greatest diameter 0.87 mm; thickness 0.13 mm. (Plate 1, figures 15-16), Greatest diameter 0.60 mm; thickness 0.10 mm.

Occurrence. - *Haplophragmoides rota*, although not the most abundant species in many samples in the highest part of the Mancos Shale, is consistently found beginning 2440 feet above the base of the formation at Delta in Units D7 and D8. It therefore is selected as the species designating the youngest Assemblage Zone of the Mancos Shale.

Haplophragmoides rota was originally described from the Bearpaw Formation in Alberta (Nauss, 1947). Tappan (1962) found the species to be restricted to the Barrow Trail and Sentinel Hill Members of the Campanian Shrader Bluff Formation. The present known range of this boreal species is restricted to Campanian strata.

Genus THALMANNAMMINA Porkorny, 1951

Thalmannammina sp.

Plate 1, figure 17; Plate 2, figures 1-2.

Trochammina sp. Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 51, pl. 15, figs. 14a-b.

Remarks. - Test free, subglobular; coiling strepto-spiral in adult whorls, possibly planispiral involute in juvenile whorls, five to six chambers visible, earlier chambers not visible on spiral side; umbilicus tiny with three to three and one-half chambers visible on umbilical side; chambers uninflated in early chambers of last whorl becoming regularly more inflated in later chambers, sub-globular about two times wider than long, increasing rapidly in size and enveloping earlier chambers, the last chamber comprising about one-third of the maximum diameter of the test; sutures straight, flush between first chambers of last whorl, becoming depressed between later chambers; wall agglutinated with grain size varying from fine to coarse on different specimens; aperture not distinctly visible on most specimens but apparently an interiomarginal slit umbilical-extraumbilical in position with an indication on one specimen (pl. 1, fig.17) that an apertural lip may have been present.

The species is represented by fourteen specimens from one sample of the Mancos Shale 3664 to 3674 feet above the base of the section at Delta.

Thalmannammina sp. is different from any species known to the writer. Cushman's Trochammina sp. appears to belong to this species.

The species has been assigned to the genus Thalmannimmina on the basis of adult morphology. A juvenile specimen (small figured specimen) shows most of the test to be planispiral involute and not streptospiral throughout. The presence of this species in the Mancos Shale changes the reported first appearance of the genus from Eocene (Loeblich and Tappan, 1964) to upper Cretaceous.

Figured specimen: (Plate 2, figures 1-2), Maximum diameter 0.63 mm; Minimum diameter 0.50 mm.

Figured specimen: (Plate 1, figure 17), Maximum diameter 0.53 mm; Minimum diameter 0.45 mm.

Occurrence. - *Thalmannimmina* sp. occurs in only one sample 440 below the top of the section in Unit D8 at Delta in the upper part of the *Haplophragmoides rota* Assemblage Zone.

Genus COSCINOPHRAGMA Thalmann, 1951

Coscinophragma codyensis (Fox)

Polyphragma codyensis Fox, 1954, U. S. Geol. Survey Prof. Paper 254-E, p. 113, pl. 25, figs. 1-4.

Clavulina? sp. Wickenden, 1932, Jour. Pal., vol. 6, p. 205, pl. 29, fig. 5.

Polyphragma sp. Cushman, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 15, pl. 15, figs. 15, 16.

Remarks. - Specimens are identical with the primary types. *Coscinophragma codyensis* is characterized by its large size, its cylindrical form, and its uniformly inflated chambers.

Hypotype: Maximum length 1.20 mm; width 0.70 mm.

Occurrence. - In the Mancos Shale *C. codyensis* occurs rarely in the *Gavelinella kansasensis* Assemblage Zone at Delta. This is the same stratigraphic horizon as reported by Fox (1954). The common occurrence of this species in Niobrara equivalent strata in parts of the Western Interior and in Canada led to its consideration as a possible zonal fossil (Fox, 1954). Its occurrence in the Mancos Shale fauna does not support this possibility. It is not found in the Wolcott section.

Genus AMMOBACULITES Cushman, 1910

Ammobaculites coprolithiforme (Schwager)

Haplophragmium coprolithiforme Schwager, 1868, Benecke's Geogn. palent. Beitrage, vol. 1, p. 654, fig. 3.

Ammobaculites coprolithiforme Schwager - Cushman, 1927, Royal Soc. Can. Trans., 3rd Ser., vol. 21, p. 130, pl. 1, figs. 6,7.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 22, pl. 3, figs. 7-9.

Remarks. - Numerous specimens of *Ammobaculites* are present in the Mancos Shale. Most are crushed. Those not crushed are identical with forms identified by Cushman (1927, 1946). Consequently, the writer has provisionally referred all specimens of *Ammobaculites* to *A. coprolithiforme*.

Maximum length 0.80 mm; maximum width 0.32 mm; maximum thickness 0.16 mm.

Occurrence. - *Ammobaculites coprolithiforme* has been reported throughout the Upper Cretaceous in the Gulf Coast. In the Mancos Shale the species is present in the silty and sandy parts of the Mancos Shale in Units D1, D3, D6, D7, D8 at Delta and Units W6 and W7 at Wolcott.

Genus FLABELLAMMINA Cushman, 1928

Flabellammina compressa (Beissel)

Plate 1, figures 2, 9.

Haplophragmium compressum Beissel, 1891, Preus. geol. Landesanstalt Abh., new ser., vol. 3, p. 16, pl. 4, figs. 11-23.

Flabellammina compressa Beissel - Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 25, pl. 4, figs. 3-6.

Remarks. - *Flabellammina compressa* is characterized by a strongly compressed test, distinctly depressed sutures, and few chambers in the uncoiled portion of the test.

Figured hypotype: (Plate 1, figure 2), Length 2.1 mm; maximum diameter 1.0 mm. (Plate 1, figure 9), Length 1.2 mm; maximum diameter 0.50 mm.

Occurrence. - A few specimens of *F. compressa* occur near the top of Unit D7 and in Unit D8 at Delta. It has previously been reported from Tayloran strata in the Gulf Coast (Cushman, 1946). In the Western Interior it has been reported from the Niobrara equivalents of the Cody Shale in Wyoming (Fox, 1939). Fox (1939) considers the species to be a guide for the Cody Shale. However, the few specimens that have been found in the Mancos Shale occur stratigraphically higher. Consequently, in the Western Interior the range appears greater than previously reported by Fox.

Family TEXTULARIDAE Ehrenberg, 1838

Genus SPIROPLECTAMMINA Cushman, 1927

Spiroplectammina lalickeri Albritton and Phleger
Plate 1, figure 5.

Spiroplectammina lalickeri Albritton and Phleger, 1937, Jour. Paleontology, vol. 11, p. 353, text. figs. 2, 3.
Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 29, pl. 6, figs. 28, 29.

Remarks. - Spiroplectammina lalickeri is characterized by the gradual increase in chamber size resulting in sides that diverge slowly from the initially coiled chambers. Spiroplectammina lalickeri differs from S. semicomplanata Carsey by its slower increase in test diameter.

Figured hypotype: Length 0.67 mm; diameter 0.31 mm; thickness 0.16 mm.

Occurrence. - *Spiroplectammina lalickeri* is present throughout the *Gavelinella kansasensis* Assemblage Zone to the lower part of the *Gavelinella henbesti* Assemblage Zone at Delta. Cushman (1946) reports its occurrence throughout Tayloran strata in the Gulf Coast.

Genus BIGENERINA d'Orbigny, 1826

Bigenerina hastata Cushman

Plate 1, figure 4.

Bigenerina hastata Cushman, 1927, Royal Soc. Canada Trans., 3rd ser., vol. 21, sec. 4, p. 131, pl. 1, fig. 9.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 30, pl. 6, fig. 25.

Remarks. - *Bigenerina hastata* is characterized by its numerous uniserial indistinct chambers and slightly protruding aperture.

Figured hypotype: Length 0.68 mm; diameter 0.18 mm.

Occurrence. - A few specimens are present in the *Gavenlinella dakotensis* Assemblage Zone in the Gallup, Delta, and Wolcott sections. Lamb (1968) reports that *B. hastata* occurs abundantly in northern part of the San Juan Basin and considers it a zone fossil. This is not corroborated in the sections studied by the writer.

Family TROCHAMMINIDAE Schwager, 1877

Genus TROCHAMMINA Parker and Jones, 1859

Trochammina uniforma n. sp. (Hirsch)

Plate 2, figures 3-5, 6-8, 9-10;

Plate 4, figures 1-3.

Description. - Test free, very low trochospiral with flat spiral side consisting of 2-2-1/2 whorls, early whorls flat or depressed, 5-7 chambers, commonly 6, visible on the umbilical side; umbilicus broad, deep; chambers lobulate, globular, twice as wide as long, increasing moderately but uniformly in size; sutures distinct, depressed, straight and radial on the umbilical side, straight or slightly curved and oblique on the spiral side; aperture on interiomarginal umbilical-extraumbilical slit with no evidence of an apertural lip; wall agglutinated.

Figured holotype: Greatest diameter 0.38 mm; thickness 0.20 mm.

Figured paratype: Greatest diameter 0.50 mm; thickness 0.32 mm.

Remarks. - *Trochammina uniforma* is characterized by a low trochospiral arrangement of globular chambers, generally six in the final whorl. *Trochammina uniforma* differs from *T. globigerniformis* (Parker and Jones) by having more chambers in the final whorl and from *T.*

ribstonensis Wickenden and *T. umiatensis* Tappan by its low trochospiral chamber arrangement. *Trochammina uniforma* differs from *T. albertensis* Wickenden by having a convex rather than a concave umbilical side.

Occurrence. - *Trochammina uniforma* occurs commonly in the Mancos Shale in Unit D8 at Delta in the *Haplophragmoides rota* Assemblage Zone.

Family ATAXOPHRAGMIIDAE Schwager, 1877

Genus GAUDRYINA d'Orbigny, 1839

Gaudryina bentonensis (Carman)

Plate 1, figures 3, 8.

Spiroplectammina bentonensis Carman, 1929, Jour. Paleon., vol. 3, p. 311, pl. 34, figs. 8-9.

Gaudryina bentonensis Carman - Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 33, pl. 7, figs. 15, 16.

Remarks. - *Gaudryina bentonensis* is characterized by small chambers in its triserial section, a prominent biserial section with nearly parallel sides, and indistinct sutures. *Gaudryina bentonensis* is a variable species with twisting of the biserial portion common and with the rare development of ultimate triserial chambers.

Figured hypotype: (Plate 1, figure 3), Length 1.1 mm; diameter 0.18 mm. (Plate 1, figure 8), Length 0.64 mm; diameter 0.20 mm.

Occurrence. - Gaudryina bentonensis was originally described from the Benton Formation in Wyoming. Fox (1954) reports its presence in the Cody Shale in Wyoming. In the Gulf Coast the species has a wide stratigraphic distribution ranging from Austinan to Navarroan strata. In the Mancos Shale G. bentonensis has been found in Units D4, D7, and D8 at Delta, Units W6 and W7 at Wolcott, and Unit 2 at Gallup. The species is restricted to non-calcareous, generally silty shales. Its distribution is evidently ecologically controlled in the Mancos Shale.

Family ATAXOPHRAGMIDAE Schwager, 1877

Genus DOROTHIA Plummer, 1931

Dorothia bulleta (Carsey)

Plate 1, figure 13.

Gandryina bulleta Carsey, 1926, Texas Univ. Bull. 2612, p. 28, pl. 4, fig. 4.

Dorothia bulleta Carsey - Loetterle, 1937, Nebraska Geol. Survey, 2nd ser., Bull. 12, p. 58, pl. 10, figs. 6a-b.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 46, pl. 12, figs. 21-26.

Remarks. - Gandryina bulleta is characterized by its cylindrical shape, slow increase in chamber size resulting in sides that are nearly parallel throughout its length. Gandryina bulleta differs from D. glabrella Cushman by its cylindrical rather than flattened outline.

Figured hypotype: Length 0.60 mm; diameter 0.30 mm.

Occurrence. - *Dorothia bulleta* is present in a few samples in Unit D8 at Delta in the *Haplophragmoides rota* Assemblage Zone. On the Gulf Coast *D. bulleta* is reported from Tayloran and Navarroan strata (Cushman, 1946). Loetterle (1937) reports the occurrence of the species from the Lower Pierre Formation in Nebraska.

Suborder	ROTALIINA	Delage and Herouard, 1896
Family	NODOSARIIDAE	Ehrenberg, 1838
Genus	NODOSARIA	Lamarck, 1812

Nodosaria bighornensis Young

Nodosaria bighornensis Young, 1951, Jour. Paleon., v. 25, no. 1, p. 58, pl. 12, figs. 17, 19.

Remarks. - *Nodosaria bighornensis* is a distinctive species which is characterized by relatively uninflated chambers, by increase moderately but uniformly in size, and by 7 to 8 thin but elevated costae which run the length of the test. Every specimen found in the Mancos Shale is very similar to Young's figured paratype.

Nodosaria bighornensis differs from *N. obscura* Reuss in less inflated chambers.

Maximum length 0.27 mm; maximum diameter of last chamber 0.10 mm.

Occurrence. - Nodosaria bighornensis is restricted to Unit D1 at Delta in the Gavelinella dakotensis Assemblage Zone. It has previously been recorded only from the Frontier Formation. Because it has only been found in a stratigraphically correlative position in the Mancos Shale, it may well prove to be a useful guide fossil. Its present limited occurrence also may well indicate ecological restriction.

Genus DENTALINA Risso, 1826

Dentalina communis (d'Orbigny)

Nodosaria communis d'Orbigny, 1826, Ann. des Sciences Natur., vol. 7, p. 254, no. 35.

Garsey, 1926, Univ. Texas, Bull. 3101, p. 34, pl. 7, fig. 5.

Dentalina communis d'Orbigny - Plummer, 1931, Univ. Texas, Bull. 3101, p. 149, pl. 11, fig. 4.

Loetterle, 1937, Nebraska Geol. Survey, Bull. 12, 2nd ser., p. 25, pl. 3, fig. 1.

Remarks. - Dentalina communis is characterized by a slightly curved outline, depressed sutures, and a smooth wall.

Occurrence. - Only seven specimens of Dentalina communis were found in Unit G1 at Gallup in the Gavelinella dakotensis Assemblage Zone. It has previously been reported from the Cretaceous in the Gulf Coast and from the

Niobrara Formation in Nebraska and South Dakota.

Dentalina cf. D. consobrina (d'Orbigny)
Plate 3, figures 14, 15.

Dentalina consobrina d'Orbigny, 1846, Foram. Foss. Vienna, p. 46, pl. 2, figs. 1-3.

Dentalina cf. D. consobrina Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 69, pl. 24, figs. 23-27.

Remarks. - Numerous incomplete uniserial straight or slightly curved tests consisting of elongate inflated chambers with wide depressed sutures have been found in the Mancos Shale. All specimens found in the Mancos Shale are partial tests of only adult chambers. The figured specimen has a radiate aperture produced on a short neck. The specimens are similar to the Cushman hypotypes. Consequently these specimens are referred to Dentalina cf. D. consobrina. Cushman (1946) noted these partial tests may indeed be chambers of large Dentalina lorneiana d'Orbigny.

Figured hypotypes: Width of ultimate chamber 0.22 mm.

Occurrence. - Specimens of D. consobrina were found in Unit G1 at Gallup in the Gavelinella dakotensis Assemblage Zone where it is associated with D. lorneiana. In the Gulf Coast the species has been reported from Tayloran and Navarroan strata (Cushman, 1946).

Dentalina lorneiana d'Orbigny

Plate 3, figure 17.

Dentalina lorneiana d'Orbigny, 1840, Soc. Geol. France Mem., 1st ser., vol. 4, p. 14, pl. 1, figs. 8, 9.

Loetterle, 1937, Nebraska Geol. Survey, Bull. 12, 2nd ser., p. 25, pl. 2, fig. 5.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 66, pl. 23, figs. 7-11.

Remarks. - *Dentalina lorneiana* is characterized by chambers that increase in length greatly but only slightly in width as added and by slightly inflated chambers with flush or shallow sutures.

The specimens in the Mancos Shale compare well with the hypotypes selected by Cushman (1946).

Figured hypotype: Length 1.20 mm; width of ultimate chamber 0.22 mm.

Occurrence. - *Dentalina lorneiana* occurs in several samples of the Mancos Shale in Unit G1 at Gallup in the *Gavelinella dakotensis* Assemblage Zone, in Unit D5 at Delta and Unit W5 at Wolcott in the *Gavelinella kansasensis* Assemblage Zone, and in Unit D7 at Delta in *Gavelinella henbesti* Assemblage Zone. It is a long ranging species in the Gulf Coast and has been found in the Niobrara Formation in Kansas. The fact that it occurs in the Greenhorn Equivalent in the Mancos Shale also corroborates the probable long range in the Western Interior.

Dentalina reflexa Morrow

Dentalina reflexa Morrow, 1934, Jour. Pal., vol. 8, p. 189, pl. 29, figs. 5, 20.

Loetterle, 1937, Nebraska Geol. Survey Bull., 2nd ser., Bull. 12, p. 24, pl. 2, fig. 4.

Cushman, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 66, pl. 23, figs. 13, 14.

Remarks. - Dentalina reflexa is characterized by chambers which increase greatly in length and by oblique sutures.

Figured hypotype: Length 0.45 mm; diameter 0.10 mm.

Occurrence. - Dentalina reflexa occurs rarely in the upper part of Unit D2 at Delta in the Gavelinella dakotensis Assemblage Zone.

It has previously been reported from the Niobrara Formation (Morrow, 1934; Loetterle, 1937). Fox (1954) reports its occurrence in the Greenhorn Formation in Wyoming.

Genus FRONDICULARIA Defrance, 1826

Frondicularia frontierensis Young

Frondicularia frontierensis Young, 1951. Jour. Pal., vol. 25, no. 1, p. 61, pl. 13, figs. 1-3.

Remarks. - Two partial specimens of Frondicularia have been found in the Mancos Shale. They are tentatively identified as *F. frontierensis*. The species is distinguished by its elongate shape and its lack of ornamentation.

Occurrence. - *Frondicularia frontierensis* occurs in Unit G1 at Gallup in the upper part of the *Gavelinella dakotensis* Assemblage Zone. Young (1951) described it from the Frontier Formation in Montana.

Frondicularia aclis Morrow

Plate 3, figure 5.

Frondicularia aclis Morrow, 1934, Jour. Paleo., vol. 8, p. 193, pl. 29, fig. 30.

Remarks. - *Frondicularia aclis* is characterized by its compressed test, the bulbous proloculus, the aperture produced on a short neck, and discontinuous costae parallel to the length of the test.

Frondicularia aclis differs from *F. inversa* Reuss by its costae.

Figured hypotype: Length 0.70 mm; width 0.15 mm; thickness 0.10 mm.

Occurrence. - Only a few specimens of *F. aclis* were found in one sample 354 feet above the base of the formation (Unit W5) at Wolcott in the *Gavelinella kansasensis* Assemblage Zone. Morrow (1934) reports the species to be extremely rare in the basal Niobrara Formation in Kansas.

Frondicularia inversa Reuss

Plate 3, figure 4.

Frondicularia inversa Reuss, 1844, Geognostische Skizzen Boehmen, vol. 2, pt. 1, p. 211.

________, 1845, Verstein boehm. Kreideform, pt. 1, p. 31, pl. 8, figs. 15-19.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 86, pl. 33, figs. 11-18.

Remarks. - Only juvenile or broken adult tests of Frondicularia inversa were recovered from the Mancos Shale. They, however, show the general morphologically important features of the species, including the strongly compressed test, flush sutures, proloculus with a short spine, and terminal radiate aperture on a short neck.

Frondicularia inversa differs from F. dunbari Morrow by overlapping chambers.

Figured hypotype: Length 0.70 mm; width 0.17 mm; thickness 0.10 mm.

Occurrence. - Single specimens of F. inversa were found in several samples throughout Unit G1 at Gallup in the Gavelinella dakotensis Assemblage Zone. Cushman (1946) reported its occurrence in Austin and Taylor strata of the Gulf Coast. It had previously been reported throughout the Cretaceous strata.

Genus LENTICULINA Lamarck, 1804

Lenticulina gaultina (Berthelin)

Plate 3, figures 21-22, 23-24;

Plate 4, figures 1-2, 3-4.

Cristellaria gaultina Berthelin, 1880, Geol. Soc. France, Man. 5, ser. 3, vol. 1, p. 49, pl. 3 (26), figs. 15-19.

Cristellaria washitensis Carsey, 1926, Texas Univ. Bull. 2612, p. 38, pl. 7, fig. 9.

Lenticulina gaultina Tappan, 1940, Jour. Paleon., vol. 14, no. 2, p. 101, pl. 15, fig. 11.

Eicher, 1965, Jour. Paleon., vol. 39, no. 5, p. 903, pl. 106, fig. 5.

Remarks. - Lenticulina gaultina is characterized by its circular outline, uniflated chambers, and its flush, thick, indistinct sutures.

Figured hypotypes: Maximum diameter 0.70 mm; thickness 0.27 mm.

Occurrence. - In the Mancos Shale L. gaultina is abundant in several samples in Unit G1 at Gallup and Unit W3 at Wolcott in the Gavelinella dakotensis Assemblage Zone. The species has previously been reported from the Graneros Formation in eastern Colorado and the Washita and Woodbine Groups in the Gulf Coast.

Lenticulina kansasensis Morrow

Lenticulina kansasensis Morrow, 1934, Jour. Pal., vol. 8, no. 2, p. 189, pl. 30, figs. 23a-b.

Loetterle, 1937, Nebraska Geol. Survey Bull., 2nd Ser., Bull. 12, p. 22, pl. 1, figs. 6a-b.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 56, pl. 18, fig. 15.

Eicher, 1966, Contr. Cush. Found. Foram. Res., vol. 17, pt. 1, p. 25, pl. 5, fig. 15.

Remarks. - Lenticulina kansasensis is distinguished by its large size, large number of chambers in the last whorl, elevated curved sutures, and keeled periphery.

Size: Maximum diamter 0.73 mm; maximum diameter 0.30 mm.

Occurrence. - In the Mancos Shale several specimens were found in Unit D5 at Gallup and Unit W5 at Wolcott in the Gavelinella kansasensis Assemblage Zone. It is a widely distributed species in the Western Interior and has been reported to occur in the Niobrara Formation in Nebraska (Loetterle, 1937), the Carlile Formation in eastern Colorado (Eicher, 1966) and South Dakota (Fox, 1954), and the Cody Shale in Wyoming (Fox, 1954).

Lenticulina muensteri (Roemer)

Robulina muensteri Roemer, 1839, Verstein. norddeutschen Oolithengebirges, Nachtrag., p. 48, pl. 22, fig. 29.

Rubulus muensteri Roemer - Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 53, pl. 17, figs. 3-9.

Remarks. - *Lenticulina muensteri* is characterized by its nearly circular outline, flush, smooth, radial, gently curved, limbate sutures, and by uninflated chambers. *Lenticulina muensteri* differs from both *L. kansasensis* Morrow and *L. sublaevis* Morrow in having flush sutures.

Size: Maximum diameter 0.70 mm; thickness 0.37 mm.

Occurrence. - *Lenticulina muensteri* is present in several samples in Unit G1 at Gallup and Unit D5 at Delta. In the Western Interior Fox (1954) reports the occurrence of the species in the basal part of the Cody Shale in Wyoming. In the Gulf Coast *L. muensteri* is a long ranging species in the Upper Cretaceous (Cushman, 1946).

Lenticulina sublaevis Morrow

Lenticulina sublaevis Morrow, 1934, Jour. Pal., vol. 8, no. 2, p. 189, pl. 30, figs. 14, 20a-b.

Loetterle, 1937, Nebraska Geol. Survey Bull., 2nd ser., Bull. 12, p. 66, pl. 16, figs. 10a-b.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 56, pl. 18, fig. 18.

Remarks. - *Lenticulina sublaevis* is characterized by limbate slightly raised sutures. The species differs from *L. kansasensis* by its smoother surface and lack of sharply elevated sutures. Specimens in the Mancos Shale are generally poorly preserved.

Size: Specimens range from 0.67 mm to 0.90 mm in diameter and 0.38 mm to 0.46 mm in thickness.

Occurrence. - Lenticulina sublaevis occurs infrequently in the Mancos Shale in Unit D5 at Delta and Unit W5 at Wolcott in the Gavelinella kansasensis Assemblage Zone. Occurrences of this species in the Niobrara or correlative formations have been reported by Morrow (1934), Loetterle (1937), and Fox (1954). The stratigraphically restricted occurrence of this species suggests that L. sublaevis might serve as a useful guide fossil for lower Niobrara strata. Kent (1967), however, does not report the occurrence of the species in Niobrara correlatives in northern Colorado which indicates that L. sublaevis does not range geographically as widely as previously suggested (Loetterle, 1937).

Genus MARGINULINA d'Orbigny, 1826

Marginulina gallupina n. sp. (Hirsch)

Plate 3, figures 9, 10.

Marginulina sp. 1. Fox, 1954, U. S. Geol. Survey Prof. Paper 254-E, p. 115, pl. 25, fig. 11.

Description. - Test free, large, slightly compressed throughout its length, elongate, the length being about three times the width, initial chambers forming a curve convex to the apertural side, later chambers forming a rectilinear series that is straight or concave to the apertural side; chambers ovate, distinctly wider than long, slightly inflated, increasing rapidly in size from the initial coiled portion then increasing moderately in size; sutures distinct, slightly curved, adult sutures not inclined toward slightly coiled early chambers, limbate, heavily thickened in the rectilinear part of the test; aperture radiate, produced on a short neck on the dorsal angle; wall calcareous, smooth, lacking ornamentation except for thickened sutures.

Holotype: Length 1.82 mm; width 0.45 mm; thickness 0.30 mm.

Paratypes: Length 1.85 mm; width 0.50 mm; thickness 0.35 mm. Length 1.05 mm; width 0.30 mm; thickness 0.23 mm (not figured).

Remarks. - Marginulina gallupina is a distinctive species differeing from M. plummerae Cushman in compressed chambers throughout with no distinctly inflated adult chambers and in thickened sutures. It differs from M. siliqua Cushman in fewer coiled chambers, in sutures between the rectilinear chambers more or less perpendicular to the length, and in absence of an early spinose portion. The specimen of Marginulina sp. 1. Fox at the U. S. National Museum is identical to the specimens of M. gallupina in the Mancos Shale.

Eleven specimens have been recovered from two samples in the Mancos Shale. Although the species is presently limited in number of specimens, the fact that the species is morphologically constant warrants the naming of the new species. Furthermore it has been reported from another area of the Western Interior.

Occurrence. - *Marginulina gallupina* is present at the bottom and top of Unit G1 at Gallup in the *Gavelinella dakotensis* Assemblage Zone. Fox (1954) reports its presence in the upper Greenhorn and lower Cody Formations in Wyoming. Its present known range is late Cenomanian early Turonian. The fact that it previously had been reported in only one other area indicates a limited ecological distribution.

Genus MARGINULINOPSIS A. Silvestri, 1904

Marginulinopsis amplaspira Young, 1951

Plate 3, figure 8.

Marginulinopsis amplaspira Young, 1951, Jour. Pal., vol. 25, no. 1, p. 54, pl. 11, figs. 15, 17-21; pl. 12, figs. 1-4, 6, 8-14; figs. 5, 14-16, 18-21; figs. 6, 2-16, 20.

Fox, 1954, U. S. Geol. Survey Prof. Paper 254-E, p. 115, pl. 25, figs. 13, 14.

Remarks. - The specimens agree with *M. amplaspira* Young in the polygonal to circular peripheral outline, the marked angles between the sutures and the periphery, the closely appressed early uniserial chambers, the more inflated and less appressed final chambers, and the protruding terminal aperture located near the outside edge of the ultimate chamber.

Figured hypotype: Maximum length 0.68 mm; maximum width 0.25 mm.

Occurrence. - Marginulinopsis amplaspira was first reported from the Frontier formation of southern Montana where it occurs abundantly in the "Vascoceras" beds. Fox (1954) reports the occurrence of M. amplaspira in the Greenhorn formation in the Belle Fourche section, the Frontier formation in the Cumberland Gap section, and the Cody shale (unit 2) at Greybull, Wyoming.

In the Mancos Shale a few specimens of M. amplaspira have been found at Gallup 130 feet above the base of the formation in the Gavilinella dakotensis Assemblage Zone.

Palmula suturalis (Cushman)

Plate 3, figure 11.

Flabellina suturalis Cushman, 1935, Cushman Lab. Foram. Res. Contr., vol. 11, p. 86, pl. 13, figs. 9-18.

Palmula suturalis Cushman - Loetterle, 1937, Nebraska Geol. Survey Bull., ser. 2, Bull. 12, p. 28, pl. 3, fig. 5.

Cushman, 1946, U. S. Geol. Prof. Paper 206, p. 82, pl. 32, figs. 3-14.

Remarks. - Palmula suturalis is distinguished by its distinct somewhat elevated sutures and smooth surface.

Figured hypotype: Length 0.84 mm; maximum diameter 0.42 mm.

Occurrence. - Palmula suturalis is common in several samples of the Mancos Shale at Wolcott where it occurs in Unit W5 in the Gavelinella kansasensis Assemblage Zone. Only one broken specimen was found at Delta in the same zone. Significantly, its occurrence in the Niobrara Formation in Nebraska (Loetterle, 1937) suggests that it may be of correlative value in the Western Interior. Cushman (1946) reports the species to have a wide range in the Gulf Coast extending from Austinan to Navarroan strata.

Palmula sp.

Plate 4, figure 5.

A single specimen of Palmula sp. with terminal end broken off was found 260 feet above the base of the Mancos Shale at Gallup in the Gavelinella dakotensis Assemblage Zone. The triangular shaped compressed test has an initial coiled portion of chambers that are more inflated and project above and below the remainder of the test. Later chambers are strongly arched chevrons shaped in a rectilinear series. With the exception of slightly raised limbate sutures between the rectilinear chambers no ornamentation is present. No aperture is present on the broken specimen but it is undoubtedly terminal. The specimen is poorly preserved.

The specimen is very similar to *P. suturalis* (Cushman) but differs from *P. suturalis* Cushman in more highly arched chambers and less curved sutures between the rectilinear chambers.

Maximum length 1.25 mm; maximum width 0.90 mm.

Genus SARACENARIA Defrance, 1824

Saracenaria reesidei Fox

Plate 3, figure 20.

Saracenaria reesidei Fox, 1954, U. S. Geol. Survey Prof. Paper 254-E, p. 114, pl. 25, figs. 7,9, not fig. 8.

Remarks. - *Saracenaria reesidei* is characterized by its elongate test, its chambers which increase in width only moderately in the uncoiled portion of the test, and its keeled periphery.

Saracenaria reesidei differs from *S. bononiensis* (Bertheln) in having costae. One specimen of *S. reesidei* figured by Fox (1954, pl. 25, fig. 8) is identical to the hypotypes of *S. bononiensis* (Bertheln) figured by Tappan (1940). Fox (1954) implies that surface ornamentation is a variable character on *S. reesidei*. It is present on many but not on all specimens in the Greenhorn Formation in Wyoming. It is likely that *S. reesidei* should be put in synonomy with *S. bononiensis*. However, there are too few specimens in the Mancos Shale to diagnose population ornamentation.

Figured hypotype: Length 0.38 mm; thickness 0.13 mm.

Occurrence. - Four specimens of Saracenaria reesidei have been found in two samples at Gallup in Unit G1 in the Gavelinella dakotensis Assemblage Zone. Fox (1954) described the species from the Greenhorn and Cody Formations in Wyoming where it is associated with a Greenhorn fauna. Its present known range is thus restricted to the upper Cenomanian - lower Turonian in the Western Interior. It may well have this limited range.

Genus VAGINULINA d'Orbigny, 1826

Vaginulina kochii Roemer

Plate 3, figures 12, 18, 19.

Vaginulina kochii Roemer, 1840, Verst. norddeutsch. Kreide, p. 96, pl. 15, fig. 10.

Cushman & Alexander, 1930, Cush. Lab. Foram. Res. Contr., vol. 6, no. 1, p. 1, pl. 1, figs. 1-9.

Tappan, 1940, Jour. Pal., vol. 14, no. 2, p. 109, pl. 17, figs. 2-4.

Vaginulina n. sp. Young, 1951, Jour. Pal., vol. 25, no. 1, p. 60, pl. 13, fig. 13.

Vaginulina sp. 1 Fox, 1954, U. S. Geol. Survey Prof. Paper 254-E, p. 116, pl. 25, fig. 21.

Remarks. - Vaginulina kochii is characterized by by its nearly spherical proloculus, compressed flat chambers, subparallel sides, and slightly raised sutures.

Figured specimen: Maximum length 1.30 mm; maximum width 0.28 mm; maximum thickness 0.13 mm.

Occurrence. - In the Mancos Shale *Vaginulina kochii* occurs in Unit G1 at Gallup in the *Gavelinella dakotensis* Assemblage Zone. *Vaginulina sp. 1* Fox reported from the Greenhorn Formation is conspecific with *V. kochii*. Previously it had been described only from Lower Cretaceous strata (Cushman and Alexander, 1930; Tappan, 1940). The range of the species thus must be extended to the Upper Cenomanian - Lower Turonian. Also the occurrence of *Vaginulina kochii striolata* (Plummer) identified as *Vaginulina sp. 2* Fox (1954) and *Vaginulina n. sp.* Young (1951) in the Greenhorn and Frontier Formations, respectively, corroborates the extension of the range of the species.

Family GLANDULINIDAE Reuss, 1860

Genus BULLOPORA Quenstedt, 1852

Bullopora laevis (Solas)

Plate 1, figure 11.

Wellina laevis Solas, 1877, Geog. Mag., dec. 2, vol. 4, p. 103, pl. 6, figs. 1-3.

Bullopora laevis Solas - Wickenden, 1932, Jour. Paleon., vol. 6, p. 206, pl. 29, figs. 6-8.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, pl. 42, figs. 1-4.

Remarks. - Bullopora laevis is characterized by its smooth globular chambers. In the Mancos Shale only individual chambers with two or more stolon-like connecting tubes of this attached species were found. The chambers are identical with hypotypes at the U. S. National Museum and with specimens from the Cody Shale of Wyoming.

Figured hypotype: Length 0.50 mm; maximum diameter 0.30 mm.

Occurrence. - Bullopora laevis is present 2250 to 2500 feet above the base of the Mancos Shale in Unit D7 at Delta in the Gavelinella henbesti Assemblage Zone and at Wolcott a few specimens were found in Unit W5. Wickenden (1932) reports the species to be restricted to 430 feet below the top of the Alberta Shale. Fox (1939) reports its occurrence in the Niobrara equivalent of the Cody Shale in Wyoming. Although the species' distribution is undoubtedly environmentally controlled because of its attached habit, its present known range is limited to Niobrara equivalents in the Western Interior. In the Gulf Coast the species ranges from Austinan to Navarroan strata (Cushman, 1946).

Family TURRILINIDAE Cushman, 1927

Genus NEOBULIMINA Cushman and Wickenden, 1928

Neobulimina canadensis Cushman and Wickenden

Plate 4, figures 7, 13.

Neobulimina canadensis Cushman and Wickenden, 1928, Cushman Lab. Foram. Res. Contr., vol. 4, p. 13, pl. 1, figs. 1, 2.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 125, pl. 52, figs. 11-12.

Tappan, 1962, U. S. Geol. Survey Prof. Paper 236-C, p. 185, pl. 48, figs. 18-27.

Remarks. - *Neobulimina canadensis* is characterized by its tiny test, its subglobular chambers, and its distinct but almost flush sutures.

Neobulimina canadensis differs from *N. minima* Tappan in its larger size, a less rapid increase in chamber size, and less depressed sutures. *Neobulimina albertensis* (Stelck and Wall) has more globular chambers and depressed sutures.

Figured hypotype: Length 0.25 mm; diameter 0.10 mm.

Occurrence. - *Neobulimina canadensis* has a long range in the Gulf Coast extending from Eaglefordian to Navarroan strata (Cushman, 1946). In Canada and the Alaskan Coastal Plain *N. canadensis* is restricted to Campanian strata (Nauss, 1947; Tappan, 1962). *Neobulimina canadensis* occurs in the Mancos Shale in Unit G1 at Gallup in the *Gavelinella dakotensis* Assemblage Zone. Significantly its only other reported occurrence in the Western Interior of the United States is in the Greenhorn Formation in Wyoming (Fox, 1954).

Genus PRAEBULIMINA Hopker, 1953

Praebulimina careyae (Plummer)

Plate 4, figure 6, 12.

Buliminella carseyae Plummer, 1931, Univ. Texas Bull. 3101, p. 179, pl. 8, fig. 9.

Loetterle, 1937, Nebraska Geol. Survey, 2nd Ser., Bull. 12, pl. 37, vol. 5, fig. 10.

Praebulimina carseyae Plummer - Tappan, 1962, U. S. Geol. Survey Prof. Paper 236-C, p. 186, pl. 48, figs. 11-15.

Remarks. - *Praebulimina carseyae* is characterized by a blunt initial end, gradual increase in chamber size, moderately inflated chambers, and a last whorl comprising one-half of the length of the test.

Figured hypotype: Length 0.25 mm; maximum diameter 0.12 mm.

Occurrence. - *Praebulimina carseyae* is a long ranging species in the Gulf Coast and has been reported from Austinan through Navarroan strata (Cushman, 1946). In the Western Interior it has been reported from the Niobrara Formation (Loetterle, 1937) and from the Cody

Shale (Fox, 1954). The species is abundant in several samples of the Mancos Shale in Units D7 and the base of D8 at Delta. A few specimens occur in Unit D6 at Wolcott.

Praebulimina wyomingensis (Fox)
Plate 4, figure 8.

Bulimina wyomingensis Fox, 1954, U. S. Geol. Survey Prof. Paper 254-E, p. 118, pl. 26, figs. 8-11.

Praebulimina wyomingensis Eicher, 1965, Jour. Pal., vol. 39, no. 5, p. 903, pl. 106, fig. 4.

Remarks. - Praebulimina wyomingensis is characterized by its globular chambers, rapid increase in chamber size, and broad aperture.

Figured hypotype: Maximum length 0.22 mm; maximum width 0.12 mm.

Occurrence. - Praebulimina wyomingensis is common in several samples in Unit G1 at Gallup in the Gavelinella dakotensis Assemblage Zone where it is associated with species characteristic of the upper Greenhorn Formation. Although originally reported to be restricted to the Greenhorn Formation (Fox, 1954), Eicher (1965) reports the occurrence of the species in the Graneros Shale. It is likely that the species does not range above the Greenhorn Formation.

Family DISCORBIDAE Ehrenberg, 1838

Genus VALVULINERIA Cushman, 1926

Valvulineria loetterlei (Tappan)

Plate 6, figures 10-12.

Gyroidina loetterlei Tappan 1940, Jour. Pal., vol. 14, no. 2, p. 120, pl. 19, figs. 10a-c.

Gyroidina n. sp. Young, 1951, Jour. Pal., vol. 25, no. 1, p. 65, pl. 14, figs. 14-16.

Gyroidina cf. G. nitida Reuss - Stelck, et al., 1956, Res. Council Alberta, Rept. 75, p. 33, pl. 1, figs. 11-13, pl. 2, figs. 7-9.

Valvulineria loetterlei, Tappan, 1962, U. S. Geol. Survey, Prof. Paper 236-C, p. 194, pl. 54, figs. 1-4.

Eicher, 1966, Contr. Cush. Found. Foram. Res., vol. 17, pt. 1, pl. 5, fig. 11.

Remarks. - Valvulineria loetterlei in the Mancos Shale compares well with the primary types. It is characterized by small size, shape, and the number of chambers in the final whorl. It differs from Gyroidina nitida (Reuss) in having 6 to 7 chambers in the final whorl.

Figured hypotype: Maximum diameter 0.25 mm; maximum thickness 0.10 mm.

Occurrence. - In the Mancos Shale V. loetterlei occurs abundantly in Unit G1 at Gallup in the Gavelinella dakotensis Assemblage Zone. Tappan (1940) reports this species from the Washita Group and the Grayson Formation of the Gulf Coast now considered to be Genomanian in age (Loeblich and Tappan, 1961). It has also been reported from the Frontier Formation in Montana (Young, 1951), Albian strata in Canada (Stelck, *et al.*, 1956), and the Cretaceous in Alaska (Tappan, 1962). The occurrence of *V. loetterlei* in the Carlile Shale (Eicher, 1966) corroborates the evidence from the Mancos Shale that the range of the species should be extended to Lower Turonian.

Valvulineria plummerae Loetterle

Plate 8, figures 16-18.

Valvulineria plummerae Loetterle, 1937, Nebraska Geol. Survey, 2nd Ser., Bull. 12, p. 41, pl. 6, figs. 5a-c, 6.

Gyroidina nitida Plummer not Reuss, 1931, Univ. of Texas, Bull. 3101, p. 191, pl. 14, figs. 5a-c.

Remarks. - *Valvulineria plummerae* is characterized by 8 to 9 chambers in the last whorl, and slightly depressed radiate sutures on the umbilical side.

Figured hypotype: Maximum diameter 0.27 mm; thickness 0.10 mm.

Occurrence. - *Valvulineria plummerae* occurs abundantly in several samples in Unit G1 at Gallup in the *Gavelinella dakotensis* Assemblage Zone. The species also occurs in Unit W5 at Wolcott. In the Western Interior it has previously been reported from the upper Greenhorn

Formation in Wyoming (Fox, 1954) and from the Niobrara Formation (Loetterle, 1937). The species has also been reported from the Washita Group of Texas (Plummer, 1931). It appears that the species is long ranging. Vulvulineria plummerae occurs only in calcareous sediments and is associated with a varied benthonic and planktonic foraminiferal fauna.

Family HETEROHELICIDAE Cushman, 1927

Genus HETEROHELIX Ehrenberg, 1843

Heterohelix globulosa (Ehrenberg)

Plate 4, figures 16-17.

Textularia globulosa Ehrenberg, 1834, K. preuss. Akad. Wiss. Berlin, Abh., p. 135, pl. 4, fig. 4b.

Guembelina globulosa Ehrenberg - Egger, 1899, K. bayer. Akad. Wiss., Math.-naturh. Abt., Abh., Kl. 2, vol. 21, pt. 1, p. 32, pl. 14, fig. 43.

Morrow, 1934, Jour. Pal., vol. 8, no. 2, p. 194, pl. 29, figs. 18a-b.

Loetterle, 1937, Nebraska Geol. Survey Bull., 2nd ser., Bull. 12, p. 33, pl. 4, figs. 8a-b.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 105, pl. 45, figs. 9-15.

Heterohelix globulosa Ehrenberg - Gallitelli, 1957, U. S. Nat. Mus. Bull. 215, p. 137, pl. 31, figs. 12-15.

Eicher, 1965, Contr. Cushman Found. Foram. Res., vol. 17, pt. 1, p. 26, pl. 5, figs. 9, 10.

Eicher, 1965, Jour. Pal., vol. 39, no. 5, p. 904, pl. 106, fig. 3.

Pessagno, 1967, Paleont. Amer., vol. 5, no. 37, p. 260, pl. 87, figs. 5-9, 11-13.

Remarks. - Abundant specimens found in all sections of the Mancos Shale show wide variability. *Heterohelix globulosa* is characterized by its triangular shaped test, its globular chambers which increase rapidly in size and its fine costae that are sometimes visible on mature chambers. It differs from *H. moremani* in more globular chambers and a more flaring test.

Figured hypotype: Length 0.28 mm; maximum diameter 0.14 mm.

Occurrence. - In the Mancos Shale *H. globulosa* occurs in Unit G1 at Gallup, Unit D2 at Delta, Unit W3 at Wolcott in the *Gavelinella dakotensis* Assemblage Zone; in Unit D5 at Gallup and Unit W5 at Wolcott in the *Gavelinella kansasensis* Assemblage Zone; and Unit D6 at Delta in the *Gavelinella henbesti* Assemblage Zone. *Heterohelix globulosa* is probably the most abundant species in the Mancos Shale. It occurs abundantly in many samples and, in addition to *Hedbergella delrioensis*, it is one of the few species found abundantly in the samples containing only planktonic Foraminifera. Several samples contained only *H. globulosa* attesting to its probable wide tolerance of ecological conditions.

Heterohelix globulosa has in the past been reported as occurring in many areas throughout Upper Cretaceous strata. In view of the fact that many of these occurrences were reported prior to the study of the Heterohelicidae by Gallitelli (1957), it is likely that the species at times has been previously misidentified. Pessagno (1967) restricts the distribution of *H. globulosa* to Campanian and Maestrichtian strata in the Gulf Coastal Plain. He apparently is referring previous reports on the occurrence of *H. globulosa* in Albian, Cenomanian and Turonian strata to *H. moremani* or *H. reussi*. However, the range of *H. globulosa* in the Western Interior must be extended downward to the Upper Cenomanian. Eicher (1965, 1966) reports it from Cenomanian and Lower Turonian strata in the Graneros, Greenhorn, and Carlile Formations. Tappan (1962) reports it from the Seabee Formation on the Arctic Slope of Alaska.

Heterohelix moremani (Cushman)

Plate 4, figures 9-10.

Guembelina moremani, Cushman, 1938, Cushman Lab. Foram. Res. Contr., vol. 14, pt. 10, pl. 2, figs. 1-3.
Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 103, pl. 44, figs. 15-17.

Guembelina globifera Morrow (not Reuss), 1934, Jour. Pal., vol. 8, p. 194, pl. 29, figs. 15a-b, 17.

Heterohelix moremani Cushman - Pessagno, 1967, Paleon. Amer., vol. 5, no. 37, p. 260, pl. 48, figs. 10, 11, pl. 89, figs. 1, 2.

Remarks. - Heterohelix moremani is characterized by its slightly tapering test and globular chambers which increase only slightly after juvenile stages. In juvenile stages H. moremani is indistinguishable from H. globulosa.

Figured hypotype: Length 0.30 mm; maximum diameter 0.14 mm.

Occurrence. - In the Mancos Shale H. moremani is restricted to Unit G1 at Gallup in the Gavelinella dakotensis Assemblage Zone at Gallup where it is commonly associated with H. globulosa. Heterohelix moremani has been reported from the Greenhorn, Carlile, and Niobrara Formations in Kansas (Morrow, 1934). Fox (1954) reports an abundant occurrence of the species from the uppermost Greenhorn Formation in South Dakota in addition to rare occurrences in the Carlile and Cody Formations.

Heterohelix striata (Ehrenberg)

Plate 4, figures 14-15.

Textilaria striata Ehrenberg, 1838, K. preuss. Akad., Wiss. Berlin, Abh., p. 135, pl. 4, figs. 1a, 2a, 3a.

Guembelina striata Ehrenberg - Egger, 1899, K. bayer, Akad. Wiss., Math.-naturh. Abt., Abh., KI, 2, vol. 21, p. 33, pl. 14, figs. 37-39.

Cushman, 1946, U. S. Geol. Survey Bull. 206, p. 104, pl. 45, figs. 4, 5.

Heterohelix striata Ehrenberg - Pessagno, 1967, Palaeont. Amer., vol. V, no. 37, p. 264, pl. 78, figs. 4, 5, pl. 88, figs. 3-7, pl. 98, fig. 16.

Remarks. - Specimens of Heterohelix striata are easily identified in the Mancos Shale and are characterized by distinct costae and great thickness of the test.

Figured hypotype: Length 0.32 mm; maximum width 0.22 mm; thickness 0.16 mm.

Occurrence. - Heterohelix striata occurs commonly at Delta from 1250 to 2090 feet above the base of the Mancos Shale in Unit D6 where it is the only species present in several samples. The species has not previously been reported from the Western Interior. Pessagno (1967) reports the species from Lower Campanian through Maestrichtian strata in the Gulf Coast.

Genus GUEMBELITRIA Cushman, 1933

Guembelitria cretacea Cushman

Plate 4, figure 18.

Guembelitria cretacea Cushman, 1933, Contr. Cushman Lab. Foram. Res., vol. 9, p. 37, pl. 4, figs. 12a-b.

________, 1946, U. S. Geol. Survey Prof. Paper 206, p. 103, pl. 44, figs. 14a-c.

Gallitelli, 1957, U. S. Nat. Museum., Bull. No. 215,

p. 136, pl. 31, figs. 1a-c.

Pessagno, 1967, Palaeont. Amer., vol. 5, no. 37, p. 258, pl. 87, figs. 1-3.

Remarks. - Guembelitria cretacea is characterized by its spherical chambers, depressed sutures, and arched aperture. It differs from G. harrisi Tappan by its more inflated chambers and higher aperture.

Figured hypotype: Length 0.12 mm; greatest diameter 0.08 mm.

Occurrence. - In the Mancos Shale G. cretacea occurs only in the lower part of Unit G1 at Gallup in the Gavelinella dakotensis Assemblage Zone. In the Gulf Coast G. cretacea has been reported only from Maestrichtian strata (Pessagno, 1967). The occurrence of G. cretacea in the Mancos Shale extends the range of the species to lower Turonian.

Family PLANOMALINIDAE Bolli, Loeblick, and Tappan, 1957

Genus GLOBIGERINELLOIDES Cushman and Ten Dam, 1948

Globigerinelloides prairiehillensis Pessagno

Plate 5, figures 8-9.

Globigerinelloides prairiehillensis Pessagno, 1967, Palaeont. Amer., vol. 5, no. 37, p. 277, pl. 60, figs. 2, 3; pl. 83, fig. 1; pl. 90, figs. 1-2, 4; pl. 97, figs. 3, 4.

Remarks. - Globigerinelloides prairiehillensis is characterized by 6-7 chambers in the final whorl, a low interiomarginal aperture in an equatorial position, and a papillate surface.

Globigerinelloides prairiehillensis differs from G. asperus (Ehrenberg) by being larger, having a slit-like aperture, and by not being distinctly hispid.

Figured hypotype: Diameter 0.33 mm; thickness 0.13 mm.

Occurrence. - Globigerinelloides prairiehillensis was originally described from the Taylor in Texas. Its range is indicated by Pessagno (1967, p. 254) to be from Santonian to lower Maestrichtian. The occurrence in the Mancos Shale in Unit D7 at Delta in the Gavelinella henbesti Assemblage Zone closely corresponds to the first appearance of the species. The species is common only at Delta.

Family ROTALIPORIDAE Sigal, 1958

Genus HEDBERGELLA Bronniman and Brown, 1958

Hedbergella amabilis Loeblich and Tappan

Plate 5, figures 6-7.

Hedbergella amabilis Loeblich and Tappan, 1961, Micropaleont., vol. 7, no. 3, p. 274, pl. 3, figs. 1-10.

Pessagno, 1967, Paleont. Amer., vol. 37, no. 5, p. 281, pl. 52, figs. 6-8.

Remarks. - *Hedbergella amabilis* is characterized by its very low trochospiral arrangement of chambers and its clavate chambers in the last whorl.

Figured specimen: Maximum diameter 0.28 mm; thickness 0.10 mm.

Occurrence. - *Hedbergella amabilis* occurs rarely in the Mancos Shale in Unit G1 at Gallup in the *Gavelinella dakotensis* Assemblage Zone and in Unit D5 at Delta and Unit W5 at Wolcott in the *Gavelinella kansasensis* Assemblage Zone at Wolcott and Delta. Originally described from the Eagle Ford Group (Loeblich and Tappan, 1961), it has since been reported from the upper Woodbine to lower Taylor Groups in the Gulf Coast (Pessagno, 1967). In the Western Interior it has been reported from the Greenhorn Formation in Kansas (Loeblich and Tappan, 1961).

Hedbergella brittonensis Loeblich and Tappan

Plate 6, figures 1-3.

Hedbergella brittonensis Loeblich and Tappan, 1961, Micropaleon., vol. 7, no. 3, p. 274, pl. 4, figs. 1-8.

Pessagno, 1967, Paleont. Amer., vol. 37, no. 5, p. 282, pl. 52, figs. 9-12.

Globigerina cretacea Morrow not d'Orbigny, 1934, Jour. Pal., vol. 8, no. 2, p. 198, pl. 30, figs. 7-8, 10a-b.

Remarks. - Hedbergella brittonensis is characterized by high trochospiral arrangement of chambers, globular chambers, and spinose surfaces. None of the specimens in the Mancos Shale have as high a spire as some of the paratypes from the Eagle Ford Group but they are identical to the holotype and the paratype from the Greenhorn Formation.

Hedbergella brittonensis differs from H. delrioensis in its larger size and higher spire.

Figured specimen: Maximum diameter 0.63 mm; minimum diameter 0.50 mm; thickness 0.37 mm.

Occurrence. - Hedbergella brittonensis occurs abundantly in Unit G1 at Gallup in the Gavelinella dakotensis Assemblage Zone where it is associated with H. delrioensis. It has previously been reported from the Hartland Shale Member of the Greenhorn Formation and from the Gulf Coast where it is restricted to upper Cenomanian strata.

Hedbergella delrioensis (Carsey)

Plate 5, figures 1-3.

Globigerina cretacea d'Orbigny var. delrioensis Carsey, 1926, Texas Univ., Bull. 2612, p. 43.

Globigerina cretacea Tappan, 1940, Jour. Pal., vol. 14, no. 2, p. 121, pl. 19, fig. 11.

Tappan, 1943, Jour. Pal., vol. 17, no. 5, p. 512, pl. 82, figs. 16-17.

Praeglobotruncana gautierensis Bronniman - Bolli, 1959, Bull. Amer. Pal., no. 179, vol. 39, p. 265, pl. 21, figs. 3-6.

Hedbergella delrioensis Carsey - Loeblich and Tappan, 1961, Micropal., vol. 7, no. 3, p. 275, pl. 2, figs. 11-13.

Eicher, 1965, Jour. Pal., vol. 39, no. 5, p. 904, pl. 106, figs. 2, 6.

________, 1966, Contr. Cushman Found. Foram Res., vol. 17, pt. 1, p. 27, pl. 5, figs. 12, 13.

Pessagno, 1967, Paleont. Amer., vol. 5, no. 37, p. 282, pl. 48, figs. 1, 2, 3-5.

Remarks. - Hedbergella delrioensis is characterized by a small to medium sized deeply umbilicate test, globular chambers, low trochospiral arrangement of chambers (4-6, usually 5) in the last whorl. It differs from H. planispira in its larger size.

Figured specimen: Maximum diameter 0.34 mm; minimum diameter 0.28 mm; thickness 0.19 mm.

Occurrence. - Hedbergella delrioensis is one of the more abundant planktonic species in the Gavelinella dakotensis Assemblage Zone at Gallup, Delta and Wolcott. It also occurs in the Gavelinella kansasensis Assemblage Zone in Unit D5 at Delta and Unit W5 at Wolcott. It has been reported from strata of earliest Cenomanian to Middle Turonian age in the Western Interior (Loeblich and

Tappan, 1961; Eicher, 1965, 1966). Although it has been described only from strata ranging up to Middle Turonian, its range is probably greater. Previous to revision of planktonic foraminiferal taxonomy (Loeblich and Tappan, 1957, 1961) it was identified as Globigerina cretacea d'Orbigny along with other species of Hedbergella. Pessagno (1967) reports the range in the Gulf Coast to be Albian to lower Campanian. Although the range of H. delrioensis is great, in the Western Interior it is extremely abundant only in the Greenhorn Formation and correlative strata. The writer has examined samples from the Jetmore Chalk Member of the Greenhorn Formation, a chalk composed primarily of this species. The characteristic occurrence of this species in much of the chalk in the Greenhorn Formation has been reported by others. (Fox, 1954, Hattin, personal commun.; Eicher, personal commun.). Thus, it is suggested that the abundant occurrence of this species is of great correlative value in the Western Interior.

Hedbergella planispira (Tappan)
Plate 5, figures 4-5, 10-12;
Plate 7, figures 1-3.

Globigerina planispira Tappan, 1940, Jour. Pal., vol. 14, no. 2, p. 122, pl. 19, figs. 12a-c.

Globorotalia? youngi Fox, 1954, U. S. Geol. Survey Prof. Paper 254-E, p. 119, pl. 26, figs. 15-18.

<u>Praeglobotruncana planispira</u> Tappan - Bolli, Loeblich, and Tappan, 1957, U. S. Nat. Mus., Bull. 215, p. 40, pl. 9, fig. 3.

Bolli, 1959a, Bull. Amer. Pal., no. 179, vol. 39, p. 267, pl. 22, figs. 3-4.

Olsson, 1964, Micropal., vol. 10, no. 2, p. 161, pl. 1, figs. 4-5.

Eicher, 1965, Jour. Pal., vol. 39, no. 5, p. 905, pl. 106, fig. 1.

<u>Praeglobotruncana modesta</u> Bolli, 1959, Bull. Amer. Pal., no. 179, vol. 39, p. 267, pl. 22, fig. 2.

<u>Hedbergella planispira</u> Tappan - Loeblich and Tappan, 1961, Micropal., vol. 7, no. 3, p. 276, pl. 5, figs. 4-11.

<u>Remarks</u>. - <u>Hedbergella planispira</u> is characterized by small size, low trochospiral arrangement of chambers, 6-8 chambers in the last whorl, and by the small increase in chamber size in the last whorl.

Figured hypotype: Maximum diameter 0.20 mm; maximum thickness 0.13 mm.

<u>Occurrence</u>. - In the Mancos Shale <u>H. planispira</u> is restricted to the <u>Gavelinella dakotensis</u> Assemblage Zone at Gallup, Delta, and Wolcott, Units G1, D2, W3, respectively. In other parts of the Western Interior <u>H. planispira</u> is restricted to Late Genomanian - Early Turonian strata (Fox, 1954; Loeblich and Tappan, 1961; Eicher, 1965, 1966). The species is also restricted in the

Gulf Coastal Plain and Europe from Albian to Turonian strata (Pessagno, 1967). Olsson (1964), however, describes the species from the Campanian of the Atlantic Coastal Plain. Although Pessagno considers H. planispira of Olsson to be conspecific with H. holmdelensis Olsson, the range of the species might be significantly greater than just lower Upper Cretaceous. The species may have been overlooked because of its small size. Its range in the Western Interior is presently limited to the upper Greenhorn limestone and correlative strata. As such, it must be considered a valuable guide fossil in the Western Interior.

Genus LOEBLICHELLA Pessagno, 1967

Loeblichella coarctata (Bolli)
Plate 6, figures 4-6;
Plate 7, figures 7-9.

Praeglobotruncana coarctata Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 55, pl. 12, figs. 2a-3c.

Loeblichella coarctata Bolli - Pessagno, 1967, Paleont. Amer., vol. 5, no. 37, p. 288, pl. 48, figs. 14-16, 20; pl. 61, figs. 4, 5; pl. 62, figs. 1-3, 6-8; pl. 76, figs. 7-9.

Remarks. - The genus Loeblichella is characterized by having sutural supplementary apertures on the spiral side. Pessagno (1967) shows the supplementary apertures to be located at the intersection of the spiral and radial sutures. The Mancos Shale specimens have chambers filled with calcite. Most have sutures filled with foreign material. A few specimens have deep depressions at suture intersections on the spiral side. These may well be supplementary apertures.

The specimens of L. coarctata range widely in size and inflation of chambers. They all are characterized by a very low trochospiral arrangement of chambers in the last whorl which become very long relative to their width and by an extraumbilical - umbilical primary aperture. A few specimens are identical to the primary types. The Mancos Shale specimens show a range of variability in chamber shape in the final whorl from angled to ovate. The few specimens with ovate chambers may well fall within the range of L. hessi s.s. Pessagno. Since Pessagno (1967) indicates that L. hessi s.s. and L. coarctata s.s. are closely related with transitional forms common and since most specimens in the Mancos Shale are morphologically intermediate between L. hessi s.s. and L. coarctata s.s., all specimens are considered to be L. coarctata. The writer is of the opinion that L. coarctata has a wide morphological range and that L. hessi should be put in synonomy with it. Their ranges are identical. The specimens in the Mancos Shale are, however, too few to validate this opinion.

Figured hypotype: Maximum diameter 0.45 mm; thickness 0.18 mm.

Occurrence. - A few specimens of Loeblichella coarctata occur in many samples of the Mancos Shale wherever several planktonic species are abundant in the Gallup, Delta and Wolcott sections. The lower-most occurrence of the species is in the upper half of Unit G1 at Gallup in the Gavelinella dakotensis Assemblage Zone. Originally the species was described from the Campanian in Trinidad (Bolli, 1957). Pessagno (1967) indicates the range to be Upper Cenomanian to Maestrichtian in Gulf Coast strata. If the lower limit of the species range as indicated by Pessagno (1967) is valid, then the occurrence of L. coarctata in the Gavelinella dakotensis Assemblage Zone marks the first appearance of the species.

Loeblichella coarctata occurs in Unit D5 at Delta and Unit W5 at Wolcott.

Genus ROTALIPORA Brotzen, 1942

Rotalipora greenhornensis (Morrow)

Globorotalia greenhornensis Morrow, Jour. Pal., vol. 8, no. 2, p. 199, pl. 31, fig. 1.

Planulina greenhornensis Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 159, pl. 65, fig. 3.

Thalmanninela greenhornensis Bronniman and Brown, 1956, Eclogae geol. Helv., vol. 48, p. 535, pl. 20, figs. 7-9.

Rotalipora greenhornensis Loeblich and Tappan, 1961, Micropal., vol. 7, no. 3, p. 299, pl. 7, figs. 5-10.

Eicher, 1965, Jour. Pal., vol. 39, no. 5, p. 906, pl. 106, fig. 11.

Remarks. - Rotalipora greenhornensis is characterized by a deep umbilicus, a sharply angled and keeled periphery, distinct curved depressed sutures, and inflated chambers on the umbilical side with an umbilical shoulder. The Mancos specimens are identical with the primary types.

Occurrence. - Several specimens occur in the Mancos Shale near the base of the Gavelinella dakotensis Assemblage Zone in Unit G1 at Gallup and Unit W3 at Wolcott. Although Morrow (1934) restricted the range of the species to the Greenhorn Formation in Kansas, Eicher (1965) describes the species from the Graneros Formation in Eastern Colorado. There is apparently a decrease in abundance of the species northward from the Gulf Coast (Eicher, personal communication). Rotalipora greenhornensis elsewhere, however, occurs worldwide in Cenomanian and Lower Turonian strata.

Family MARGINOTRUNCANIDAE Pessagno, 1967

Genus MARGINOTRUNCANA Hofker, 1956

Marginotruncana renzi (Gandolfi)

Plate 7, figures 13-15.

Globotruncana renzi Gandolfi, 1942, Riv. Ital. Pal., Ann. 48, mem 4, p. 124, text - fig. 45a-c, pl. 4, fig. 15.

Globotruncana c.f. lapparenti coronota Bolli - Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 58, pl. 14, figs. 3a-c.

Marginotruncana renzi Gandolfi - Pessagno, 1967, Paleont. Amer., vol. 37, no. 5, p. 310, pl. 55, figs. 4-7; pl. 65, figs. 20-23; pl. 98, figs. 3-4. (See Pessagno for additional synonomy)

Remarks. - Marginotruncana renzi is characterized by having five to six petaloid chambers in the last whorl, a plano-convex test, beaded sutures on the spiral side, and depressed or flush, curved sutures on the umbilical side.

According to Pessagno (1967, p. 311) M. renzi has had a "chaotic taxonomic history." The specimens were originally compared with and considered conspecific with the specimen of Globotruncana c.f. lapparenti coronata Bolli (Bolli, 1957, loc cit) at the U. S. National Museum. Since then Pessagno has placed that specimen in synonomy with M. renzi Gandolfi. The writer follows Pessagno by referring the specimens in the Mancos Shale to *M. renzi*.

Marginotruncana renzi differs from *Globotruncana bulloides* Vogler in its plano-convex test, an umbilical-extraumbilical primary aperture, and depressed or flush sutures on the umbilical side. It differs from *M. difformis* (Gandolfi) in a nearly flat spiral side and depressed curved sutures on the umbilical side.

Figured hypotype: Maximum diameter 0.50 mm; thickness 0.25 mm.

Family GLOBOTRUNCANIDAE Brotzen, 1942

Genus ARCHAEOGLOBIGERINA Pessagno, 1967

Archaeoglobigerina bosquensis Pessagno

Plate 7, figures 4-6.

Archaeoglobigerina bosquensis Pessagno, 1967, Paleont. Amer., vol. 37, no. 5, p. 316, pl. 60, figs. 6-12.

Remarks. - *Archaeoglobigerina bosquensis* is characterized by six to eight chambers in the last whorl, a small deep umbilicus, and chambers which increase in size gradually. Pessagno (1967) states that the species is characterized by a relatively high trochospiral coil. The illustrations of the holotype show that only the last whorl is high spired whereas the early whorls are low trochospiral. The specimens in the Mancos Shale are typically low spired in the early whorl and have a high spire in the final whorl. Only one specimen in the Mancos

Shale is high spired throughout. Upon careful examination a faint carinal band is visible on the chambers of the last whorl.

Archaeoglobigerina bosquensis differs from *A. cretacea* d'Orbigny by an average of seven chambers in the last whorl and by the absence of a distinct double keel.

Figured specimen: Maximum diameter 0.58 mm; thickness 0.30 mm.

Occurrence. - *Archaeoglobigerina bosquensis* has been found only in one sample at Wolcott where it occurs abundantly and is associated with *A. cretacea* 550 feet above the base of the formation. At Delta it occurs rarely in the *Gavelinella kansasensis* Assemblage Zone. *Archaeoglobigerina bosquensis* occurs only in samples that contain *Marginotruncana renzi* (Gandolfi). Its present known range is Lower Santonian (Pessagno, 1967). It apparently occurs only in samples containing a varied benthonic fauna.

Archaeoglobigerina cretacea (d'Orbigny)

Plate 7, figures 10-12.

Globigerina cretacea d'Orbigny, 1840, Soc. Geol. France, Mem., Paris, vol. 2, no. 1, p. 34, pl. 3, figs. 12-14.

Globotruncana cretacea d'Orbigny - Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, pp. 8-10, pl. 7, figs. 1a-c.

Archaeoglobigerina cretacea d'Orbigny - Pessagno, 1967, Paleont. Amer., vol. 5, no. 37, p. 317, pl. 70, figs. 3-8; pl. 94, figs. 4-5.

Remarks. - *Archaeoglobigerina cretacea* is characterized by a low trochospiral arrangement of subspherical chambers, a uniform small increase in size of chambers of the last whorl, extremely weak double carinal bands which are more apparent in the early chambers of the last whorl, and interiomarginal umbilical aperture. *Archaeoglobigerina* cretacea differs from *A. blowi* Pessagno by the more spherical chambers.

Figured hypotype: Maximum diameter 0.60 mm; thickness 0.30 mm.

Occurrence. - In the Mancos Shale *Archaeoglobigerina cretacea* occurs in the lower half of the *Gavelinella henbesti* Assemblage Zone at Delta. The upper limit of the species apparently is ecologically controlled because above its stratigraphic range at Delta no planktonic Foraminifera have been found. In the Gulf Coast it ranges from basal Coniacian to middle Maestrichtian strata (Pessagno, 1967). The probable range in the Mancos Shale is Upper Santonian- Lower Campanian.

Family OSANGULARIIDAE Loeblich and Tappan, 1964

Genus GYROIDINOIDES Brotzen, 1942

Gyroidinoides subconicus (Morrow)

Plate 6, figures 7-9.

Globorotalia subconica Morrow, 1943, Jour. Pal., vol. 8, no. 3, p. 200, pl. 30, figs. 11a-c, 18.

Loetterle, 1937, Nebraska Geol. Survey, Bull. 12, 2nd series, p. 43, pl. 6, figs. 10a-c.

Remarks. - Gyroidinoides subconicus is characterized by a flat to depressed spiral side, convex angular conical umbilical side, a smooth to slightly lobulate periphery which is angled but not keeled, and a deep, small umbilicus.

Loeblich and Tappan (1961, p. 259) in their synonomy place G. subconicus in the genus Globorotalites. However, Morrow (1934) and Loetterle (1937) do not mention a keel and the holotype shows no evidence for either a keel or poreless periphery. The Mancos specimens are identical with the primary types and show neither a keel nor poreless margin. The species is therefore placed in the genus Gyroidinoides.

Figured specimen: Maximum diameter 0.25 mm; thickness 0.13 mm.

Occurrence. - Seventeen specimens of Gyroidinoides subconicus have been found in the Mancos Shale in the Gavelinella kansasensis Assemblage Zone at Wolcott.

Loetterle (1937) records its occurrence as widely distributed in the Fort Hays Member of the Niobrara Formation in Kansas. The fact that it has previously been found only in a limestone suggests a limited ecological distribution.

Family CAUCASINIDAE N. K. Bykova, 1959

Genus CASSIDELLA Hofker, 1951

Cassidella tegulata (Reuss)

Plate 4, figure 11.

Virgulina tegulata Reuss, 1851, Haidinger's Nat. Abh., vol. 4, p. 29, pl. 4, fig. 12.

Bolivina tegulata Reuss - Morrow, 1934, Jour. Paleon., vol. 8, no. 2, p. 196, pl. 30, figs. 21a-b.

Loxostomum tegulatum Reuss - Cushman, 1931, Tenn. Div. Geol., Bull. 41, p. 51, pl. 8, fig. 8.

Young, 1951, Jour. Paleon., vol. 25, no. 1, p. 64, pl. 14, fig. 13.

Remarks. - Cassidella tegulata is characterized by its elongate slender biserial test, by its slight twisting and by its low broad chambers.

Figured hypotype: Length 0.33 mm; maximum width 0.13; thickness 0.05 mm.

Occurrence. - Cassidella tegulata is present in the Gavelinella dakotensis Assemblage Zone at Gallup. In other parts of the Western Interior it has been reported from the Frontier Formation (Young, 1951) and from the Upper Greenhorn Formation in Wyoming (Fox, 1954) and Kansas (Morrow, 1934). It is possible that this distinctive species has a restricted range. Although rare it is useful for correlation.

Family LOXOSTOMIDAE Loeblich and Tappan, 1962

Genus LOXOSTOMUM Ehrenberg, 1858

Loxostomum clavatum (Cushman)

Bolivina clavatum Cushman, 1927, Cushman Lab. Forma. Res. Contr., vol. 2, pt. 4, p. 87, pl. 12, figs. 5a-b.

Loxostomum clavatum Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 130, pl. 54, figs. 4-9.

Remarks. - Loxostomum clavatum differs from L. cushmani Wickenden in its highly tapered test and in possessing more crenulations.

Figured hypotype: Length 0.80 mm; diameter 0.22 mm.

Occurrence. - In the Mancos Shale L. clavatum occurs commonly in the Gavelinella henbesti Assemblage Zone at Delta. In the Gulf Coast Cushman (1946) reports its stratigraphic range to be from Austinan to Tayloran strata. However, it is typically Tayloran in age.

Family ANOMALINIDAE Cushman, 1927

Genus ANOMALINOIDES Brotzen, 1942

Anomalinoides sp.

Plate 8, figures 1-3, 4-6.

Description. - Test free, nearly planispiral with portions of early chambers visible on the spiral side, and only chambers of the last whorl visible on the opposite umbilical side, biconvex, broadly rounded, 8-9 chambers visible on the umbilical side; periphery slightly lobulate; chambers distinct, wider than long, increasing slowly in size; sutures distinct, slightly depressed; aperture an equatorial slit extending from the umbilical side of the periphery to the last 3-4 chambers of the spiral side bordered by a narrow lip extending from the periphery to the umbilical margin of the last 3-4 chambers of the spiral side; wall calcareous, hyaline with extremely large perforations.

Figured specimen: Plate 8, figures 1-3; maximum diameter 0.27 mm, thickness 0.17 mm.

Figured specimen: Plate 8, figures 4-6; maximum diameter 0.26 mm, thickness 0.14 mm.

Remarks. - Anomalinoides sp. differs from all similar species by its large perforations. Because of the limited number of specimens in only a few samples, the writer considers it inappropriate to name a new species at this time.

Occurrence. - *Anomalinoides sp.* occurs in three samples in the uppermost part of the *Haplophagnoides rota* Assemblage Zone at Delta.

Genus GAVELINELLA Brotzen, 1942

Gavelinella austinana (Cushman)

Planulina austinana Cushman, 1940, Cush. Lab. Foram. Res. Contr., vol. 14, p. 68, pl. 12, figs. 2a-c.
Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 156, pl. 64, fig. 10.

Remarks. - *Gavelinella austinana* is distinguished by its compressed lobulate trochospiral test, slightly inflated chambers numbering eight to ten in the last whorl, distinct fine perforations, and apertural flap which broadens to a triangular flap in the umbilicus. Specimens in the Mancos Shale are identical with the primary types.

Gavelinella austinana differs from *G. dakotensis* by its larger size, a distinctly lobulate test, raised sutures, with rather depressed, rarely flush, sutures in the final whorl. Small specimens of *G. austinana* are difficult to distinguish from *G. dakotensis* because they tend not to have a lobulate periphery.

Figured specimen: Maximum diameter 0.43 mm; minimum diameter 0.30 mm; maximum thickness 0.13 mm.

Occurrence. - *Gavelinella austinana* is abundant near the top of the G. dakotensis Assemblage Zone at

Gallup. Although it has been reported only from the Austinan in the Gulf Coast (Cushman, 1946), in the Mancos Shale it is associated with a varied and typical equivalent Upper Greenhorn fauna. Its range must therefore be extended down to the Upper Cenomanian - Lower Turonian.

Gavelinella bighornensis (Young)

Plate 9, figures 10-12.

Anomalina bighornensis Young, 1951, Jour. Paleon., vol. 25, no. 1, p. 66, pl. 14, figs. 17-22.

Remarks. - Gavelinella bighornensis is distinguished by its small size, by its uninflated chambers numbering 8 to 10 in the final whorl, and in being coarsely perforated.

Maximum diameter 0.23 mm; thickness 0.05 mm.

Occurrence. - Gavelinella bighornensis occurs rarely in the Gavelinella dakotensis Assemblage Zone at Gallup. It has previously been recorded from the Frontier Formation 30 feet below the "Vascoceras" beds (Young, 1951) and from the Greenhorn Formation in Wyoming (Fox, 1954).

Gavelinella dakotensis (Fox)

Plate 8, figures 13-15.

Planulina dakotensis Fox, 1954, U. S. Geol. Survey Prof. Paper 254-E, p. 119, pl. 26, figs. 19-21.

Gavelinella dakotensis Fox - Eicher, 1965, Jour. Pal., vol. 39, p. 30, pl. 6, fig. 7.

________, 1967, Jour. Pal., vol. 41, p. 186, pl. 19, fig. 12.

Description. - Test free, trochospiral, small, slightly biconvex, strongly compressed; periphery rounded, subacute; 2-2½ whorls visible on spiral side, 7-9 chambers visible on opposite side forming a shallow umbilicus; chambers distinct, not inflated in early portion of test, last 3-4 slightly inflated; sutures distinct, limbate, raised or flush in early whorls becoming depressed in last 3-4 chambers; wall calcareous finely perforate; surface smooth; aperture a low interiomarginal - extra-umbilical slit bordered by a narrow lip extending from the periphery to the umbilicus.

Figured specimen: Maximum diameter 0.23 mm; thickness 0.08 mm.

Remarks. - Gavelinella dakotensis differs from G. ammonoides (Reuss) in fewer chambers in the final whorl, from G. tumida Brotzen in greater compression and in raised or flush limbate sutures; from Gavelinella kansasensis (Morrow) in smaller size and absence of a calcareous umbonal boss.

Occurrence. - This species is very common in the Mancos Shale at Gallup. A few specimens occur near the base of the formation at Delta and Wolcott. The distinctiveness of the species and its wide distribution in a limited stratigraphic interval suggest usefulness as a zonal fossil.

Gavelinella dakotensis has been reported as abundant in the Greenhorn Formation in South Dakota (Fox, 1954) where it is restricted to the upper Greenhorn. Eicher (1965) describes the species from the upper Greenhorn and lower Carlile Formations in eastern Colorado.

Gavelinella henbesti (Plummer)

Plate 9, Figures 1-3, 4-6.

Amomalina henbesti Plummer, 1936, Texas Univ., Bull. 3501, p. 290, pl. 5, figs. 7-10.

Cushman, 1946, U. S. Geol. Survey, Bull. 206, p. 155, pl. 64, fig. 2.

Planulina complanata Plummer-Loetterle, 1937, Nebraska Geol. Survey, Bull. 12, 2nd ser., p. 48, pl. 8, figs. 1a-c.

Remarks. - Gavelinella henbesti is characterized by a much compressed umbonate test, parts of early chambers exposed on the umbilical side of the test, and by a trochospiral chamber arrangement that is nearly planispiral.

Gavelinella henbesti is one of the most easily recognized and abundant species in the upper part of the Mancos Shale. Although many samples which contain G. henbesti also contain a number of other benthonic and planktonic species, several yielded only specimens of G.

henbesti. Other samples yielded a few specimens of other species including G. henbesti.

Occurrence. - Gavelinella henbesti occurs abundantly from 2000 to 2600 feet above the base of the formation at Delta and from 1800 feet to 2000 feet at Wolcott. It is known from the Fort Hays Member of the Niobrara Formation and from the Taylor and the Navarroan of the Gulf Coast.

Gavelinella kansasensis (Morrow)

Plate 9, figures 7-9.

Planulina kansasensis Morrow, 1934, Jour. Pal., vol. 8, no. 2, p. 201, pl. 30, figs. 2a-c, 12a-c, 15a-c.

Loetterle, 1937, Nebraska Geol. Survey, Bull. 12, 2nd ser., p. 49, pl. 8, figs. 2a-c.

Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 157, pl. 64, fig. 12.

Remarks. - Gavelinella kansasensis is characterized by the large number of chambers (10-11) in the last whorl, its large size, and its relative thinness.

Occurrence. - Gavelinella kansasensis occurs commonly in samples from 500 to 1100 feet above the base of the formation at Delta. Also, it has been found in several samples at Wolcott. Because of its wide geographic distribution in the Western Interior and its limited vertical range it has been chosen as a zone fossil. In other parts of the Western Interior it is known from the upper Carlile

Formation, the Niobrara Formation of Kansas, and from the Niobrara equivalent of the Cody Shale (Fox, 1954).

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APPENDIX 1

PLATES OF FORAMINIFERA

PLATE 1

Figures 1, 18. Reophax troyeri

Hypotypes from the Delta Section 3514 feet above the base of the formation in the Haplophragmoides rota Assemblage Zone.

Figure 1 (x 50); Figure 18 (x 25)

Figures 2, 9. Flabellammina compressa (Beisel)

Hypotypes from the Delta section 3524 feet above the base of the formation in the Haplopragmoides rota Assemblage Zone.

Figure 1 (x 50); Figure 9 (x 41)

Figures 3, 8. Gaudryina bentoensis (Carman)

Hypotypes from the Delta section 3514 feet above the base of the formation in the Haplophragmoides rota Assemblage Zone.

Figure 3. Hypotype (x 41) showing uniserial arrangement of adult chambers.

Figure 8. Hypotype (x 82) showing biserial arrangement of adult chambers.

Figure 4. Bigenerina hastata Cushman (x 65)

Hypotype from the Gallup Section 120 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figure 5. Spiroplectammina lalickeri Albritton and Phleger (x 65)

Hypotype from the Delta section 1090 feet above the base of the formation in the *Gavelinella kansasensis* Assemblage Zone.

Figures 6-7. *Haplophragmoides bonanzaensis* Steck and Wall (x 80)

Hypotype from the *Haplophragmoides rota* Assemblage Zone 3514 feet above the base of the formation at Delta.

Figure 10, 15-16. *Haplophragmoides rota* Nauss

Figure 10. (x 80) Crushed specimen from the Delta section.

Figures 15-16. (x 68) Hypotype from the Delta section 3514 feet above the base of the formation.

Figure 11. *Bullopora laevis* (Solas) (x 80)

Hypotype from Delta section 2250 feet above the formation in the *Gavelinella henbesti* Assemblage Zone.

Figure 12. *Saccammina difflugiformis* (Brady) x 65

Hypotype from the Delta section 3514 feet above the base of the formation in the *Haplophragmoides rota* Assemblage Zone.

Figure 13. *Dorothia bulleta* (Carsey) x 80

Hypotype from the Delta section 3490 feet above the base of the formation in the *Haplophragmoides rota* Assemblage Zone.

Figure 14. *Ammodiscus cretaceus* x 35

Hypotype from the Delta section 3524 feet above the base of the formation in the *Haplophragmoides rota*

Figure 17. Thalmannammina sp. (x 80)

Specimen from Delta section 514 feet above the base of the formation in the Haplophragmoides rota Assemblage Zone.

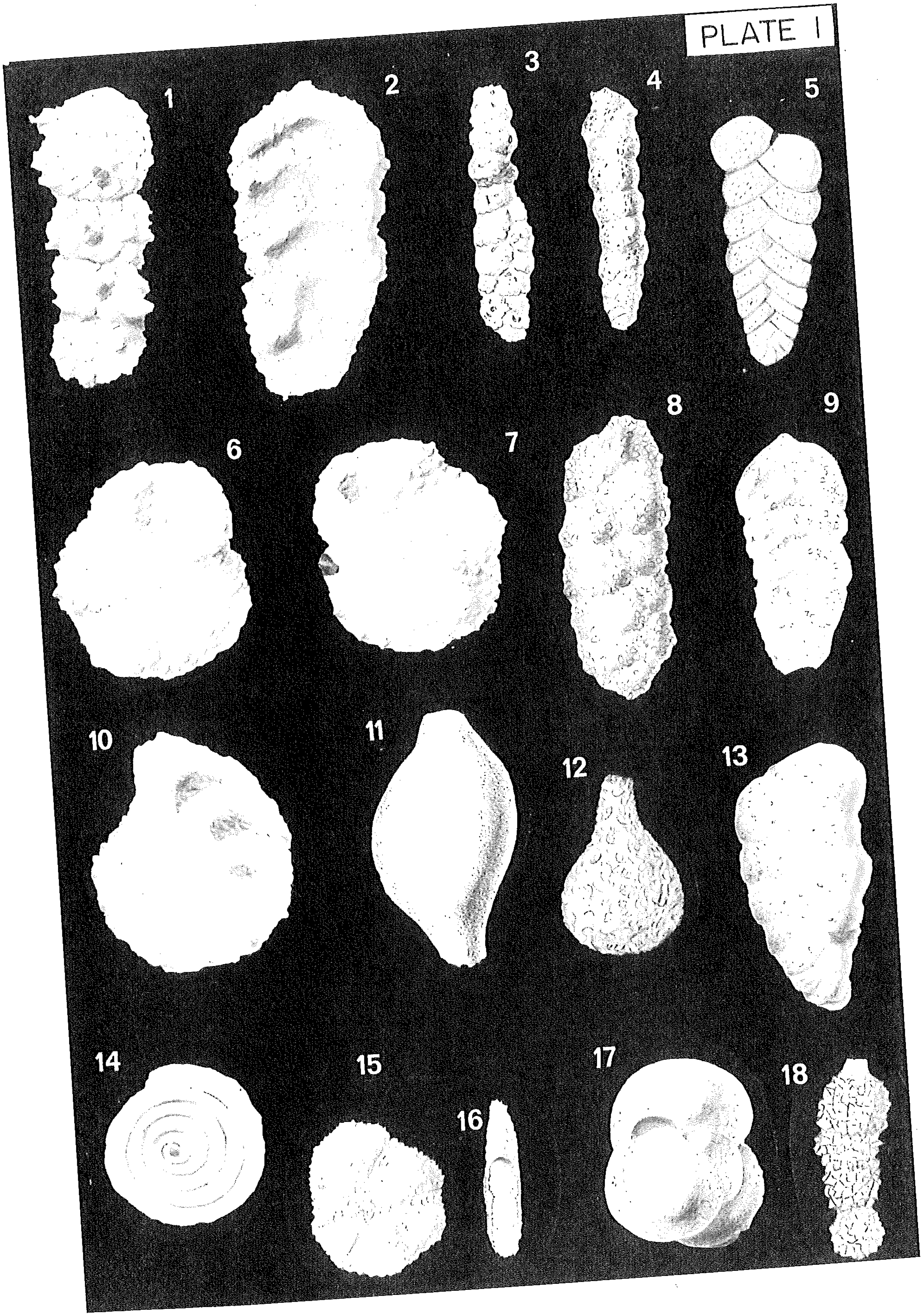

PLATE 2

Figures 1-2. *Thalmannammina sp.* (x 55)

Figured specimen from the Delta section 3514 feet above the base of the formation in the *Haplophragmoides rota* Assemblage Zone.

Figures 3-5, 6-8, 9-10. *Trochammina* sp.

Figures 3-5 (x 112)

Figures 6-8 (x 80)

Figures 9-10 (x 80)

All figured specimens from the Delta section 3520 feet above the base of the formation in the *Haplophragmoides rota* Assemblage Zone.

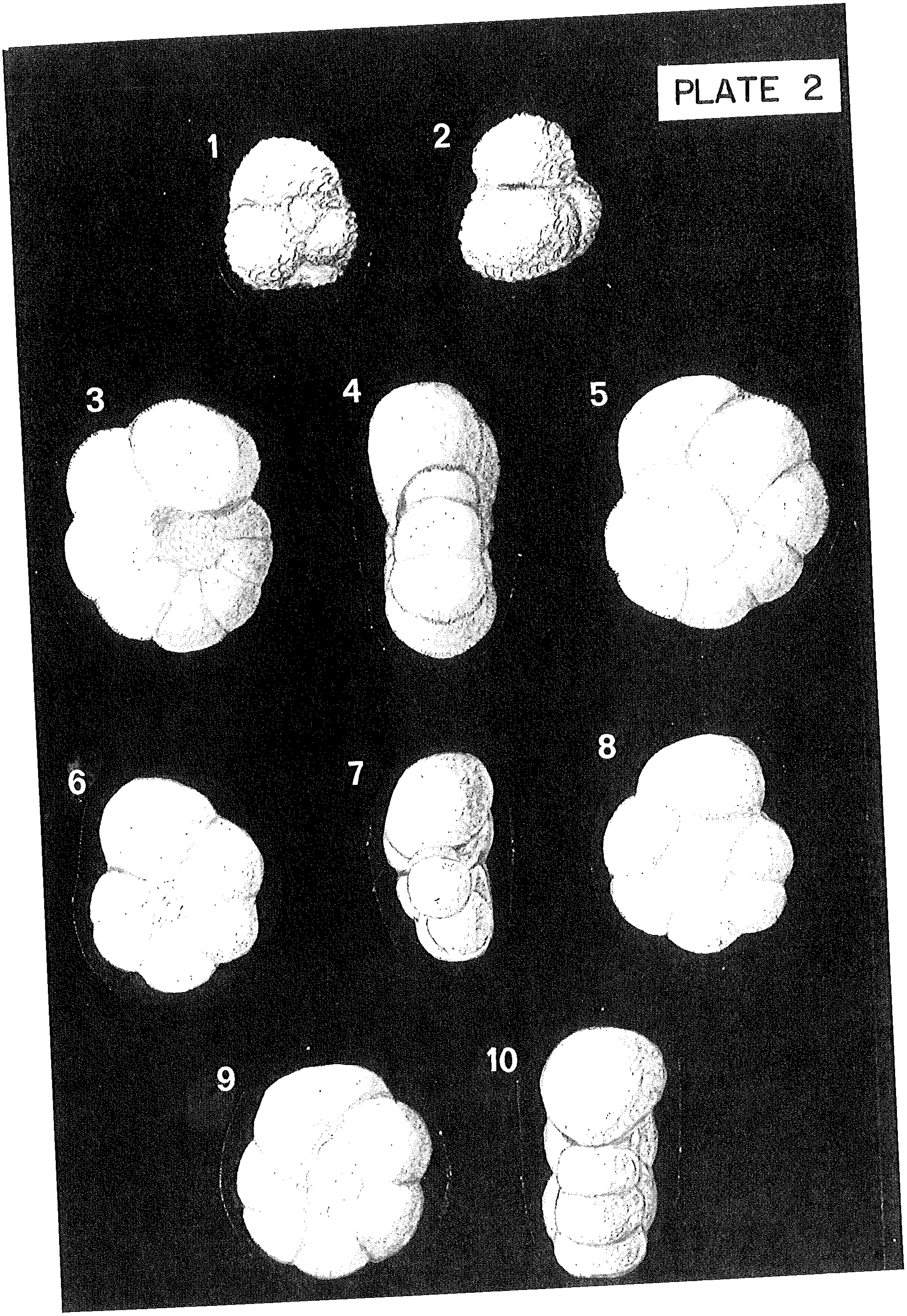
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PLATE 3

Figures 1-3. Trochammina uniforma n. sp. Hirsch (x 68)

Paratype from the Delta section 3520 feet above the base of the formation in the Haplophragmoides rota Assemblage Zone.

Figure 4. Frondicularia aelis Morrow (x 82)

Hypotype from the Wolcott section 354 feet above the base of the formation in the Gavelinella kansasensis Assemblage Zone.

Figure 5. Frondicularia inversa Reuss (x 82)

Hypotype from the Gallup section 140 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figures 6-7. Haplophragmoides bonanzaensis Stelck & Wall (x 65)

Hypotype from the Delta section 3710 feet above the base of the formation in the Haplophragmoides rota Assemblage Zone.

Figure 8. Marginulinopsis amplaspira Young (x 76)

Hypotype from the Gallup section 130 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figures 9, 10. Marginulina gallupina n. sp. Hirsch

Figure 9. Holotype (x 24) from the Gallup section 130 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figure 10. Paratype (x 19) from the Gallup section 130 feet above the base of the formation in the *Gavelinella dakotensis* Assemblage Zone.

Figure 11. *Palmula suturalis* (d'Orbigny) (x 32)

Hypotype from the Wolcott Section 354 feet above the base of the formation in the *Gavelinella kansasensis* Assemblage Zone at Delta.

Figures 12, 18, 19. *Vaginulina kockii* Roemer

All hypotypes are from the Gallup Section in the *Gavelinella dakotensis* Assemblage Zone.

Figure 12. Hypotype (x 40) 130 feet above the base of the formation.

Figures 18, 19. Hypotypes (x 40) 150 feet above the base of the formation.

Figure 13. *Dentalina reflexa* Morrow (x 67)

Hypotype from the Delta Section 60 feet above the base of the formation in the *Gavelinella dakotensis* Assemblage Zone.

Figures 14, 15. *Dentalina* cf. *D. consobrina* d'Orbigny (x 30)

Hypotype from the Gallup section 150 feet above the base of the formation in the *Gavelinella dakotensis* Assemblage Zone.

Figures 17, 25. *Dentalina lorneiana* (d'Orbigny) (x 40)

Hypotypes from the Gallup section 290 feet above the base of the formation in the *Gavelinella dakotensis* Assemblage Zone.

Figure 20. Saracenaria reesidei Fox (x 68)

Hypotype from the Gallup section 130 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figures 21-22, 23-24. Lenticulina gaultina (Berthelin) (x 83)

Hypotypes from the Gallup section 130 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

PLATE 3

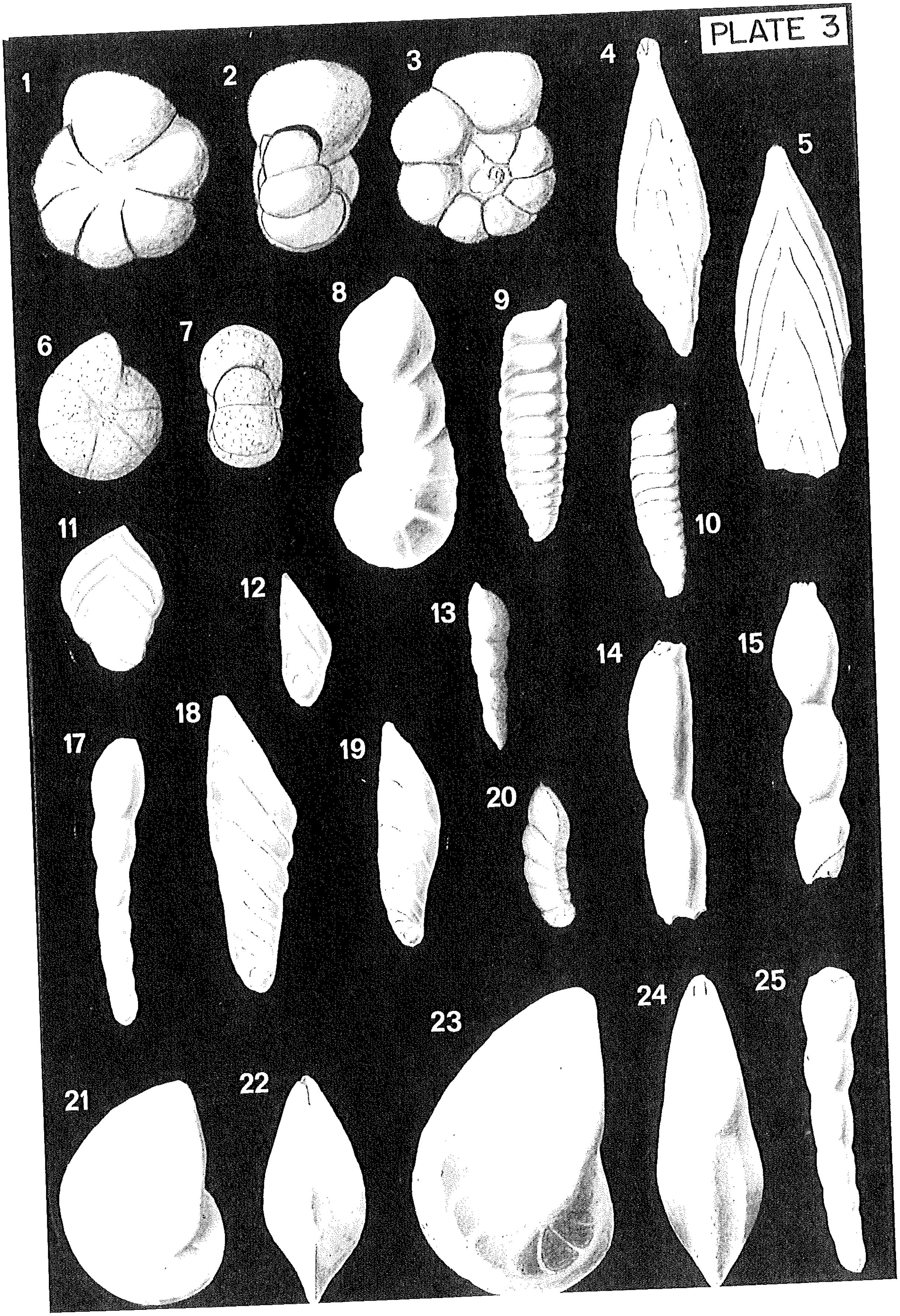

PLATE 4

Figures 1-2, 3-4. Lenticulina gaultina (Berthelin) (x 83)

Hypotypes from the Gallup section in the Gavelinella dakotensis Assemblage Zone.

Figure 5. Palmula sp. (x 30)

Specimen from the Gallup section in the Gavelinella dakotensis Assemblage Zone.

Figure 6, 12. Praebulimina carseyae (Plummer) (x 180)

Hypotypes from the Wolcott section 770 feet above the base of the formation in the Gavelinella henbesti Assemblage Zone.

Figures 7, 13. Neobulimina canadensis Cushman and Wickenden

Hypotypes from the Gavelinella dakotensis Assemblage Zone at Gallup.

Figure 7 (x 112); Figure 13 (x 80)

Figure 8. Praebulimina wyomingensis (Fox) (x 112)

Hypotype from the Gallup section 180 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figures 9-10. Heterohelix moremani (Cushman) (x 140)

Hypotype from the Gallup section 130 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figure 11. Cassidella tegulata (Reuss) (x 130)

Hypotype from the Gallup section 110 feet above the base of the formation in the Gavelinella dakotensis

Assemblage Zone.

Figures 14-15. *Heterohelix striata* (Ehrenberg) (x 110)

Hypotype from the Delta section in the *Gavelinella henbesti* Assemblage Zone.

Figures 16-17. *Heterohelix globulosa* (Ehrenberg) (x 65)

Hypotype from the Gallup section in the *Gavelinella dakotensis* Assemblage Zone.

Figure 18. *Guembelitria cretacea* Cushman (x 180)

Hypotype from the Gallup section in the *Gavelinella dakotensis* Assemblage Zone.

PLATE 4

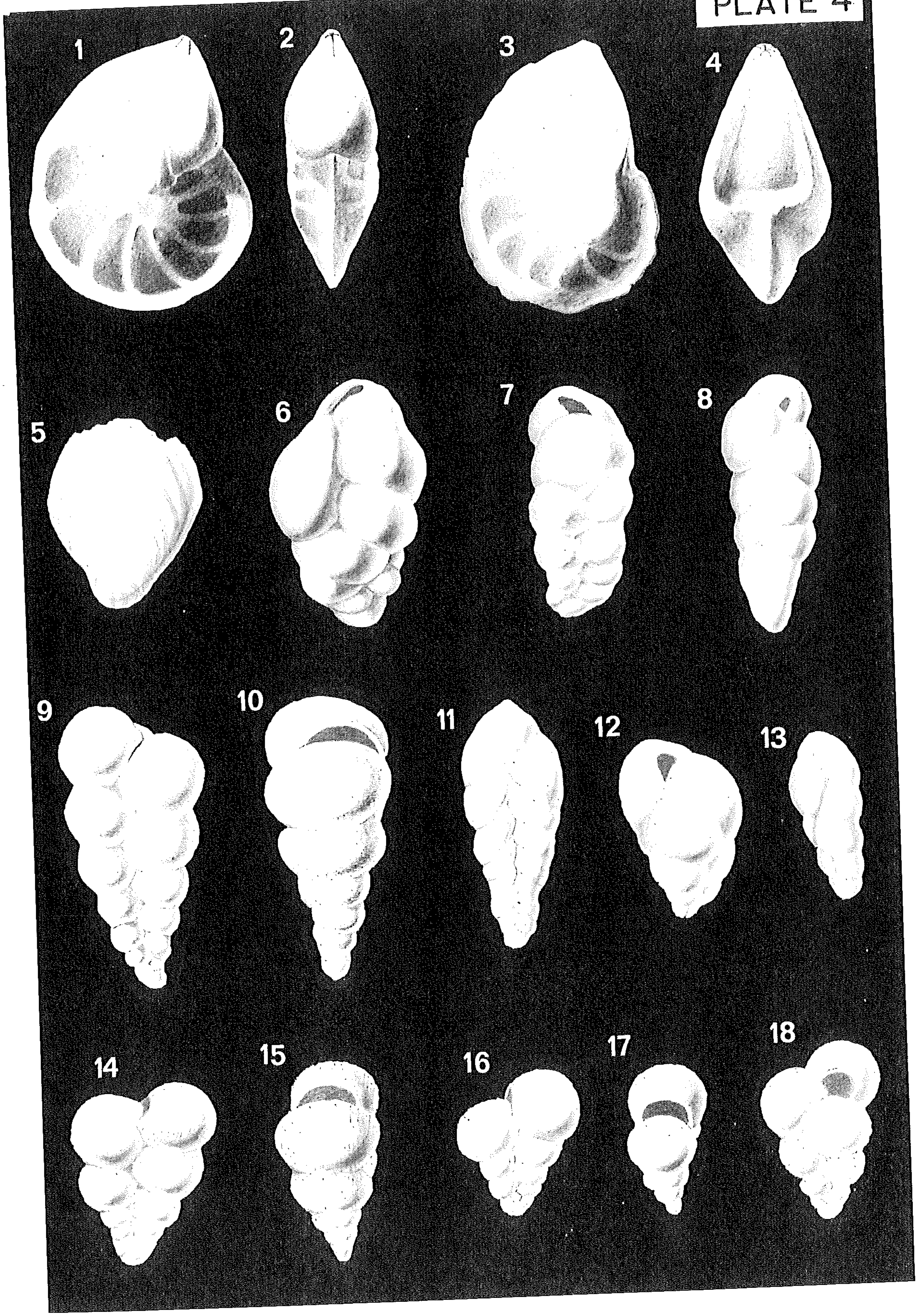

PLATE 5

Figures 1-3. Hedbergella delrioensis (Carsey) (x 100)

Hypotype from the Gallup section 150 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figures 4-5, 10-12. Hedbergella planispira (Tappan) (x 150)

Hypotype from the Delta section 500 feet above the base of the formation in the Anomalinoides kansasensis Assemblage Zone.

Figures 6-7. Hedbergella amabilis Loeblich and Tappan (x 100)

Hypotype from the Wolcott section 552 feet above the base of the formation in the Anomalinoides kansasensis Assemblage Zone.

Figures 8-9. Globigerinelloides prairiehillensis Pessagno (x 100)

Hypotype from the Delta section 2290 feet above the base of the formation in the Anomalinoides henbesti Assemblage Zone.

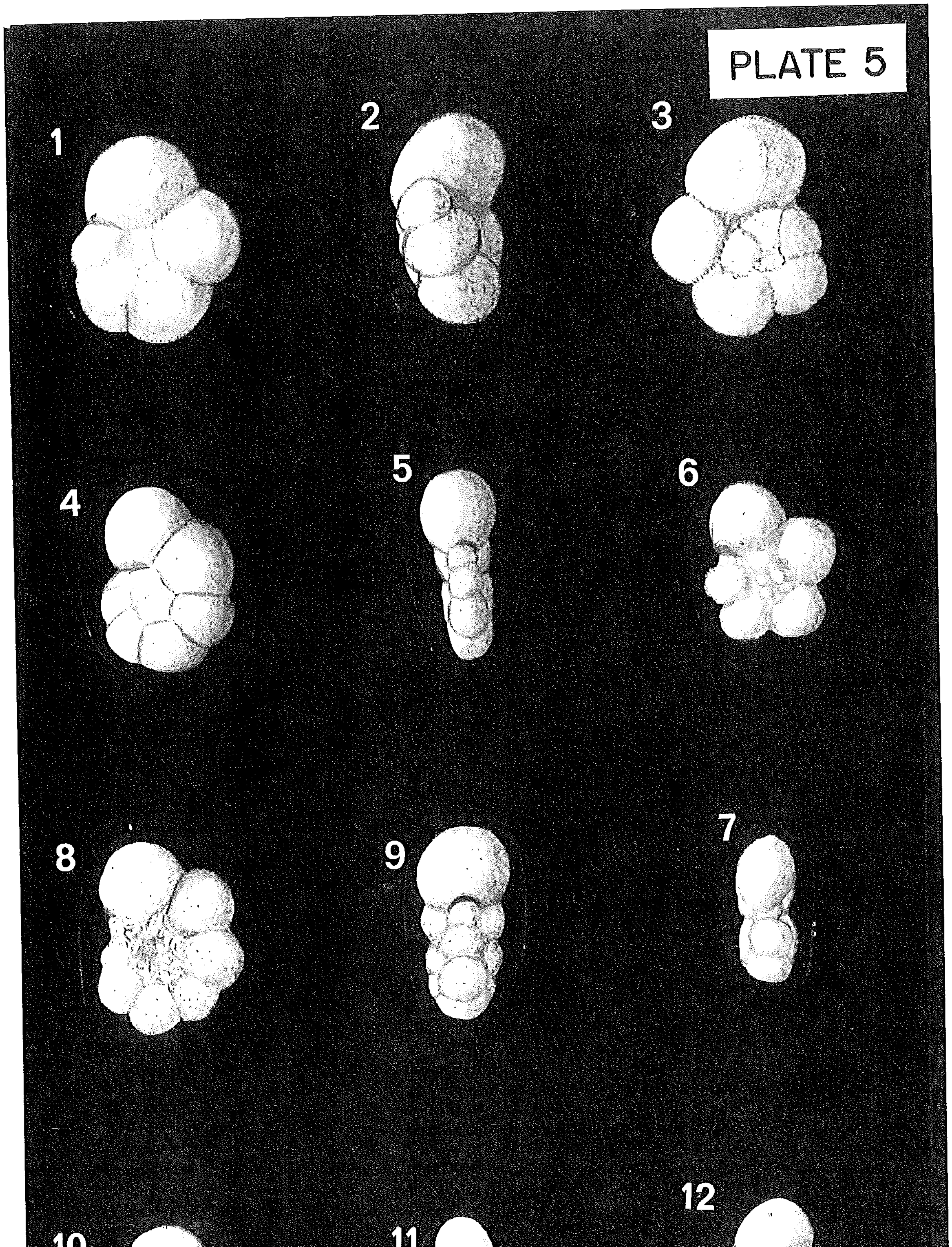
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PLATE 6

Figures 1-3. Hedbergella brittonensis Loeblich and Tappan (x 50)

Hypotype from the Gallup section 136 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figures 4-6. Loeblichella coarctata (Bolli) (x 150)

Hypotype from the Gallup section 262 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figures 7-9. Gyroidinoides subconicus (Morrow) (x 100)

Hypotype from the Wolcott section 352 feet above the base of the formation in the Gavelinella kansasensis Assemblage Zone.

Figures 10-12. Valvulineria lotterlei (Tappan) (x 100)

Hypotype from the Gallup section 130 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

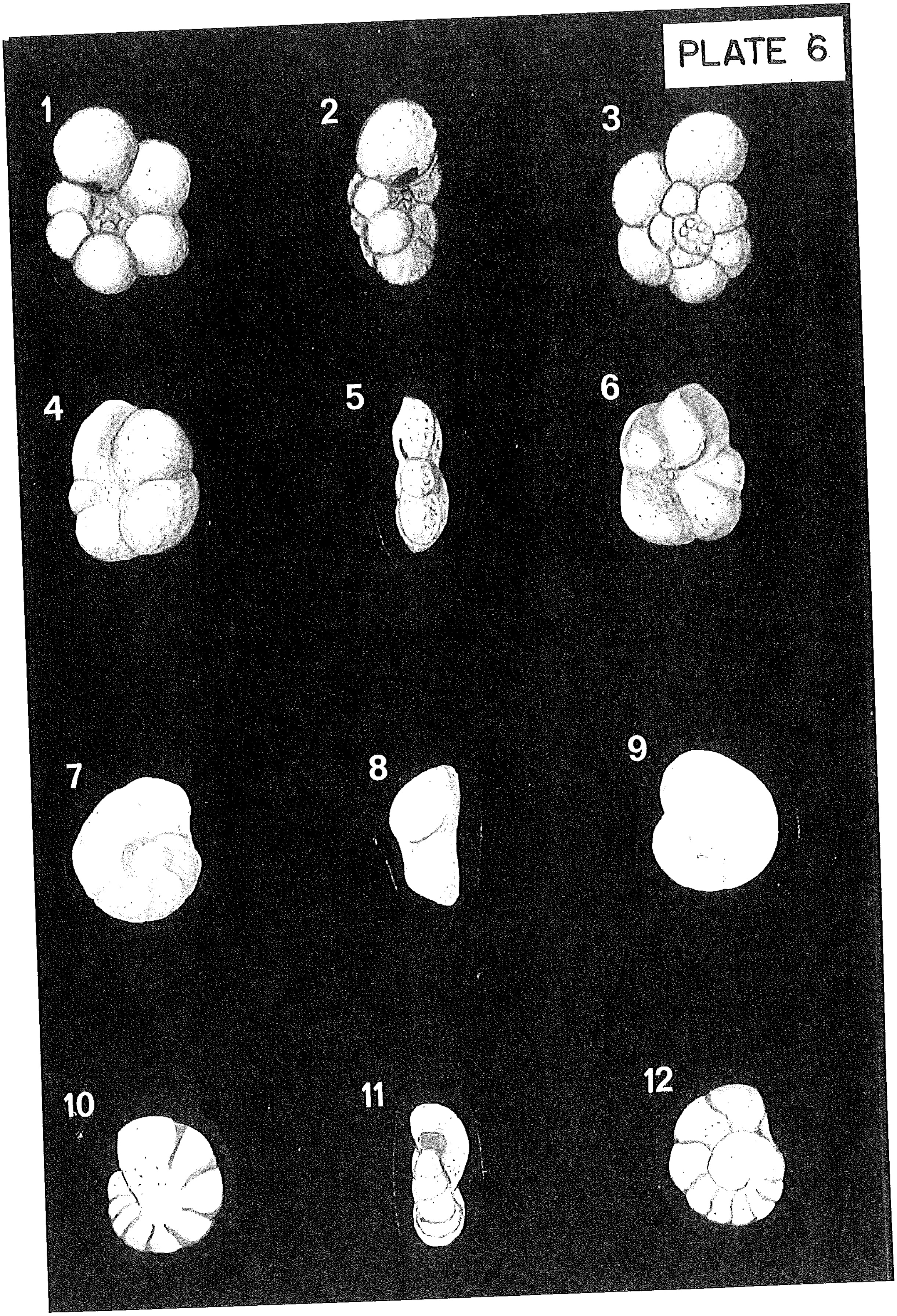
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PLATE 7

Figures 1-3. Hedbergella planispira (Tappan) (x 140)

Hypotype from the Gallup section 150 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figures 4-6, 10-12. Archaeglobogerina bosquensis Pessagno (x 70)

Hypotype from the Wolcott section 558 feet above the base of the formation in the Gavelinella kansasensis Assemblage Zone.

Figures 7-9. Loeblichella coarctata Pessagno (x 70)

Hypotype from the Gallup section 282 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figures 10-12. Archaeoglobogerina cretacea (d'Orbigny) (x 70)

Hypotype from the Wolcott section 354 feet above the base of the formation in the Gavelinella kansasensis Assemblage Zone.

Figures 13-5. Marginotruncana renzi (Gandolfi) (x 70)

Hypotype from the Delta section 920 feet above the base of the formation in the Gavelinella kansasensis Assemblage Zone.

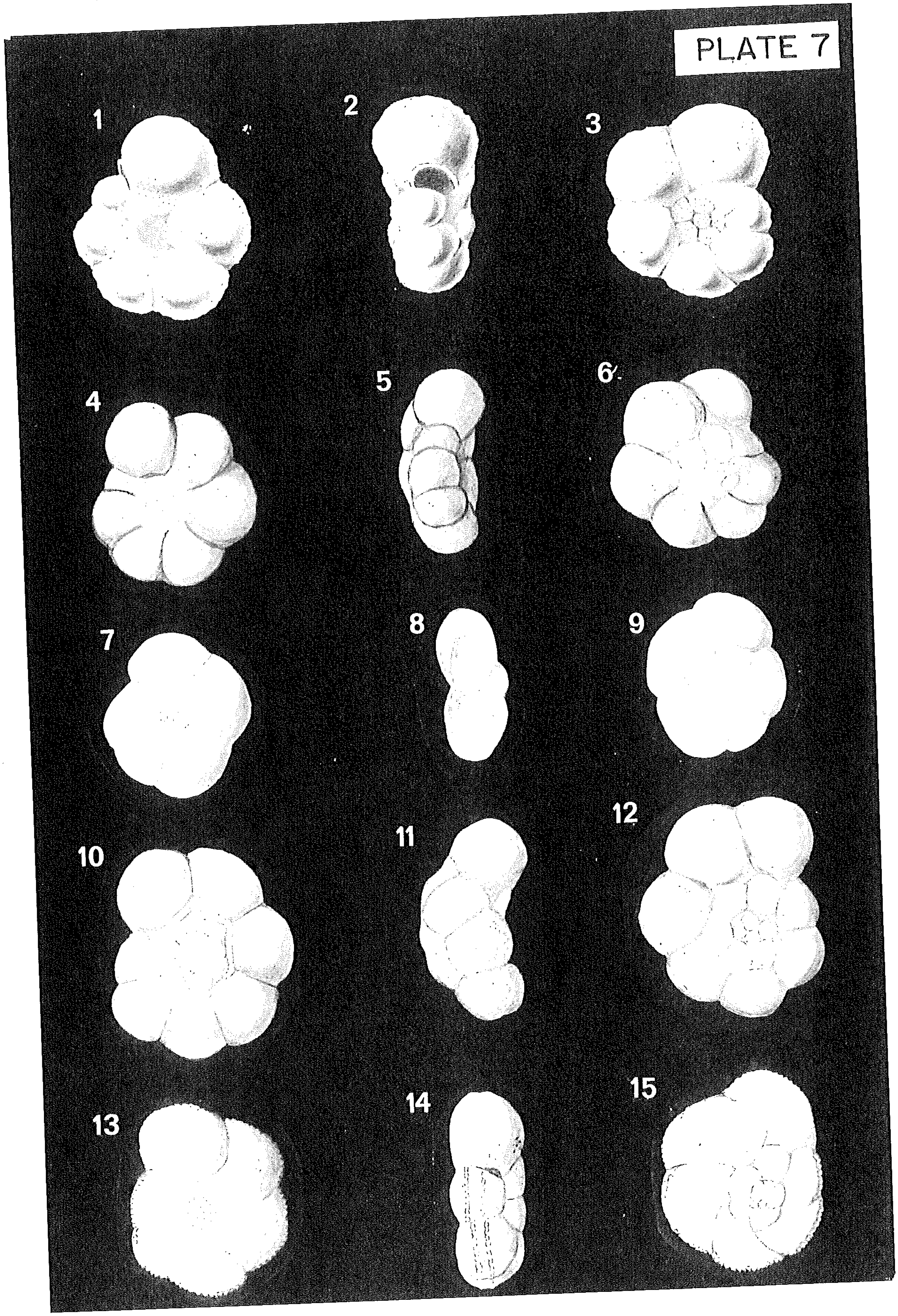
PLATE 7
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PLATE 8

Figures 1-3, 4-6. Anomalinoides sp.

Figures 1-3 (x 120)

Figures 4-6 (x 120)

Figured specimens from the Delta section 3514 feet above the base of the formation in the Haplophragmoides rota Assemblage Zone.

Figures 7-9, 10-12. Valvulineria lotterlei (Tappan) (x 120)

Hypotypes from the Gallup section 130 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

Figures 13-15. Gavelinella dakotensis (Fox) (x 120)

Hypotype from the Gallup section 150 feet above the base of the formation.

Figures 16-18. Valvulineria plummerae Lotterle (x 120)

Hypotype from the Gallup section 130 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

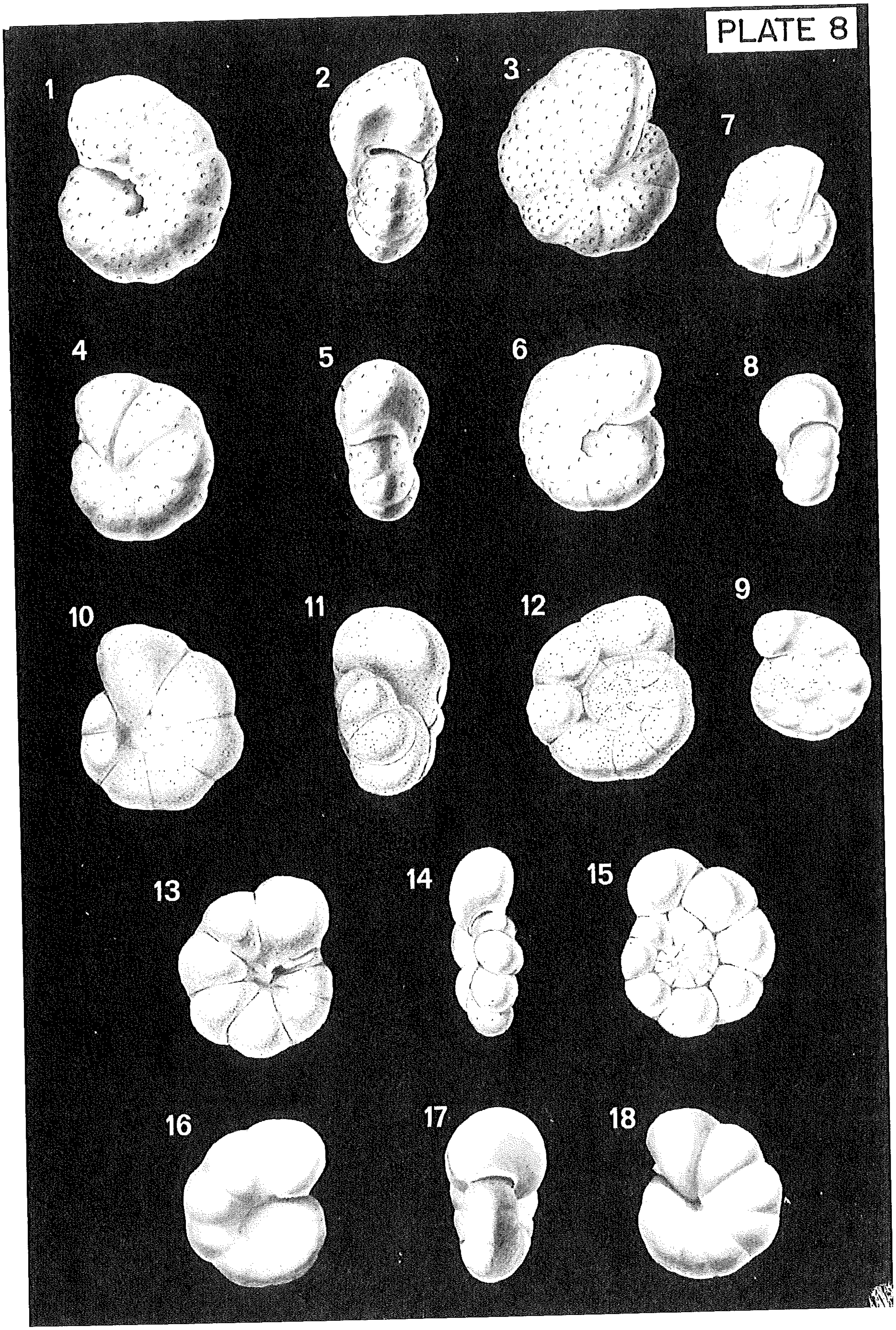
PLATE 8
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PLATE 9

Figures 1-3, 4-6. Gavelinella henbesti (Plummer) (x 78)

Hypotypes from the Delta Section 3240 feet above the base of the formation.

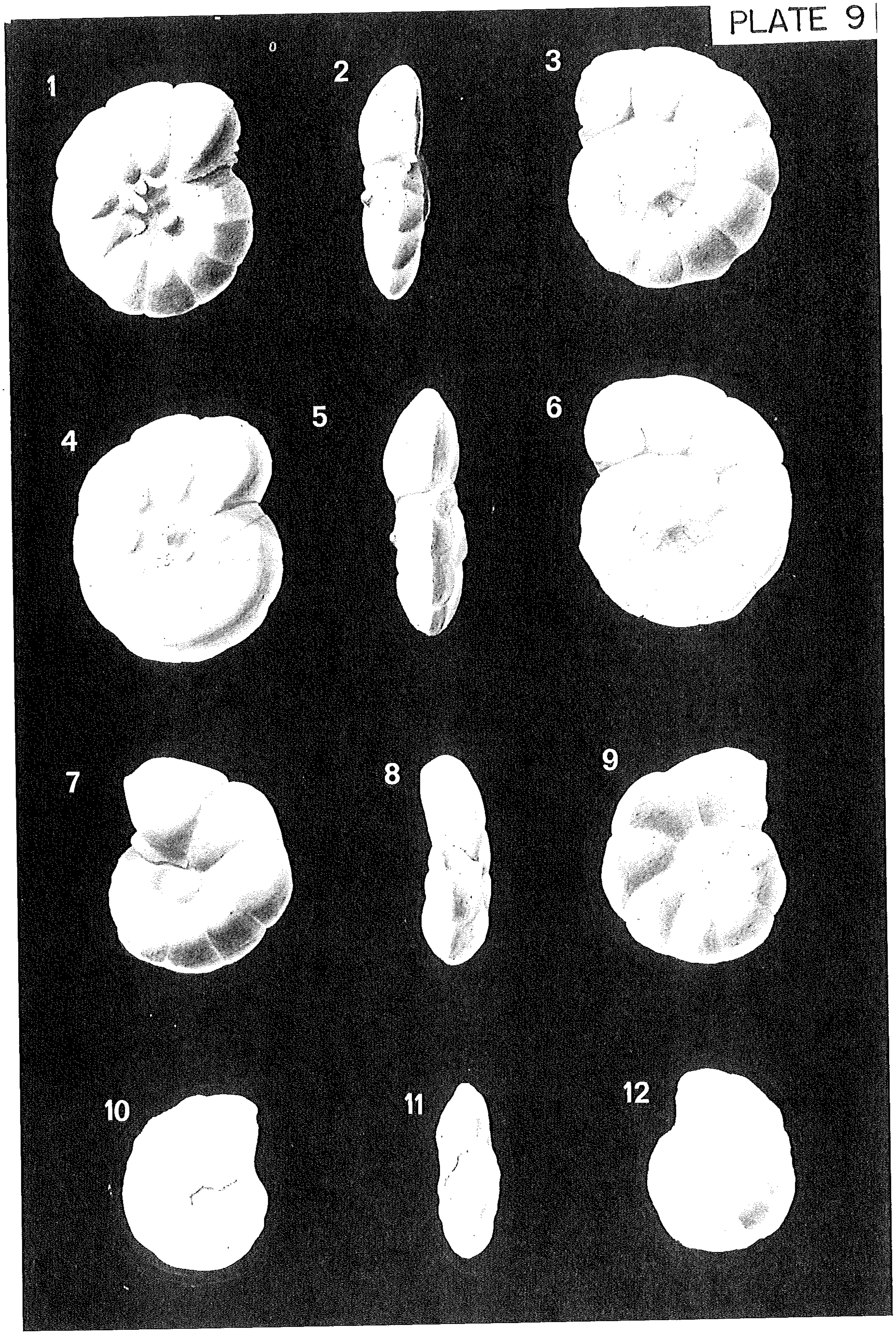
Figures 7-9. Gavelinella kansasensis (Morrow) (x 78)

Hypotype from the Wolcott Section 354 feet above the base of the formation.

Figures 10-12. Gavelinella bighornensis (Young) (x 120)

Hypotype from the Gallup Section 130 feet above the base of the formation in the Gavelinella dakotensis Assemblage Zone.

PLATE 9



VITA

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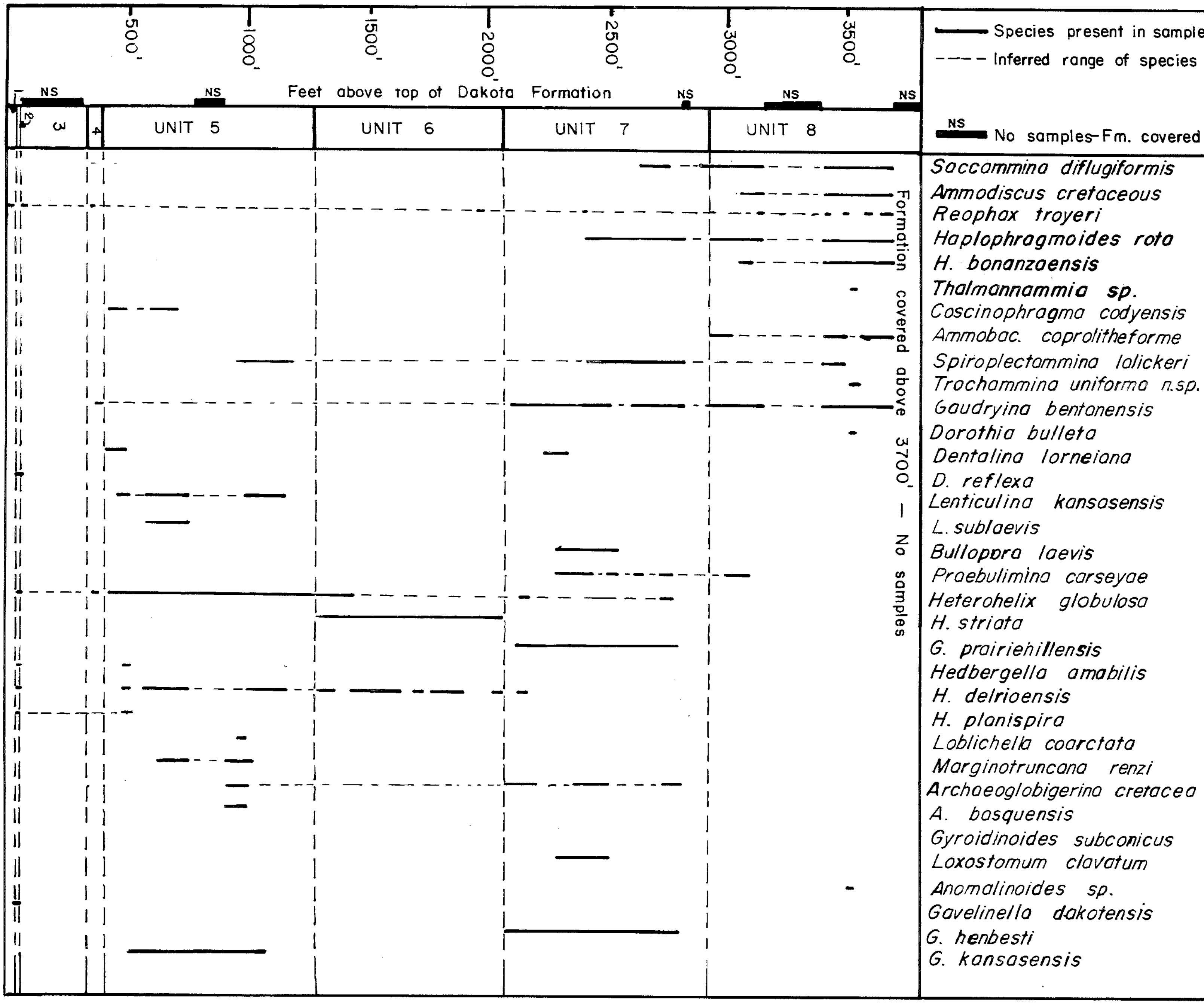

FIGURE 4 STRATIGRAPHIC DISTRIBUTION OF FORAMINIFERA AT DELTA

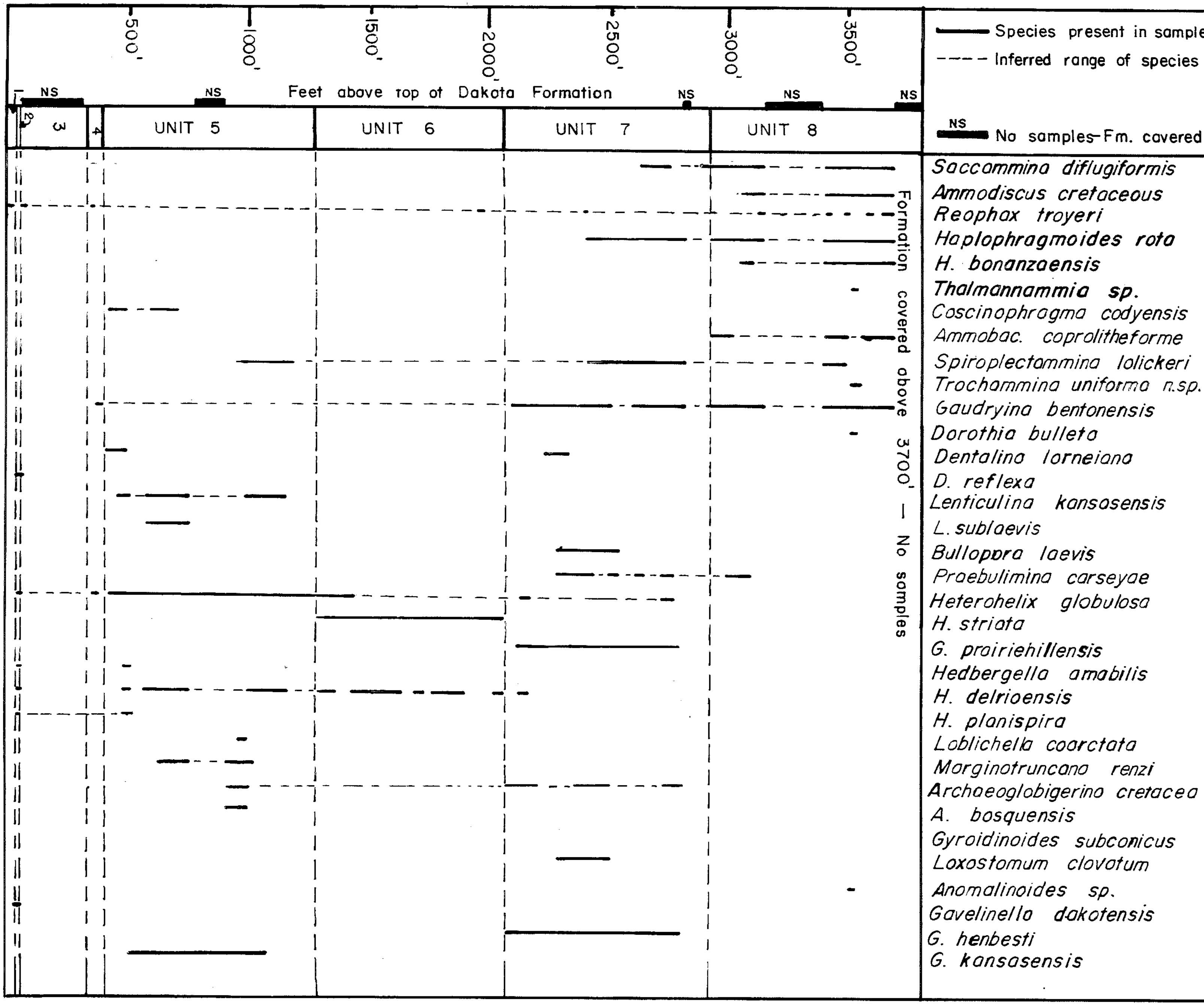

FIGURE 4 STRATIGRAPHIC DISTRIBUTION OF FORAMINIFERA AT DELTA