Micropaleontology and Paleoecology of the Tununk Member of the Mancos Shale

by

R. H. Lessard

1847
1896

UTAH GEOLOGICAL AND MINERAL SURVEY
a division of the
UTAH DEPARTMENT OF NATURAL RESOURCES
State Capitol, Salt Lake City, Utah

SPECIAL STUDIES 45 PRICE $2.00 NOVEMBER 1973

STATE OF UTAH
Calvin L. Rampton, Governor

DEPARTMENT OF NATURAL RESOURCES
Gordon E. Harmston, Executive Director

UTAH GEOLOGICAL AND MINERAL SURVEY
William P. Hewitt, Director

Micropaleontology and Paleoecology of the Tununk Member of the Mancos Shale

by

R. H. Lessard

1847
1896

UTAH GEOLOGICAL AND MINERAL SURVEY
a division of the
UTAH DEPARTMENT OF NATURAL RESOURCES
State Capitol, Salt Lake City, Utah

SPECIAL STUDIES 45 PRICE $2.00 NOVEMBER 1973

CONTENTS

ILLUSTRATIONS

MICROPALEONTOLOGY AND PALEOECOLOGY OF THE TUNUNK MEMBER OF THE MANCOS SHALE

by R. H. Lessard[1]

ABSTRACT

The sediments of the Tununk Shale of eastern Utah were deposited in the Tununk sea of Turonian-Cenomanian age. The sea at times was continuous with the Greenhorn, Tropic, Allen Valley and Frontier seas. Twenty genera and 21 species of foraminifers are found in the Tununk sediments. The Nodosariidae is represented by the greatest number of genera (eight) and species (nine) but has low foraminiferal numbers. The presence of many *Bulimina prolixa, Discorbis austinana, Hedbergella delrioensis* and *Heterohelix globulosa* is responsible for the high foraminiferal numbers found at all sections. The microfauna and sediments of the Tununk Shale indicate that the lower 50 percent of the unit records a transgression and the upper 50 percent a regression. Facts supporting a transgressive phase include: (1) extremely high foraminiferal numbers, sometimes exceeding 30,000 per gram, and (2) high calcareous benthonic foraminiferal percentages followed by high planktonic foraminiferal percentages. Those supporting a regressive phase include: (1) a change in lithology, (2) low foraminiferal numbers to total exclusion, and (3) high percentages of agglutinated benthonic foraminifers. Lithologic evidence indicates that delta building activities were partly responsible for the regression by prograding the shoreline in an easterly direction. The microfauna and sediments and their relationship to those of the adjoining seas suggest that the maximum depth of the seaway extending from central Utah to eastern Colorado was 300 to 600 feet.

INTRODUCTION

The Tununk Shale is the lowermost member of the Mancos Shale in southeastern Utah. It records part of the transgression, deepening and regression of the first sea to invade Utah during the Cretaceous period.

The Tununk was named by Gilbert (1877, p. 4) for exposures in the Henry Mountains in southeastern Utah. Spieker and Reeside (1925, p. 437-438) applied the term to the lower Mancos of the Wasatch Plateau, Utah, and equated the unit to those parts of the Graneros and Greenhorn formations which outcrop east of the Rocky Mountains. Hintze and Stokes (1964) applied the term throughout southeastern Utah.

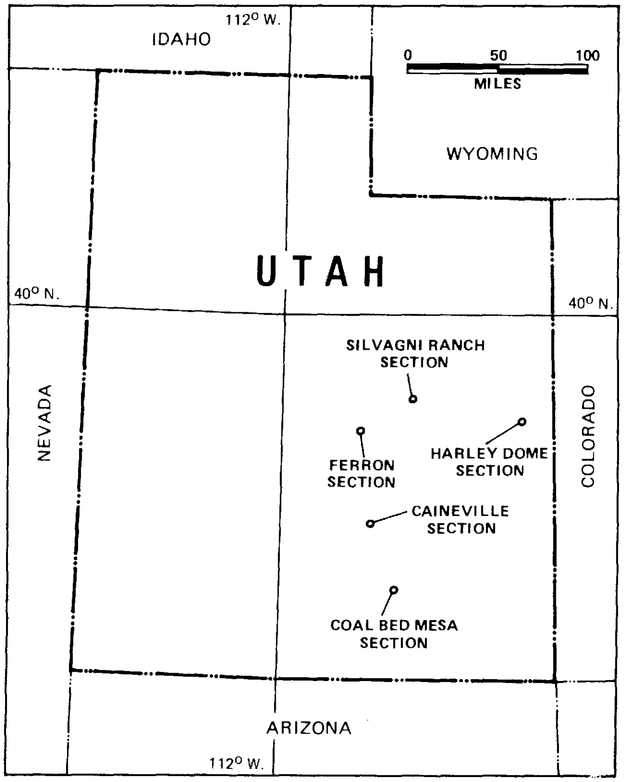


Figure 1. Map showing locations of sampled sections.

Four hundred thirty-four samples of the Tununk Shale were collected at 5-foot stratigraphic intervals from five widely spaced sections in southeastern Utah (figure 1) including:

1. Coal Bed Mesa section
   Base–SE¼ sec. 12, T. 35 S., R. 10 E.
   Top–NE¼SW¼ sec. 12, T. 35 S., R. 10 E.
2. Caineville section
   Base–NE¼NW¼ sec. 3, T. 29 S., R. 8 E.
   Top–NW¼NW¼ sec. 3, T. 29 S., R. 8 E.
3. Ferron section
   Base–SE¼SE¼ sec. 22, T. 20 S., R. 8 E.
   Top–NE¼SW¼ sec. 22, T. 20 S., R. 8 E.
4. Silvagni Ranch section
   Entire section–NE¼NW¼ sec. 24, T. 17 S., R. 14 E.
5. Harley Dome section
   Entire section–SE¼ sec. 9, T. 19 S., R. 25 E.

---

[1] Assistant professor, Earth Science Division, New Mexico Highlands University, Las Vegas, New Mexico.

The samples were broken down by boiling 150-gram segments in a weak solution of bicarbonate of soda and the microfauna separated from the remainder of the sediment by washing the sample through a 250-mesh screen. The process was repeated two or three times to achieve complete separation.

ACKNOWLEDGEMENTS

The writer would like to thank Drs. Daniel Jones, William Stokes, Richard Robison and Harry Goode and Mr. Blair Maxfield for their advice, assistance and constructive criticism in the writing of this paper. Special thanks are extended to Dr. Jones for providing the writer the opportunity that made the investigation possible. The study was partially supported by a grant from the Geological Society of America. The faunal plates were prepared by Miss Donna King.

STRATIGRAPHIC RELATIONS AND STRATIGRAPHY

The Tununk Shale overlies the Dakota Sandstone at all the localities at which it was sampled. However, it also overlies the Early Cretaceous Cedar Mountain Formation and the Jurassic Morrison Formation at other localities in Utah (Hintze and Stokes, 1964). The nature of the contact is discussed in the section on Pre-Tununk Paleogeography and Paleoecology.

In a time-stratigraphic sense, the Tununk Shale can be correlated with portions of the Tropic Shale of south central Utah, the Allen Valley Shale and Funk Valley Formation of central Utah, Unit 10 and possibly the lower portion of Unit 9 of the Frontier Formation of north central Utah and the Greenhorn Limestone of Colorado and northwestern New Mexico. The interrelationship existing among the units is discussed in the section on Paleoecology and Paleogeography of the Tununk and Adjacent Seas.

The Tununk Shale grades into the overlying Ferron Sandstone through a series of alternating sand and shale layers. The units are genetically related in that the sediments of the upper Tununk and the lower Ferron were both deposited during the regression of the Tununk sea.

Stratigraphic columns for each of the sections (figures 2 to 5) indicate that they too are genetically interrelated. The 660-foot Coal Bed Mesa and 550-foot Caineville sections exhibit this interrelationship in that both have a thin basal sandstone containing *Gryphaea newberryi* which grades into a sequence of dark gray, calcareous, slightly silty to non-silty shales and mudstones. This is followed by a thin sequence of sands and shales and a thicker sequence of laminated sediments with some exhibiting well developed cross-laminations (figure 6). The laminae become less pronounced farther up the section and are interbedded with noncalcareous siltstones and mudstones. Both sections are transitional into the overlying Ferron Sandstone through a series of alternating sandstone and shale layers.

The Tununk sediments and primary structures were compared with and found to be strikingly similar to those described by Scruton (1955) and Coleman and Gagliano (1965) from the continental shelf and Mississippi River deltaic plain of the Gulf of Mexico. On the basis of the comparison, the writer believes that the basal sandstones represent a nearshore environment, the overlying shales and mudstones suggest an offshore environment, the well developed laminated and cross-laminated sequence a prodelta and delta front environment and the poorly developed laminated sequence represents interdistributary bay and marsh deposits. Foraminiferal evidence presented in a subsequent section supports the interpretation.

The 660-foot Ferron section (figure 4) differs from the Caineville and Coal Bed Mesa sections in two ways. First, the thick, well developed laminated and cross-laminated sequence is absent and is replaced by a thin laminated sequence which grades into noncalcareous silty shales and fine sandstone layers. Although its lithology and foraminifers indicate a shallow water environment–possibly bays and marshes–its exact position in the delta-building scheme is uncertain. Second, the *Gryphaea newberryi* zone is missing and in its place is a pebble sandstone. The remaining lithology of the section is similar to the other two and, therefore, it is concluded that they are genetically related and have similar evolutionary histories.

The Harley Dome and Silvagni Ranch sections (figure 5) are 125 feet and 105 feet thick, respectively. Both have basal sandstone members with the one at Harley Dome containing *Gryphaea newberryi* and that at Silvagni Ranch, pebbles. The sandstone grades into mudstone and siltstone which in turn grade into fine sandstone and, finally, medium-grained sandstone. There are no laminations. The basal sandstone is interpreted as representing a nearshore environment and the mudstone and siltstone an offshore environment. The appearance of the upper sandstone sequence reflects the previously mentioned eastward movement of the shoreline. This also is supported by foraminiferal evidence.

AGE

The age of the Tununk Shale is difficult to ascertain from internal evidence because: (1) the unit records both a transgression and regression, which

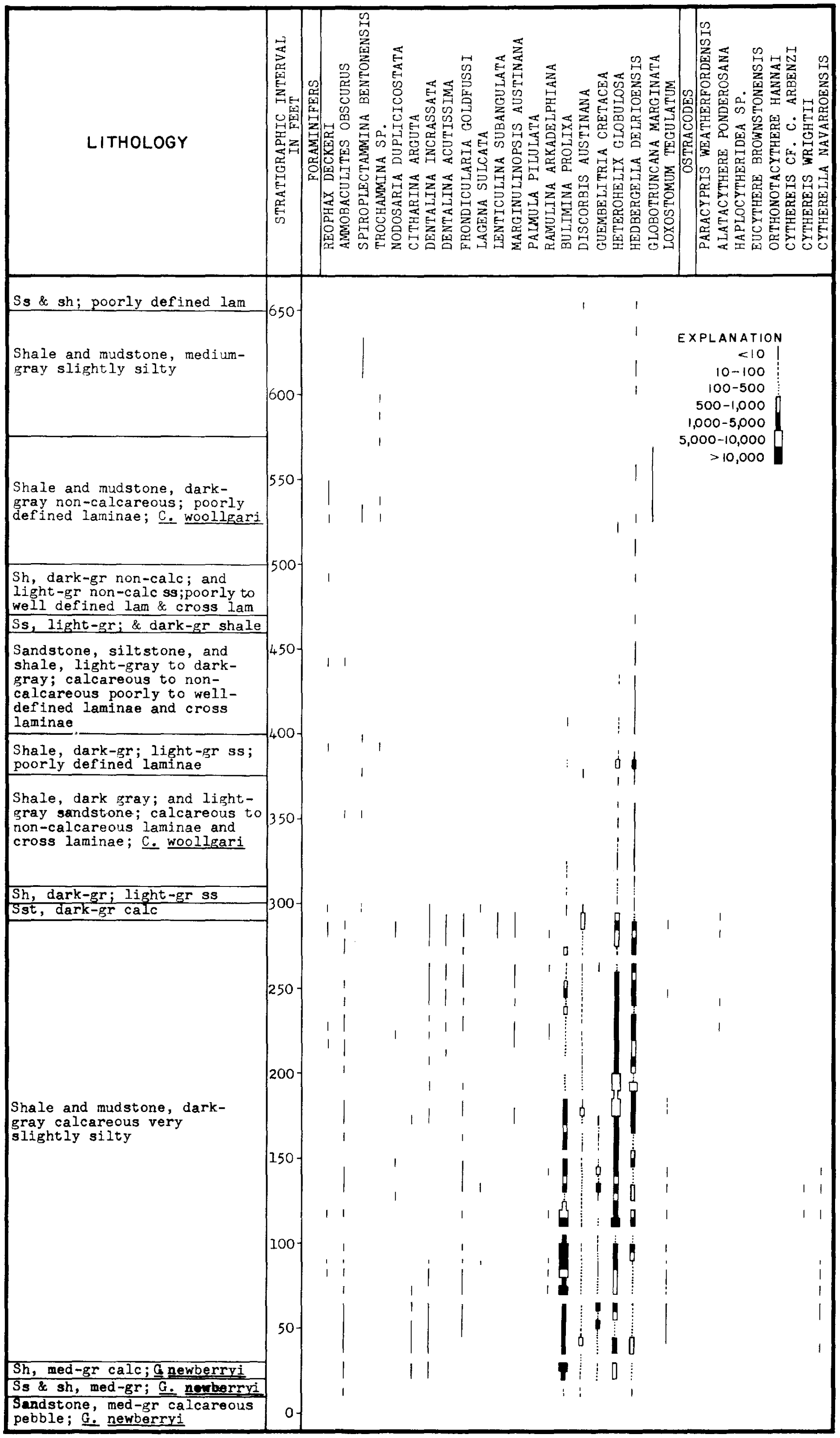


Figure 2. Lithology and stratigraphic distribution and numbers per gram of species of foraminifers and ostracodes at the Coal Bed Mesa section.

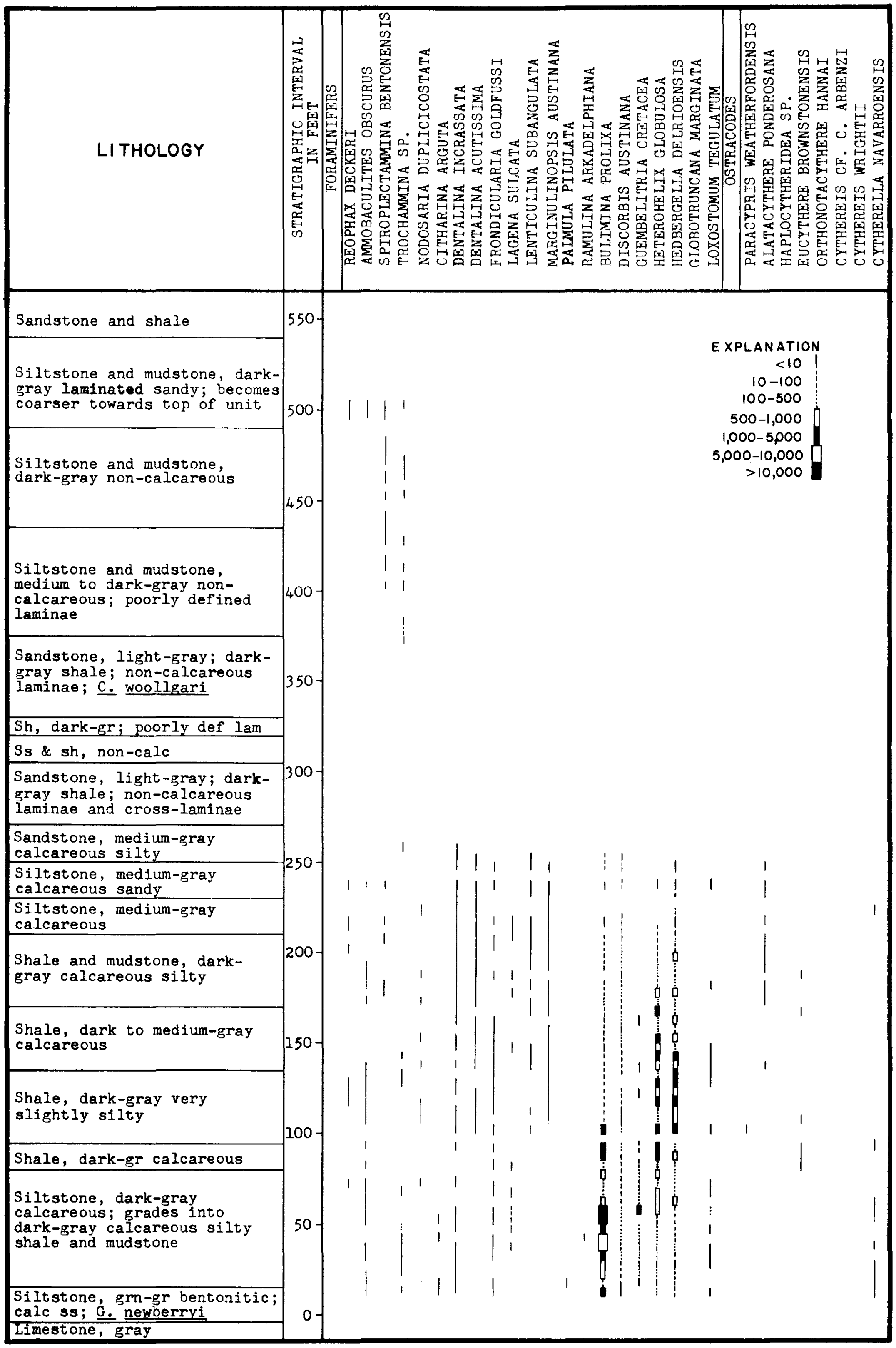


Figure 3. Lithology and stratigraphic distribution and numbers per gram of species of foraminifers and ostracodes at the Caineville section.

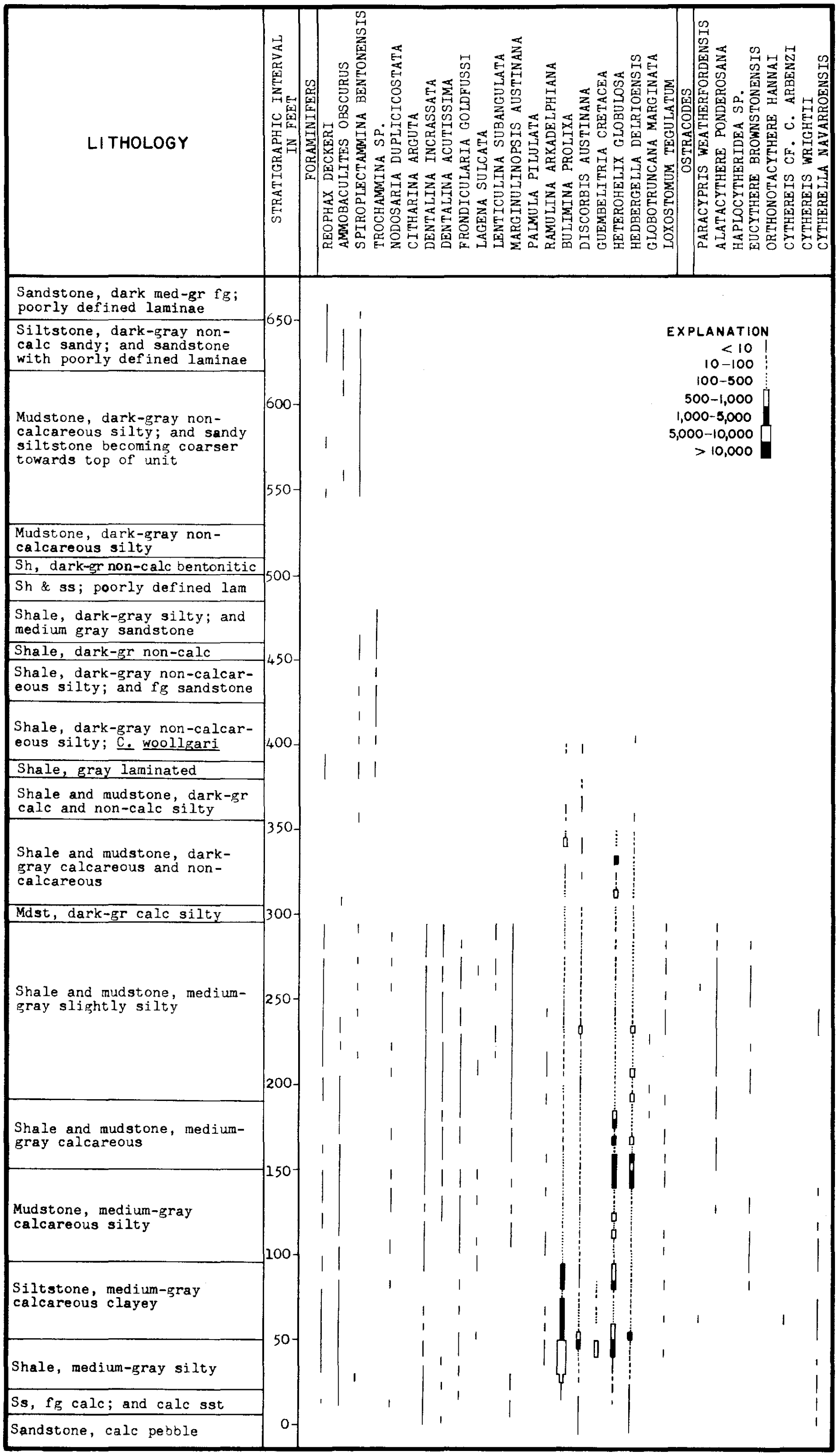


Figure 4. Lithology and stratigraphic distribution and numbers per gram of species of foraminifers and ostracodes at the Ferron section.

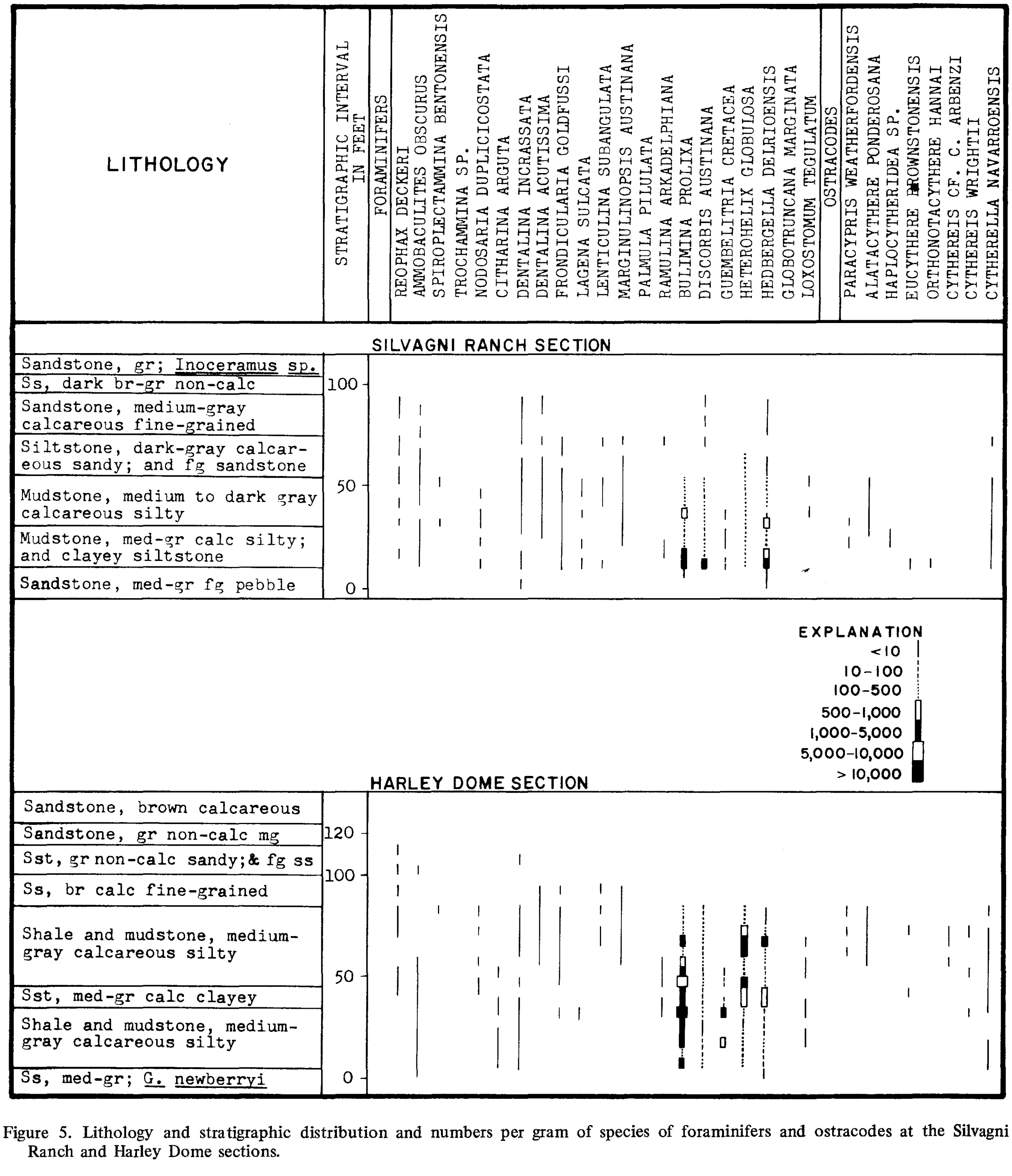


Figure 5. Lithology and stratigraphic distribution and numbers per gram of species of foraminifers and ostracodes at the Silvagni Ranch and Harley Dome sections.

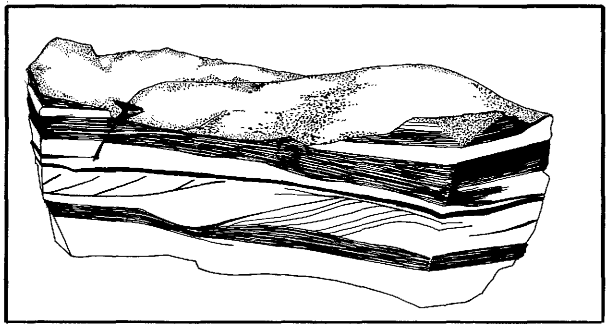


Figure 6. Laminated and cross-laminated rock from 405 feet above the base of the Coal Bed Mesa section, X1.

means that not all of its sediments were being deposited synchronously; and (2) the unit does not contain any recognized index fossil assemblages. Katich (1954, p. 46) contended that the Tununk ranged in age from Albian to Turonian. The Albian age resulted from the reported occurrence of *Inoceramus nahwisi* near the base of the unit. Katich (personal communication to W. L. Stokes) changed the initial age determination because it was based on a misidentification. The *Inoceramus nahwisi* specimen was reidentified, thus removing the Tununk from the Albian. A Cenomanian age was designated because *Gryphaea newberryi* and *Inoceramus labiatus* occur above the specimen identified as *Inoceramus nahwisi.* The fact that these are benthonic forms whose presence is due to the existence of specific environmental conditions makes them unreliable time indicators and therefore the age assignment based on their presence is somewhat tenuous.

Katich assigned a Turonian age to the upper part of the Tununk because of the presence of *Collignoniceras woollgari* (*Collignoniceras* is a junior synonym of *Selwynoceras*). This cephalopod also occurs in the upper part of the Tropic and Allen Valley shales and in the Carlile Formation. As will be shown, the sediments of the upper portion of all these units, in which *Selwynoceras woollgari* occurs, were deposited in nearshore environments of a regressive sea, a fact that suggests an alternative explanation for its presence in that it could be an environmental rather than a time zone indicator.

Stokes, Peterson and Picard (1955, p. 2007) assigned the Tununk to the Cenomanian-Turonian. The microfaunal analysis associated with this study shows that *Globotruncana marginata* first makes an appearance at 180 feet above the base of the Ferron section. It also is present in the Coal Bed Mesa section, but at 525 feet above the base of the section. Its numbers are low and its occurrence is sporadic. *Globotruncana* evolved in the Turonian (Loeblich and others, 1957, p. 46) which indicates at least part of the upper 75 percent of the Ferron section is Turonian and possibly the lower 25 percent is Cenomanian, provided that the first appearance of *Globotruncana marginata* in the Tununk Shale coincides with its first appearance on a worldwide basis.

PRE-TUNUNK PALEOGEOGRAPHY AND PALEOECOLOGY

Several interpretations of the paleogeography and paleoecology of pre-Tununk time, including those of Young (1960), McCubbin (1961) and Eicher (1969), are based on studies made of sediments and stratigraphic relationships of the Dakota Sandstone and Cedar Mountain Formation, which underlie the Tununk Shale.

Young (1960) examined the interrelationship existing between the Cedar Mountain and Naturita (the Dakota Sandstone of earlier workers) formations in the Colorado Plateau. As a result of the study, he contends that the Cedar Mountain sediments were deposited on inland floodplains by eastward-flowing streams at the same time that the Naturita sediments were being deposited in paludal, lagoonal, littoral and neritic environments. The sources of the sediments were highlands to the west (Mesocordilleran) and south (Mogollon) of the Colorado Plateau. The Cedar Mountain sediments were being deposited to the west of the Naturita depositional area and the domains were continuously being pushed westward by the intermittently advancing Mancos sea. The periods of Mancos transgression were being interrupted by regressions, during which time the sediments of the Naturita Formation were being deposited (subsequently referred to as trans-regressions). As the above description implies, Young believes that Cedar Mountain, Naturita and Mancos sedimentation occurred contemporaneously and, therefore, a facies relationship exists among these stratigraphic units.

Craig (1961, p. 1582) disagrees with the interpretation that the Naturita and Cedar Mountain formations exhibit a facies relationship. Instead he proposes that there is a widespread unconformity between the Cedar Mountain and Naturita Formation.

Shawe (1961, p. 1589) disagrees that the upper sandstones of the Dakota (Naturita) are trans-regressive and favors the proposal that they were deposited during the transgression of the Mancos sea.

McCubbin (1961) divided the Dakota Sandstone (Young's Naturita Formation) into two facies after an extensive survey of the basal Cretaceous of southwestern Colorado and southeastern Utah. The sediments of the "Lower Dakota" were deposited in stream channels, swamps and marshes at the same time those of the "Upper Dakota" were being deposited in littoral and shallow marine environments. McCubbin does not show an intertonguing of the Dakota Sandstone with the Cedar Mountain (as used by Young), but claims instead that the "Lower Dakota" sands cut into the Cedar Mountain and Morrison formations. McCubbin (1961, p. 143) interprets the Dakota terrain as being relatively stable during most of Dakota time with the paleogeography consisting of a low, swampy, deltaic plain crossed by streams to the west of the Mancos sea and separated from it by a delta-front marine environment. A sudden subsidence of the deltaic plain in late Dakota time permitted the Mancos sea to rapidly (?) transgress westward. The provenances of McCubbin's stream sediments include the Mesocordilleran Geanticline (including the Sevier orogenic belt) which lay to the west and the Mogollon Highland which lay to the southwest. The direction of stream transport varied "from northwest to east and southeast in southeastern Utah and southwestern Colorado."

Eicher (1969), to further substantiate his interpretation of the depth of the Cretaceous Greenhorn sea (a partial Tununk time equivalent), attempted to reconstruct the gradient of the streams that were responsible for the deposition of the sediments of the Cedar Mountain Formation and its equivalent, the Lytle Formation of the Front Range foothills. Eicher recognized the existence of southerly (Mogollon Highland?), easterly and westerly (Sevier orogenic belt) source areas for the sediments of these formations, but stated that the westerly was of optimum importance for his analysis and made no further mention of the others. The analysis yielded an approximate fall of between 1,400 and 6,600 feet for the area between the present-day Sanpete Valley, Utah, and Front Range foothill area, Colorado. Eicher favors a figure in the lower end of this range. Apparently the gradient remained constant, without being disturbed appreciably by aggradation, erosion or tectonic movement, throughout Cedar Mountain time and until the Mancos sea transgressed across the area.

The above three interpretations of the interrelationships and environments of deposition of the Dakota Sandstone and Cedar Mountain Formation are obviously in conflict with each other. Unlike McCubbin and Young, Eicher puts an actual value on the gradient over which the Cedar Mountain streams flowed and requires that the Mancos sea transgress over it. However, if Young's trans-regressive interpretation is correct, it would require basin sinking and consequently a periodic change in gradient in response to the occasional pulses of subsidence. This would have resulted in the destruction of the Cedar Mountain gradient by the end of Cedar Mountain time. If McCubbin and Craig are correct in their interpretation that there is an unconformity separating the Naturita (Dakota Sandstone) from the Cedar Mountain Formation with the Naturita occupying erosional channels in the Cedar Mountain, then it would potentially indicate a period in which some of Eicher's Cedar Mountain gradient was adjusted by erosion. McCubbin's "Lower Dakota" would be deposited on this erosion surface followed by a quick pulse of subsidence further reducing the Cedar Mountain gradient and allowing the Mancos sea to advance.

It was on this controversial surface that the sediments of the Tununk Shale were deposited.

TUNUNK FAUNA

The observed microfauna consists of foraminifers, ostracodes, *Inoceramus* prisms, radiolarians, fish scales, shark and fish teeth, echinoid spines, fecal pellets, gastropod protoconches and immature pelecypod valves. Other microfossils, such as spores, pollens, coccoliths and discoasterids, were not searched for. The observed macrofauna consists of large numbers of *Gryphaea newberryi,* which are restricted to the base of the unit, rare occurrences of entire valves of mature *Inoceramus sp.* localized in the lower 50 percent of the unit and sporadically populous occurrences of *Collignoniceras woollgari* in the upper 50 percent of the unit.

The results of quantitative and qualitative analyses made of the foraminifers and ostracodes are presented in the following discussion. The classification of the two groups is based on the schemes presented in Benson and others (1961) and Loeblich and Tappan (1964).

The Foraminiferida of the Tununk Shale are represented by 12 families including the Hormosinidae, Lituolidae, Textulariidae, Trochamminidae, Nodosariidae, Polymorphinidae, Buliminidae, Discorbidae, Heterohelicidae, Rotaliporidae, Globotruncanidae and Loxostomidae. The first four families contain agglutinated forms and the remainder are calcareous types. The families in turn are represented by 20 genera and 21 species.

The Nodosariidae are represented by the greatest number of genera (eight) and species (nine); species occur at all of the sections (figures 2 to 5) with the exception of *Palmula pilulata* which was observed only at Caineville and *Citharina arguta* which is apparently absent from the Ferron and Silvagni Ranch sections. Representatives of the Nodosariidae always have low foraminiferal numbers (less than 10/gram) but the group does contain some of the largest individuals of the entire foraminiferal population (including specimens of *Frondicularia, Dentalina, Lenticulina, Mar-*

ginulinopsis and *Palmula*). The Nodosariidae are restricted to the lower half of the Ferron, Caineville and Coal Bed Mesa sections, but have a greater range in the Harley Dome and Silvagni Ranch sections.

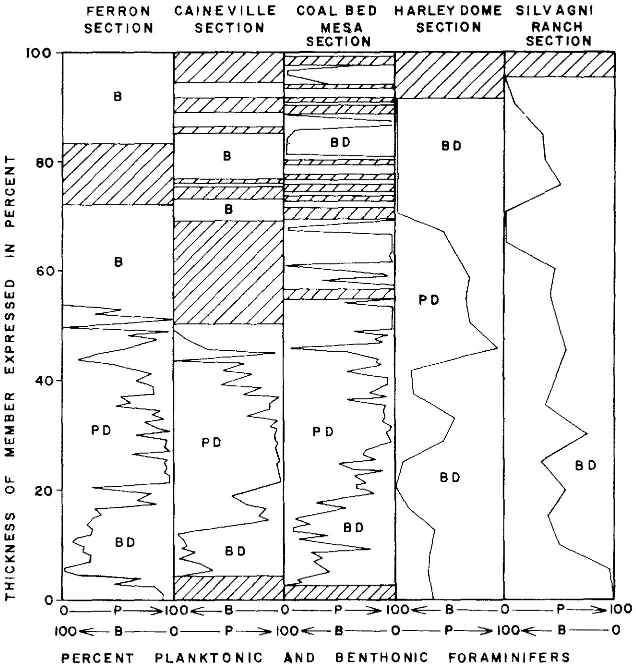
Specimens of the Buliminidae, represented by the species *Bulimina prolixa,* are extremely abundant in the lower half of each of the sections (figures 2 to 5) and are largely responsible for the high benthonic foraminiferal percentages in the lower 25 percent of these sections (figure 7). The individuals are small, ranging from 0.15 to 0.30 mm long and 0.10 to 0.15 mm wide. They are restricted to the lower two-thirds of each section.

The next most abundant benthonic species is *Discorbis austinana,* the only representative of the Discorbidae. Although not a decisive factor, its numbers help establish the high benthonic percentages in the lower 25 percent of each section (figure 7). Like *Bulimina prolixa,* the specimens are for the most part small (average diameter 0.35 mm) and restricted to the lower two-thirds of each section.

The remaining calcareous benthonic species, *Ramulina arkadelphiana* and *Loxostomum tegulatum,* the only representatives of the Polymorphinidae and Loxostomidae, respectively, occur at all sections, have low foraminiferal numbers and are generally restricted to the lower half of the sections.

The planktonic species *Hedbergella delrioensis* and *Heterohelix globulosa,* representing the Rotaliporidae and Heterohelicidae, respectively, are most numerous in the upper 25 percent of the lower half of all but the Silvagni Ranch section and are responsible for the dominant planktonic percentages that occur in this part of the sections. *Guembelitria cretacea,* also representing the Heterohelicidae, is only locally abundant and generally restricted to the lower half of the lower 50 percent of each section. *Globotruncana marginata* (Globotruncanidae) occurs sporadically and was observed only at the Caineville and Ferron sections.

The agglutinated species, *Reophax deckeri, Ammobaculites obscurus* and *Spiroplectammina bentonensis,* the only representatives of the Hormosinidae, Lituolidae and Textulariidae, respectively, are distributed sporadically in both the lower and upper halves of all the sections with *Spiroplectammina bentonensis* being the last to appear. Their foraminiferal numbers are low. The actual presence of *Trochammina sp.* is uncertain (see Systematics section).



B = 100 percent benthonic

P = 100 percent planktonic

BD = benthonic dominant

PD = planktonic dominant

////= microfauna absent

Figure 7. Percent of planktonic and benthonic foraminifers for individual sections.

In general, the ostracodes are restricted to the lower 50 percent of the section at Ferron, Caineville and Coal Bed Mesa, the lower 66 percent of the Harley Dome section and the lower 70 percent of the Silvagni Ranch section. The most persistent of the ostracodes are *Alatacythere ponderosana, Eucythere brownstonensis* and *Cytherella navarroensis* which are found at all sections with the exception of *Eucythere brownstonensis,* which is absent from the Coal Bed Mesa section. Ostracode numbers are low at all stations.

There is an overall pattern to the vertical and horizontal distribution of foraminifers and ostracodes in the Tununk Shale. At the Ferron, Caineville and Coal Bed Mesa sections, all calcareous benthonic foraminifera (with the exception of *Bulimina prolixa* and *Discorbis austinana* at Ferron and Coal Bed Mesa), the planktonic *Guembelitria cretacea* and all the ostracodes are restricted to the lower 50 percent of the section. The two calcareous benthonic species that transcend into the upper 50 percent of the Ferron and Coal Bed Mesa sections do so with considerably reduced foraminiferal numbers and with a sporadic distribution. The planktonic forms *Hedbergella delrioensis, Heterohelix globulosa* and *Globotruncana* *marginata* also extend into the upper 50 percent of the sections, but under the same restrictive conditions as the two calcareous benthonic species.

The overall decrease in number of species crossing into the upper half of the Coal Bed Mesa, Caineville and Ferron sections (figures 2 to 4) corresponds to an overall decrease in foraminifers per gram (figure 8). It also corresponds to a change in lithology (figures 2 to 4) with the introduction of fine laminae and cross-laminations at Caineville and Coal Bed Mesa (and somewhat later at Ferron) and darker sediments at Ferron.

The agglutinated species continue into the upper half of the sections although there are some noticeable gaps in occurrence. One such gap corresponds to the same stratigraphic interval occupied by the previously mentioned finely laminated and cross-laminated sediments.

Unlike their counterparts at Ferron, Caineville and Coal Bed Mesa, the Harley Dome and Silvagni Ranch benthonic and planktonic foraminifers and ostracodes continue into the upper half of their respective sections. Similar to their counterparts, however, the numbers decrease noticeably halfway through the section at Silvagni Ranch and at approximately 65 percent up from the base of the section at Harley Dome. This corresponds to an increase in coarseness of sediments rather than to an introduction of laminae.

The horizontal distribution of the microfauna is essentially the same at all sections. For instance, the same microfauna occurs at Ferron as at Harley Dome, Harley Dome being approximately 97 miles due east of Ferron.

An additional aspect of the microfauna which has been mentioned but not elaborated upon is the "smaller than average" size of some of the foraminiferal species. Green (1959, p. 36), in describing the microfauna of the Allen Valley Shale, which is almost identical to that of the Tununk, detected the smaller than average size of some of the foraminiferal species and referred to the specimens as being slightly dwarfed; he inferred that the dwarfing may be the result of unfavorable or abnormal conditions in the Allen Valley sea. Loeblich and Tappan (1964, p. 125), however, state that smaller than average specimens may indicate optimum environmental conditions and thus an ideal reproducing situation which results in large foraminiferal numbers.

PALEOECOLOGY AND PALEOGEOGRAPHY OF THE TUNUNK AND ADJACENT SEAS

As previously mentioned, the Tununk Shale can be correlated in a time-stratigraphic sense with the

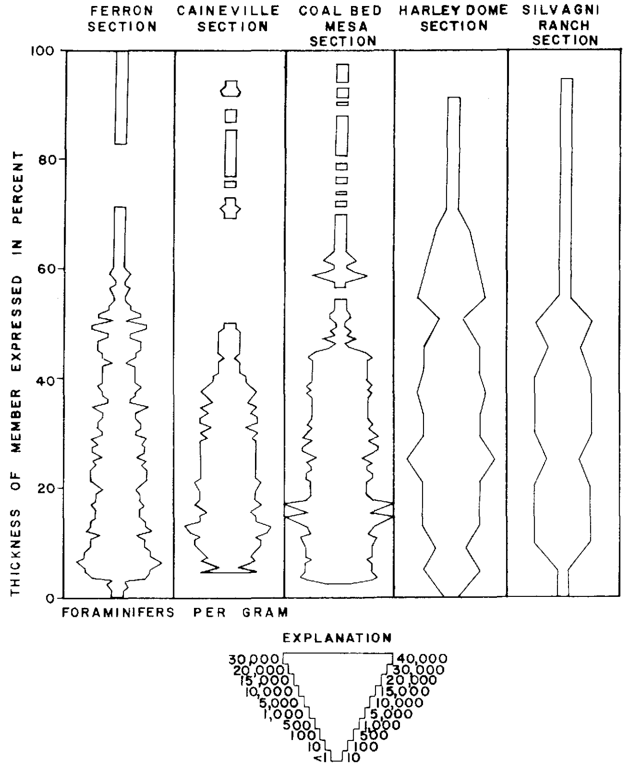


Figure 8. Foraminifers per gram of rock for individual sections.

Allen Valley Shale of central Utah, the Frontier Formation of northeastern Utah, the Tropic Shale of south central Utah and the Greenhorn Formation of Colorado and northwestern New Mexico. There is evidence to indicate that at least a portion of the sediments of each of the units was deposited in a sea and that the various seas were at times continuous with each other. These seas often are named after the unit; thus Eicher (1969, p. 1075) refers to the Greenhorn sea. To show the interrelationship which existed among the seas during Tununk time, a paleo-oceanographic map was constructed (figure 9).

Allen Valley Sea

Green (1959) attempted to interpret the paleoecology of the Allen Valley sea using the microfauna as the principal criterion. He concluded that the microfauna lived in normal open marine conditions, in temperate to subtropical temperatures and at depths ranging from neritic to upper bathyal because of: (1) a 4:1 calcareous to agglutinated ratio; and (2) the foraminiferal types and associations.

A comparison of the Tununk and Allen Valley microfaunas indicates that they contain the same foraminifers with the following exceptions: (1) *Ammobaculites obscurus, Citharina arguta* and *Guembelitria cretacea* were not observed in the Allen

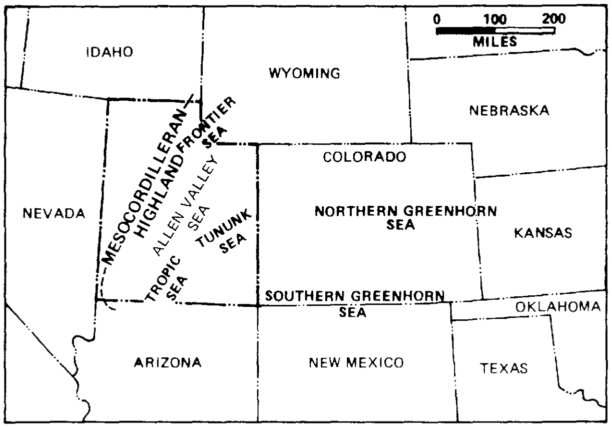


Figure 9. Paleo-oceanographic map of Tununk and adjacent seas.

Valley samples; and (2) *Epistomina caracolla* (Roemer) was not observed in the Tununk samples. Both formations also contain *Collignoniceras woollgari.* The most notable difference between the microfaunas is in the foraminiferal numbers. In the Tununk Shale hundreds to thousands of individuals per gram of sediment are normal in the lower 50 percent of each unit (figure 8), whereas in the Allen Valley Shale, the number rarely exceeds ten. The difference could either be apparent, due to a poor breakdown of the rock prior to examination (if a complete breakdown is not obtained, an accurate count cannot be made) or real, due to unfavorable environmental conditions and/or rapid sedimentation at the time of burial.

Green (1959) divided the 600-foot section of Allen Valley Shale into four major microfaunal units. The Nodosariidae and the planktonic and agglutinated foraminifers are restricted to units 1 to 3 which together constitute the lower two-thirds of the formation. The lower half of unit 4 contains a calcareous rotaloid foraminiferal fauna while the upper half is barren. Green notes that the shale becomes coarser in texture as it grades into the overlying Funk Valley Formation. Glissmeyer (1959, p. 6) reports that no foraminifers or ostracodes were found in samples collected from an exposed portion of the lower 900 feet of the overlying Funk Valley Formation which in its entirety consists of sandstones and interbedded shales. The middle shale member, which is 650 feet thick, contains a varied microfauna with many species being common to the Tununk Shale.

Frontier Sea

All the foraminifers that Peterson (1953) reports as occurring in unit 10 of the Frontier Formation of north central Utah also occur in the Tununk Shale with the exception of *Epistomina caracolla* and *Haplophragmoides excavate* Cushman. Several Tununk foraminifers, however, were not reported from the Frontier, including *Spiroplectammina bentonensis, Nodosaria duplicostata, Citharina arguta, Lenticulina sulcata, Lenticulina subangulata, Bulimina prolixa, Dentalina austinana, Globigerina cretacea* and *Heterohelix globulosa.* Their absence could be attributed to: (1) insufficient sampling as only one section was sampled at widely spaced intervals, (2) inadequate preparation techniques, (3) a combination of 1 and 2, or (4) environmental conditions. A comparison of the ostracodes indicates that six of the eight Tununk forms are present in the Frontier, including *Paracypris weatherfordensis, Alatacythere ponderosana, Eucythere brownstonensis, Orthonotacythere hannai* and *Cytherella navarroensis.* Unit 10 is one of 16 lithologic units proposed by Wegemann (1915, p. 163) and used by Jones (1953b) to describe the Frontier Formation in the Coalville area. The unit is 750 feet thick, underlain by unit 11, a sandstone 30 to 130 feet thick (Naturita equivalent?) and overlain by Unit 9, a sandstone 100 to 200 feet thick (Ferron equivalent?). Jones (1953b, p. 19), using the microfauna as the principal criterion, postulates that the sediments of the lower part of unit 10 were deposited in an open marine environment of neritic to upper bathyal depths. Jones attributes the decrease in foraminiferal numbers and species, including the exclusion of *Globigerina* (*Hedbergella*) in the upper part of the section, to: (1) a gradual decrease in temperatures; and (2) a closing of the seaway which restricted circulation.

Tropic Sea

The paleogeography of Tropic time is interpreted by Lawrence (1965, p. 89) using stratigraphic and macrofaunal evidence. The Mesocordilleran Highland lay to the west. The marine transgression of early Tropic time flooded the shoal, lagoonal and paludal areas of the Dakota landscape and resulted in the deposition of mud and sand adjacent to the highland and clay in the offshore areas. There is a change in lithology halfway through Lawrence's "typical" stratigraphic column (S½ sec. 14, T. 37 S., R. 2 W.–sec. 2, T. 37 S., R. 2 W.) which is attributed to the development of an eastern barrier which cut off normal marine circulation and resulted in the establishment of both reducing and slightly acidic conditions. Impressions of *Selwynoceras woollgari* and *Inoceramus sp.* are present in the upper half of the section, apparently indicating that they could live under adverse conditions. The restricted sea was finally flooded by deltas represented by the sediments of the overlying Straight Cliffs Sandstone. Sealy (1950, p. 15) reported *Epistomina greenhornensis, Gumbelina globulosa* (*Heterohelix globulosa*) and *Globigerina cretacea* (*Hedbergella delrioensis*) from a point approximately two-thirds from the base of a section located near Lawrence's. The author examined a sample of the Tropic from the lower half of a section in sec. 21, T. 41 S., R. 1 W., Kane County, Utah, and observed *Hedbergella delrioensis, Heterohelix globulosa* and *Marginulinopsis austinana.* The sample has high foraminiferal numbers and planktonic percentages.

Southern Greenhorn Sea

Lamb (1968), in his study of the stratigraphy of the lower Mancos Shale in the San Juan Basin, made a statistical analysis of the foraminifers. Large foraminiferal numbers, at times exceeding 1,000 per gram, are recorded from the Greenhorn Limestone and lower Carlile Shale of the Red Wash section in northwestern New Mexico and from the Graneros Shale (underlying the Greenhorn Limestone), Greenhorn Limestone and lower Carlile Shale of the Pagosa Springs section, southwestern Colorado, which is approximately 100 miles east of Red Wash. The fauna is similar to the Tununk fauna in that: (1) large numbers of *Hedbergella delrioensis, Heterohelix globulosa* and *buliminid*-like foraminifers (*Neobulimina canadensis*) are present; (2) the planktonic percentages are high; and (3) agglutinated forms and the Nodosariidae are well represented. Lamb's interpretation of the paleoecology and paleogeography of lower Mancos time is based on the faunal and a lithological analysis. The presence of abundant planktonic foraminifers and a varied benthonic population (including the Nodosariidae) near the base of the Graneros at Pagosa Springs are attributed to open marine conditions. The demise of the planktonic forms and the introduction of an agglutinated foraminiferal population in the middle and upper Graneros is explained by a decrease in the rate of basinal subsidence and/or an increase in sedimentation. The subsequent planktonic flood recorded in the sediments of the Greenhorn Limestone and lower Carlile Shale throughout the basin is attributed to a deepening of the water.

Lamb does not indicate how deep the sea was, but points out that not all workers interpret high planktonic percentages as indicative of deeper water origin. The Dakota-early Carlile transgression was followed by the middle Carlile regression which is recognized by the introduction of an agglutinated foraminiferal fauna, the restricted occurrence of *Selwynoceras woollgari* and a change in lithology. The regression is attributed to either a decrease in basinal subsidence or an increase in sedimentation. Lamb prefers an increase in sedimentation.

Northern Greenhorn Sea

Eicher (1969) attempts to determine the paleobathymetry of the Greenhorn sea in eastern Colorado by using planktonic-benthonic ratios and paleoslopes independently as criteria. As a preliminary step for his foraminiferal interpretation, he constructed a graph showing the "relationship of planktonic percentages in foraminiferal assemblages to water depth, in the Gulf of Mexico" from data derived from Phleger and Parker (1951). On the basis of a 4:1 planktonic-benthonic foraminiferal ratio, the depth of the water was estimated at 1,640 feet in late Greenhorn time (late Bridge Creek time). As previously mentioned, Eicher, as a result of an analysis of the Cedar Mountain paleoslope, estimates that the gradient upon which the Greenhorn sea transgressed had a fall of between 1,400 and 6,600 feet between Sanpete Valley, Utah, and the Front Range foothill area, Colorado; sea level would have had to rise a minimum of 1,400 feet during the westward transgression of the Greenhorn sea for the sea to move across the Sanpete Valley. This would have resulted in the sea having a minimum depth of 1,400 feet at the east extremity of the paleoslope in eastern Colorado. A final figure of between 2,000 and 3,000 feet is obtained for the depth of the water column in the central part of the Greenhorn sea in Bridge Creek time by: (1) using a minimum value for the paleoslope; and (2) considering isostatic compensation for sediment and water load. In his final discussion, Eicher concedes that perhaps the Greenhorn sea was shallower than estimated.

Tununk Sea

Eicher (1969) based his foraminiferal interpretation of the depth of the Greenhorn sea on planktonic-benthonic ratios. As previously indicated, there are high planktonic percentages in the Tununk samples which are associated with an excellent benthonic population.

For example, in Castle Valley at the Ferron locality, planktonic percentages up to 90 percent are obtained, which, according to Eicher's graph showing the "relationship of planktonic percentages in foraminiferal assemblages to water depth, in the Gulf of Mexico," indicate that water depths up to 4,500 feet were prevalent at Castle Valley during part of Tununk time. According to Eicher's paleoslope determination method, this is not the depth the location should have. Castle Valley is approximately 30 miles east of Sanpete Valley and 320 miles west of the Front Range foothill area, the high and low points respectively of Eicher's Cedar Mountain paleoslope. It, therefore, should have had a theoretical minimum paleoslope value of:

$$\frac{320}{350} \quad \text{x} \quad \frac{1{,}400 \text{ feet}}{1} = 1{,}280 \text{ feet}$$

and a minimal depth of:

$$1{,}400 \text{ feet} \quad - \quad 1{,}280 \text{ feet} \quad = \quad 120 \text{ feet}$$

in the Greenhorn sea after the maximum marine transgression without considering isostatic compensation. The 4,500-foot and 120-foot figures obviously conflict with each other, which suggests a possible error in Eicher's method(s) of computation. If the depth in Castle Valley was 4,500 feet, as indicated by the foraminiferal evidence, and if the Greenhorn sea transgressed over the minimum Cedar Mountain paleoslope to attain this depth, then the depth of the sea in eastern Colorado after the completion of its westward transgression to the Sanpete Valley would be:

$$4{,}500 \text{ feet} + 1{,}280 \text{ feet} = 5{,}780 \text{ feet.}$$

If the sea transgressed over the maximum paleoslope value of 6,600 feet, then the depth in eastern Colorado would be:

$$\frac{320}{350} \times \frac{6{,}600 \text{ feet}}{1} = 6{,}034 \text{ feet}$$

$$4{,}500 \text{ feet} + 6{,}034 \text{ feet} = 10{,}534 \text{ feet.}$$

The figures contradict the 1,640-foot value for eastern Colorado that Eicher calculated from the planktonic percentage chart. Conclusions that may be drawn from the computations include: (1) the paleoslope method of depth determination is invalid; (2) the planktonic percentage method for determining depth may be invalid for this time and area; and (3) both the paleoslope and planktonic methods are invalid.

The writer feels that both the paleoslope and planktonic methods are invalid because the 1,640- to 10,500-foot depths derived from the calculations are unsatisfactory. What conditions would cause the continental crust beneath the Tununk sea to sink 4,500 feet below sea level (the depth derived from planktonic percentage values at the Ferron section) to form a deep basin or, conversely, what conditions would cause a rise in sea level of 4,500 feet, if explanations other than crustal movements are applied? Associated with the problem is the elimination of the tremendous depth of water to allow for the ensuing Carlile regression. The regression, according to Eicher (1969, p. 1076), begins in late Bridge Creek time (the Greenhorn sea reached its maximum depth during early Bridge Creek time) and continues through Carlile time. A corresponding regression occurred in the Tununk area after approximately half the sediments of the Tununk Shale had been deposited. The evidence for the Tununk regression includes:

1. A significant decrease in the number of foraminifers per gram of sediment approximately halfway through all the sections (figure 8), except for Harley Dome where the decrease occurs about 65 percent upward through the section. A possible explanation for the inequality is that Harley Dome is farther east than the other sections and consequently was late in experiencing the ecological effects of an eastward regressing sea.

2. A corresponding decrease from high planktonic foraminiferal percentages to complete benthonic dominance as at the Ferron and Harley Dome sections (figure 7), or a temporary extermination of the foraminifers as at the Caineville section (figure 3), or a fluctuating situation in which there is either complete benthonic or planktonic dominance or no foraminifers present as at the Coal Bed Mesa section (figure 7).

3. A corresponding change in sedimentation with the introduction of fine laminae and cross-laminations, primary structures characteristic of a delta front deposit, at the Coal Bed Mesa, Caineville and Ferron sections (figures 3 to 4) and increase in the coarseness of the sediments at Harley Dome and Silvagni Ranch (figure 5) indicating a shallowing of the water column.

4. The presence of coal deposits in the overlying Ferron Sandstone.

There is evidence to indicate that the regression affected the Frontier, Tropic and Allen Valley seas. It is postulated that the decrease in the foraminiferal numbers and species and the exclusion of *Hedbergella delrioensis* that Jones (1953b, p. 20) describes as occurring in Unit 10 of the Frontier Formation was the result of the environmental effects of a regressing shoreline rather than the restriction of the overall circulation pattern of the Frontier sea. It also is postulated that the change in lithology reported by Lawrence (1965, p. 89) as occurring halfway through the typical Tropic section and which he attributes to the development of an eastern barrier could be interpreted as the result of environmental changes brought about by a retreating shoreline. Finally, the apparent exclusion of microfauna from the upper 90 feet of the Allen Valley Shale and at least a portion of the lower 900 feet of the overlying Funk Valley Formation could be attributed to the regression. This assumption would indicate that a part of the Funk Valley Formation is equivalent in time to a portion of the upper half of the Tununk Shale.

The evidence suggests that all the seas were affected by the regression. If Eicher's methods of determining paleobathymetry are valid, then up to 10,500 feet of water must be withdrawn from the area to allow for the regression. Until a geologically logical mechanism for initially introducing the water or expelling it from the area is specified, the applicability of Eicher's method is open to question.

That the microfauna remains relatively homogeneous through time and space also suggests the water did not deepen considerably from the beginning of the transgression to the beginning of the regression. The same species of benthonic foraminifers associated with the high benthonic percentages representing the initial transgression also are associated with the ensuing high planktonic percentages. Furthermore, the Ferron microfauna is identical with that of Harley Dome even though Harley Dome is 100 miles east of Ferron. If the depth of the sea had markedly increased through time, its sediments should record, at any one locality, corresponding faunal depth facies similar to those encountered by Phleger and Parker (1951, p. 54) in the Gulf of Mexico or, conversely, faunal depth facies should be recognized through space for any one time. As mentioned, the current analysis does not indicate that any such zones existed in the Tununk sea. In fact, Eicher (1969, p. 1087) mentions that the lower 425 feet of Allen Valley Shale has an upper Greenhorn fauna which suggests that a nearly homogeneous fauna existed from Allen Valley to eastern Colorado at the time that the Greenhorn sea had supposedly reached its maximum depth. It suggests that the combined Tununk, Allen Valley, Frontier, Tropic and Greenhorn sea was of nearly uniform depth unless the benthonic microfauna had a considerable depth tolerance. The suggested maximum depth of the sea is from 300 to 600 feet, with a figure in the lower range favored. This would allow the mid-Tununk-Carlile regression to occur without requiring a far-reaching upward epeirogenic movement of up to 10,500 feet or a sudden drop in sea level of the same amount.

The methods for the derivation of the 300- to 600-foot maximum depth figures are admittedly tenuous because numerous conditions could have existed at the initiation of sedimentation and during its continuum, including:

1. A ready-made basin which had a maximum depth of "X" value for the transgressing sea to occupy. This condition fits McCubbin's interpretation of the pre-Tununk paleogeography and paleoecology if the basin was formed by a pulse of subsidence of the Dakota landscape. It also supports the hypothesis that basinal subsidence is intermittent rather than continuous.

2. A basin which developed in response to slow continuous subsidence; therefore, the depth at any one locality would increase gradually as the sea transgressed westward. This condition would have developed in response to Young's interpretation of the pre-Tununk paleogeography and paleoecology and would call for the transgressions.

3. A basin which developed because of a rise in sea level over a pre-existing slope as suggested by Eicher. The gradient would be considerably less than suggested by Eicher to allow for the 300- to 600-foot maximum depths.

4. A combination of any of the above conditions.

If condition 1 existed during the initial transgression and if it was followed by a period of no tectonic subsidence, then the value of the initial maximum depth of the west Tununk sea could have been 600 feet after compensating for the effects of isostatic adjustment due to the weight of the overlying water column. This would allow 500 feet of sediments to be deposited before the initiation of delta front sedimentation. The sediments would account for the approximately 300 feet of shale in the lower half of the unit which is characterized by high foraminiferal numbers if a maximum of 60 percent compaction of the original volume is assumed to have occurred. Also the delta-front sediments could build out upon it during the regression. The depth of water at the time would be 600 minus 500 feet plus the depth resulting from isostatic adjustment from the weight of overlying sediment and compaction, and minus the depth resulting from isostatic rebound as a result of the loss of the overlying water. A renewal of subsidence would allow for the accumulation of the remaining sediments.

If condition 2 was prevalent, however, then a maximum depth of as little as 300 feet would account for the observed lithology and microfauna in the west Tununk sea. As the sea transgressed toward the west and the basin was continually subsiding, the high percentage benthonic foraminiferal sediments were deposited. When the shoreline reached its maximum extent, a maximum depth of 300 feet would have allowed for the deposition of the 200 feet (plus or minus) of high percentage planktonic foraminifera-bearing sediments and provided a depth of plus 100 feet for delta-front sedimentation if continuing basinal subsidence, compaction, isostatic adjustment due to weight of overlying sediments and loss of depth due to the withdrawal of the water column are considered.

Condition 3 would produce results similar to 1 if the rise in sea level were rapid and conditions similar to 2 if it were gradual. The rate of basinal subsidence, however, would have to be considered in the application of this condition and would tend to modify these results. Finally, if condition 4 existed, it would add complications to the interpretation but would not require the use of a deep water column.

The writer suggests that distance from shore instead of water depth accounts for the high planktonic percentages. He postulates that the initial dominant benthonic percentages resulted from favorable environmental conditions established by a nearby shoreline as the sea transgressed westward. As the shoreline continued to move westward, conditions became less favorable for large populations of benthonic forms and more favorable for the accumulation of planktonic forms. The high planktonic percentages were established when the sea was at its maximum western extent. The termination of the dominance is the result of the rapid eastward regression of the shoreline. That the regression was rapid is suggested by: (1) the thin sequence of rocks which separates the high planktonic sequence from the delta-front type sediments; and (2) the failure of the calcareous benthonic foraminifers to re-establish a populous domain. Basinal subsidence is offered as the probable cause of the combined Tununk, Carlile, Allen Valley, Frontier and Tropic transgression. The westward thickening of the Cretaceous rocks as illustrated by Weimer (1960, p. 7) and Young (1966, figure 2) indicates that the focus of the basinal subsidence was in an area adjacent to the western highlands.

Sears, Hunt and Hendricks (1941, p. 103) list the following reasons for their supposition that basin filling rather than a tectonically upward moving trough would be favorable for the "formation and preservation of regressive deposits": (1) it would provide room for deposition of thick regressive deposits; (2) it would prevent erosion of the transgressive deposits; and (3) it would seem mechanically unfeasible for reversals of the direction of movement to occur in a geosyncline and, if they did, then some evidence of their occurrences should exist in the sediments.

Reasons 1 and 2 appear valid and applicable to the study area. Therefore, that basin filling rather than uplift was responsible for this regression is suggested by: (1) the thick regressional (and transgressional) deposits which have accumulated in the basin (Weimer, 1960, p. 7); and (2) the fact that no major unconformities have been observed within the transgressive deposits of the Tununk Shale, Greenhorn Limestone, Tropic Shale, Allen Valley Shale and Unit 10 of the Frontier Formation, which would indicate that they had undergone a period of erosion. If subsidence were active during the transgression as well as the regression, it would have destroyed Eicher's Cedar Mountain paleoslope prior to late Greenhorn time. Therefore the paleoslope method for determining the paleobathymetry could not be used in this case.

To provide data on temperature stratification and to determine depth of the sea, assuming that temperature decreases with water depth, an attempt was made to determine the temperature of surface waters from planktonic foraminifers and of bottom waters from benthonic foraminifers and/or *Inoceramus prisims* by using O^{18}/O^{16} isotope ratios. The attempt was unsuccessful because of the high degree of skeletal contamination by secondary $CaCO_3$.

The preferential coiling direction of *Hedbergella delrioensis* may provide a clue to Tununk surface temperatures. More than 90 percent of the individuals at all stations coil to the right (dextrally). This preference may relate to the temperature as it does in modern-day forms. The direction of coiling in a specific temperature range depends on the species. Bandy (1960, p. 673) points out that *Globigerina pachyderma* shows dextral dominance in warm waters while *Globoratalia tumida* demonstrates sinistral (left-coiling) dominance in similar temperatures. To use coiling directions in the determination of Cretaceous temperatures, it is necessary to: (1) find localities where uncontaminated specimens of *Hedbergella delrioensis* occur; (2) determine the paleotemperatures by means of the O^{18}/O^{16} method; and (3) determine if the paleotemperatures can be correlated with a preferential coiling direction. If the O^{18}/O^{16} temperatures can be shown to correlate with the coiling directions, then the coiling directions can be used independently of temperatures in areas where contaminated samples prevent application of the oxygen isotope method.

The presence of glauconite, which is abundant in the sediments of the Tununk Shale at all the measured sections, is possibly a clue to the salinity of the Tununk sea assuming that conditions under which glauconite forms today are similar to those of formation during the Cretaceous. Cloud (1955, p. 490) states that glauconite is known to form only in "marine waters of normal salinity." That glauconite is widely distributed in the Tununk sediments indicates that conditions favorable for glauconite formation were present and suggests that these conditions included waters of normal salinity–normal in that they would tolerate glauconite formation.

SUMMARY AND CONCLUSIONS

Sediments and fauna of the upper Naturita Formation and basal Tununk Shale record the first invasion of the Cretaceous sea in Utah. In addition, the Tununk contains evidence of the deepening and subsequent regression of that sea.

The initial transgression is represented by a change in lithology from basal sandstone to shale and mudstone containing high percentages of benthonic foraminifera. The Tununk sea, when it reached its most westward extent, was continuous with the Tropic, Allen Valley, Frontier and Greenhorn seas. Its

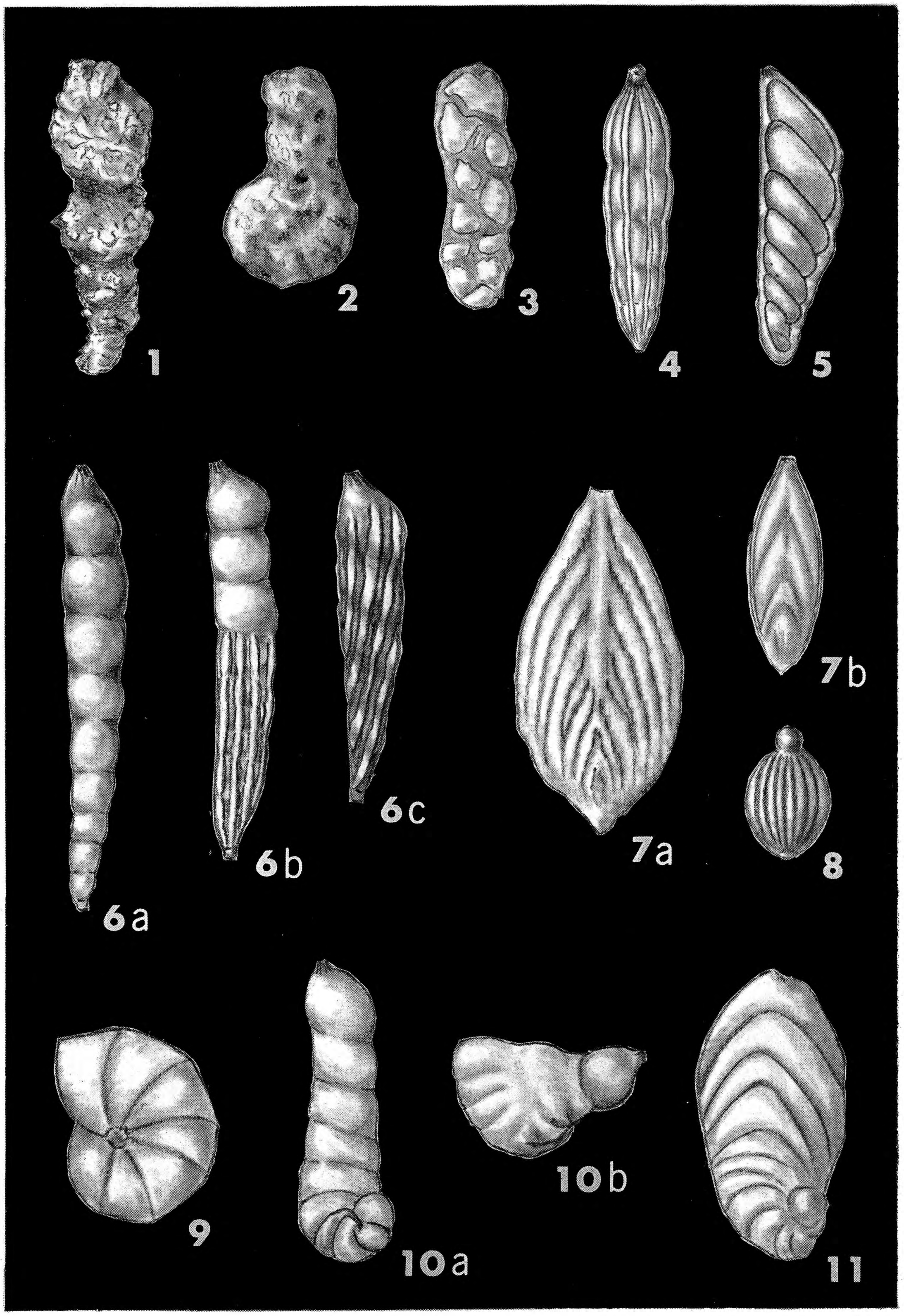


Plate 1. Micropaleontologic specimens of the Tununk Member of the Mancos Shale (explanation on page 18).

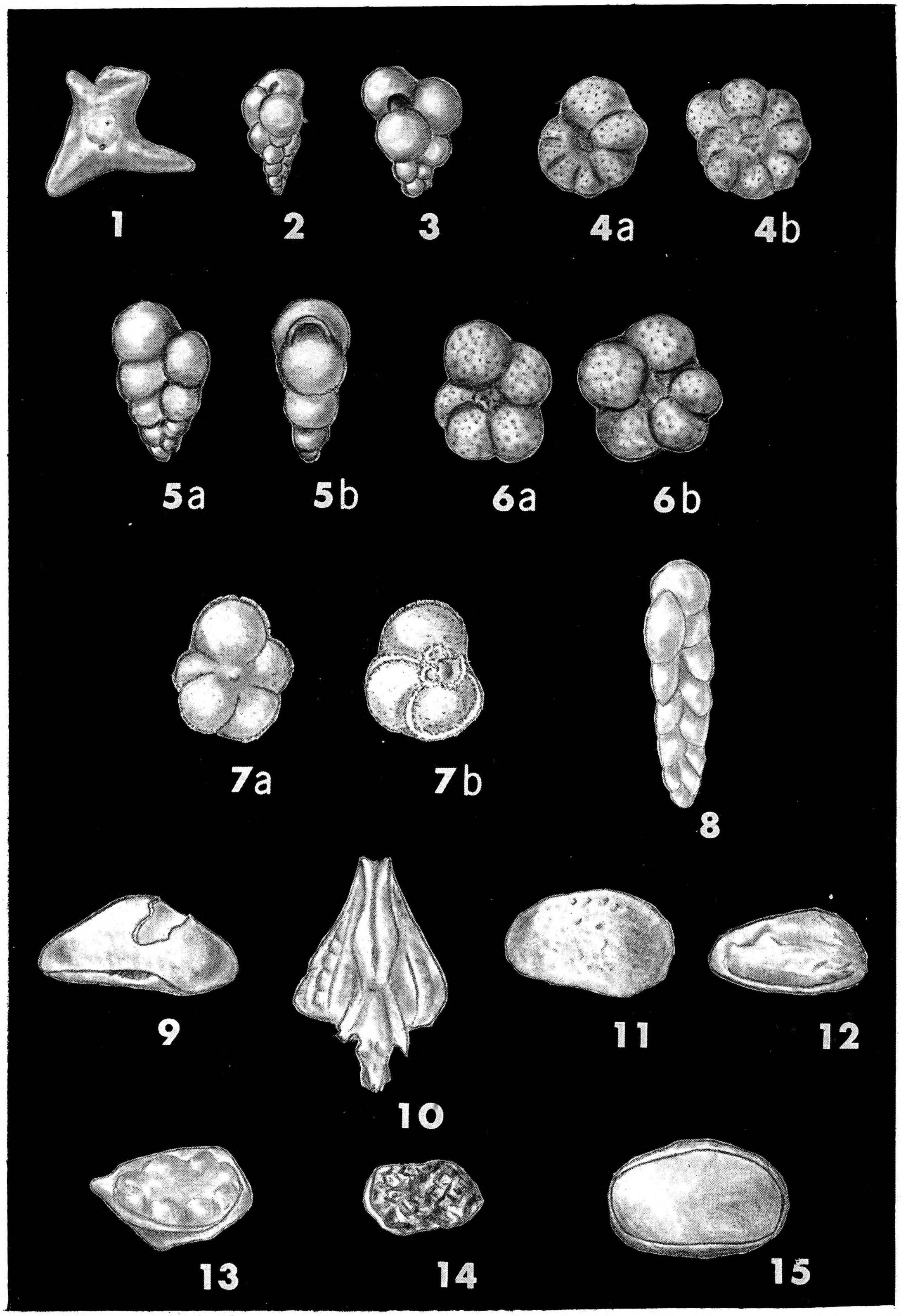


Plate 2. Micropaleontologic specimens of the Tununk Member of the Mancos Shale (explanation on page 18).

EXPLANATION

Plate 1.

Figure 1. *Reophax deckeri* Tappan. Side view of megalospheric specimen, UUM 2001, X40.
Figure 2. *Ammobaculites obscurus* Loeblich. Side view, UUM 2002, X46.
Figure 3. *Spiroplectammina bentonensis* Carman. Side view, UUM 2003, X53.
Figure 4. *Nodosaria duplicicostata* Reuss. Side view, UUM 2005, X47.
Figure 5. *Citharina arguta* (Reuss). Side view, UUM 2006, X40.
Figure 6a. *Dentalina incrassata* Beissel. Side view, UUM 2007, X35.
Figure 6b,c. *Dentalina acutissima* Reuss. 6b, side view of a specimen with costae covering lower portion of test, UUM 2008, X65; 6c, side view of a specimen with costae covering entire test, UUM 2009, X44.
Figure 7. *Frondicularia goldfussi* Reuss. 7a, side view of microspheric specimen, UUM 2010, X27; 7b, side view of megalospheric specimen, UUM 2011, X46.
Figure 8. *Lagena sulcata* (Walker and Jacob). Side view, UUM 2012, X100.
Figure 9. *Lenticulina subangulata* (Reuss). Side view, UUM 2013, X44.
Figure 10. *Marginulinopsis austinana* (Cushman). 10a, side view, UUM 2014, X40; 10b, side view of aberrant specimen, UUM 2015, X39.
Figure 11. *Palmula pilulata* Cushman. Side view, UUM 2016, X50.

Plate 2.

Figure 1. *Ramulina arkadelphiana* Cushman. Side view, UUM 2017, X60.
Figure 2. *Bulimina prolixa* Cushman and Parker. Side view, UUM 2018, X100.
Figure 3. *Guembelitria cretacea* Cushman. Side view, UUM 2019, X146.
Figure 4. *Discorbis austinana* (Cushman). 4a,b, ventral and dorsal views, UUM 2020, X50.
Figure 5. *Heterohelix globulosa* (Ehrenberg). 5a,b, side and apertural views, UUM 2021, X83.
Figure 6. *Hedbergella delrioensis* (Carsey). 6a, ventral view showing dextral coiling, UUM 2022, X60; 6b, ventral view showing sinistral coiling, UUM 2033, X60.
Figure 7. *Globotruncana marginata* (Reuss) Thalmann. 7a,b, ventral and dorsal views, UUM 2023, X44.
Figure 8. *Loxostomum tegulatum* (Reuss). Side view, UUM 2024, X80.
Figure 9. *Paracypris weatherfordensis* Vanderpool. Side view, UUM 2025, X37.
Figure 10. *Alatacythere ponderosana* (Israelsky). Top view, UUM 2026, X37.
Figure 11. *Haplocytheridea sp.* Side view, UUM 2027, X25.
Figure 12. *Eucythere brownstonensis* Alexander. Side view, UUM 2028, X33.
Figure 13. *Orthonotacythere hannai* (Israelsky). Side view, UUM 2029, X37.
Figure 14. *Cythereis* cf. *C. arbenzi* Skinner. Side view, UUM 2030, X33.
Figure 15. *Cytherella navarroensis* Alexander. Side view, UUM 2032, X29.

Plates 1 and 2. (continued)

---

maximum depth is estimated to have been between 300 and 600 feet at this time despite the sediments containing high planktonic foraminiferal percentages. High planktonic foraminiferal percentages are thought to represent distance from shore and not substantial depth as suggested by Eicher (1969). The presence of abundant glauconite in all sections indicates that normal marine conditions existed at this time. The regression is marked by a decrease in foraminiferal numbers and a change to laminated, cross-laminated and sandier sediments approximately halfway upward through the section. Lithologic evidence indicates that deltaic construction was at least partially responsible for the regression. A detailed analysis of the anatomy of the delta is needed to ascertain its size.

SYSTEMATIC PALEONTOLOGY

The classification scheme used in this study is based on Loeblich and Tappan (1964) and Benson and others (1961). The specimens are deposited in the University of Utah micropaleontology collection.

Order FORAMINIFERIDA
Family HORMOSINIDAE Haeckel, 1894
Subfamily HORMOSININAE Haeckel, 1894

Genus REOPHAX Montfort, 1808
REOPHAX DECKERI Tappan
Plate 1, figure 1

Reophax deckeri Tappan, 1940, p. 94, plate 14, figures 3a-b.
Reophax inordinatus Young, 1951, plate 11, figures 1 to 2; Green, 1959, p. 41, plate 1, figure 1.
Reophax sp. Peterson, 1953, p. 29, plate 1, figures 1 to 2.

Agglutinated test; uniserial chamber arrangement with chambers rapidly increasing in size as added; megalospheric stage with large proloculus and a few large chambers; microspheric stage with small proloculum and a large number of small chambers; sutures moderately depressed; test straight or slightly curvilinear; centrally located rounded aperture at end of a cylindrical neck.

Test is longer than broad; specimens vary in length from 0.55 to 1.50 mm and in breadth from 0.25 to 0.60 mm.

Remarks. Specimens occur at all measured sections. Forms are numerous at only a few stations.

Tests may be moderately to completely compressed due to pressure resulting from post-depositional burial. It has been found in the Frontier Formation of southern Montana by Young and in the Frontier Formation and Allen Valley Shale of Utah by Peterson and Green, respectively. The species was originally described from the Lower Cretaceous Grayson Formation of Texas by Tappan.

Figured specimen. UUM 2001

Family LITUOLIDAE de Blainville, 1825
Subfamily LITUOLINAE de Blainville, 1825
Genus AMMOBACULITES Cushman, 1910
AMMOBACULITES OBSCURUS Loeblich
Plate 1, figure 2

Ammobaculites obscurus Loeblich, 1946, p. 135, plate 22, figures 6a-b.

Agglutinated test; early portion planispiral, later portion uniserial; chambers gradually increase in size; chambers moderately rounded having a greater breadth than length; sutures slightly depressed; aperture terminal, a centrally located, rounded opening.

Test is longer than broad; specimens vary in length from 0.55 to 1.25 mm and in breadth from 0.30 to 0.60 mm.

Remarks. Specimens, present at all measured sections, vary in abundance at their respective stations. They are generally larger than those described by Loeblich. Tests are usually compressed and deformed because of post-depositional burial. In some specimens, the uniserial stage has been bent over and impressed onto the planispiral stage.

Figured specimen. UUM 2002

Family TEXTULARIIDAE Ehrenberg, 1838
Subfamily SPIROPLECTAMMININAE Cushman, 1927
Genus SPIROPLECTAMMINA Cushman, 1927
SPIROPLECTAMMINA BENTONENSIS Carman
Plate 1, figure 3

Spiroplectammina bentonensis Carman, 1929, p. 311, plate 34, figures 8 to 9.

Agglutinated test; early portion planispiral; later portion biserial; moderately compressed chambers; sutures flush, oblique to vertical axis throughout; aperture a low arch opening at base of last septal face.

Test is longer than broad; specimens range in length from 0.50 to 0.80 mm and in breadth from 0.15 to 0.30 mm.

Remarks. Although specimens occur at all measured sections, they are numerous at only a few stations. The tests sometimes contain a red iron-oxide filling. Most of the tests are poorly preserved and moderately compressed making their identification difficult.

Figured specimen. UUM 2003

Family TROCHAMMINIDAE Schwager, 1877
Subfamily TROCHAMMININAE Schwager, 1877
Genus TROCHAMMINA Parker and Jones, 1859
TROCHAMMINA SP.

Remarks. A specific identification could not be made because of the poor state of preservation of the tests. Specimens were not observed at either the Silvagni Ranch or Coal Bed Mesa sections. Forms identified as *Trochammina sp.* are possibly internal molds of specimens of *Hedbergella sp., Discorbis sp.* or *Globotruncana sp.* which were deformed by compressional forces caused by post-depositional burial.

Specimen. UUM 2004

Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus NODOSARIA Lamark, 1812
NODOSARIA DUPLICICOSTATA Reuss
Plate 1, figure 4

Nodosaria duplicicostata Reuss, 1860, p. 170, plate 1, figure 5.

Nodosaria fusula Reuss. Cushman, 1946, p. 71, plate 26, figure 5.

Nodosaria amphioxys Reuss. Cushman, 1946, p. 72, plate 26, figure 14.

Nodosaria bighornensis Young, 1951, p. 58, plate 12, figure 17 (not 19). Green, 1959, p. 58, plate 2, figure 10.

Test with hyaline, calcareous walls, uniserial chamber arrangement; chambers gradually increase in size as added; sutures slightly depressed in lower portion and moderately depressed in upper portion; well developed costae which extend from initial to terminal chamber; radiate aperture at end of short neck.

Test is longer than broad; specimens vary in length from 0.30 to 1.25 mm and in breadth from 0.10 to 0.25 mm.

Remarks. Specimens occur at all measured sections but never in large numbers. Young reports this form as occurring in the Frontier Formation of southern Montana and Green lists its occurrence in the Allen Valley Shale of Utah. It also is found in the

Austin, Taylor and Navarro groups of the Gulf Coast region.

Figured specimen. UUM 2005

Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus CITHARINA d'Orbigny *in* De La Sagra, 1839
CITHARINA ARGUTA (Reuss)
Plate 1, figure 5

Vaginulina arguta Reuss, 1860, p. 202, plate 8, figure 4.
Vaginulina bicostulata Reuss, 1860, p. 202, plate 8, figure 5.
Vaginulina n. sp. Young, 1951, plate 13, figures 13 to 14.
Vaginulina sp. Fox, 1954, plate 25, figure 21.

Flattened test with hyaline, calcareous walls; dorsal wall straight or very slightly convex; ventral wall slightly concave; noninflated chambers intersect dorsal wall at approximately 45° angles; chambers vary in number from a minimum of four in megalospheric stage to nine in microspheric stage; proloculum twice as large in megalospheric stage as in microspheric stage; chambers increase rapidly in size in megalospheric forms and gradually in microspheric; keeled on both sides; radiate aperture at terminus of dorsal side.

Test is longer than broad; specimens vary in length from 0.75 to 1.25 mm and in breadth from 0.25 to 0.40 mm.

Remarks. The species is absent from the Ferron and Silvagni Ranch sections. Where present, it is only represented by a few individuals. Reuss applied the name *Vaginulina arguta* to the microspheric form and *Vaginulina bicostulata* to the megalospheric form. Young reports the occurrence of this species in the Frontier Formation of southern Montana and Fox reports it occurring in the Greenhorn of Wyoming. It was initially described from the Cretaceous of Germany.

Figured specimen. UUM 2006

Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus DENTALINA Risso, 1826
DENTALINA INCRASSATA Beissel, 1886
Plate 1, figure 6a

Dentalina incrassata Beissel, 1886, p. 138 (type figures in Beissel, 1891, plate 7, figures 10 to 13).
Dentalina basiplanata Cushman. Cushman, 1938, p. 38, plate 6, figures 6 to 8; Peterson, 1953, p. 35, plate 1, figures 22 to 23.
Dentalina coalvillensis Peterson, 1953, p. 38, plate 2, figures 1 to 2.
Dentalina utahensis Peterson, 1953, p. 38, plate 2, figures 3 to 4.
Dentalina megalopolitana Reuss. Green, 1959, p. 54, plate 2, figure 9.
Dentalina gracilis d'Orbigny. Green, 1959, p. 54, plate 2, figure 9.

Test with hyaline, calcareous walls; curvilinear, uniserial chamber arrangement; early sutures flush, later ones depressed; sutures at slightly oblique angle to axis; chambers increasing in size and roundness as added; often with basal spine; radiate, off-centered aperture.

Test is longer than broad; specimens vary in length from 0.70 to 4.0 mm and in breadth from 0.10 to 0.45 mm.

Remarks. Specimens occur at all measured sections, their numbers being consistently low. Gradational series apparently exists between specimens of *Dentalina incrassata* and *Dentalina acutissima.* They have similar external morphological features and differ only in that *Dentalina acutissima* possesses costae. The extent and number of costae vary. In some specimens they are restricted to the lower part of the test while in others they completely cover it. Possibly the presence or absence of costae is an intra-specific variation, being a response to hereditary factors within the species and not a basis for speciation. This would make *Dentalina incrassata* a junior synonym of *Dentalina acutissima.* Peterson reports the occurrence of this species in the Frontier Formation of north central Utah and Green lists its occurrence in the Allen Valley Shale of Utah. It also was reported from the Navarro and Taylor groups of the Gulf Coast region.

Figured specimen. UUM 2007

Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus DENTALINA Risso, 1826
DENTALINA ACUTISSIMA Reuss
Plate 1, figures 6b-c

Dentalina acutissima Reuss, 1855, p. 168, plate 8, figure 13.
Dentalina confluens Reuss. Cushman, 1946, p. 68, plate 24, figures 9 to 10 (not 11 to 12).
Nodosaria xavierensis Young, 1951, p. 59, plate 12, figure 15; plate 13, figures 11 to 12; Green, 1959, p. 57, plate 2, figure 15.
Dentalina frontierensis Peterson, 1953, p. 37, plate 1, figures 25 to 26.

Dentalina summitensis Peterson, 1953, p. 39, plate 2, figures 5 to 6.
Dentalina bighornensis Fox. Green, 1959, p. 56, plate 2, figures 12 to 13.

Remarks. This species has the same basic morphological characteristics as *Dentalina incrassata.* It differs in that it possesses costae which range in number and extent of development on the test. On some specimens they completely cover the test, while on others they are restricted to the lower portion. Forms are generally associated with *Dentalina incrassata* although one may be present and the other absent. The species was reported from the Frontier Formation of southern Montana and north central Utah by Young and Peterson, respectively, from the Allen Valley Shale of Utah by Green and from the Navarro and Taylor groups of the Gulf Coastal region.

Figured specimens. UUM 2008-2009

Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus FRONDICULARIA Defrance *in* d'Orbigny, 1826
FRONDICULARIA GOLDFUSSI Reuss
Plate 1, figure 7

Frondicularia goldfussi Reuss, 1860, p. 192, plate 4, figures 7a-b. Green, 1959, p. 48, plate 1, figure 12.
Frondicularia watersi Cushman, 1936, plate 3, figures 14 to 15; Green, 1959, p. 48, plate 1, figure 15.
Frondicularia imbricata Young, 1951, p. 61, plate 13, figures 4 to 6.
Frondicularia frontierensis Young, 1951, p. 61, plate 13, figures 1 to 3.
Frondicularia inversa Reuss. Peterson, 1953, p. 39, plate 2, figures 7 to 9.
Frondicularia sp. Fox, 1954, p. 118, plate 26, figure 7.

Compressed test with hyaline, calcareous walls; equitant chamber arrangement; sides slightly curved and coming together at apertural end; number of chambers varying from 10 in microspheric stage to 5 in megalospheric stage; proloculus twice as large in megalospheric stage as in microspheric stage; centrally located basal spine formed by protrusion of lagenoid-shaped proloculus; test usually crossed by vertical costae which vary in number and prominence; centrally located radiate aperture on a short neck.

Test is longer than broad; specimens vary in length from 0.5 to 2.0 mm and in breadth from 0.22 to 0.95 mm.

Remarks. Although never in large numbers, forms occur at all sections. Reuss, in his original description, does not mention the possession of costae as a characteristic feature of the species. The number of costae in the Tununk forms range from none to many which indicates that their possession is an intra-specific variation. The species, first described from the Cretaceous of Germany, occurs in the Navarro and Taylor groups of the Gulf Coast region and was reported from the Allen Valley Shale and Frontier Formation of Utah by Green and Peterson, respectively, the Frontier Formation of southern Montana by Young and the Carlile Formation of South Dakota by Fox.

Figured specimens. UUM 2010-2011

Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus LAGENA Walker and Jacob *in* Kanmacher, 1798
LAGENA SULCATA (Walker and Jacob)
Plate 1, figure 8

Serpula (Lagena) *sulcata* Walker and Jacob, 1798, p. 634, plate 14, figure 5.
Lagena sulcata (Walker and Jacob). Carsey, 1926, p. 31, plate 7, figure 4.
Lagena acuticostata Reuss. Green, 1959, p. 59, plate 3, figures 1 to 2.

Spherical to elliptical test with hyaline, calcareous walls; unilocular; well formed vertical costae which terminate at neck; aperture is a centrally located, simple opening at the end of short neck.

Specimens vary in length from 0.15 to 0.20 mm and in breadth from 0.10 to 0.15 mm.

Remarks. Specimens occur at all measured sections. Numbers vary from section to section, being abundant at some sample locations. It is difficult to differentiate *lagena sulcata* from the proloculus of the megalospheric stage of *Frondicularia goldfussi* which illustrates the close morphological relationship existing between some members of the Nodosariidae, as pointed out by Gordon (1966, p. 325). Young reports its occurrence in the Allen Valley Shale of Utah.

Figured specimen. UUM 2012

Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus LENTICULINA Lamark, 1804
LENTICULINA SUBANGULATA (Reuss)
Plate 1, figure 9

Cristellaria (*Cristellaria*) *subangulata* Reuss, 1863, p. 74, plate 8, figure 7.

Biconvex, planispirally coiled test with hyaline, calcareous wall; eight chambers in last coil which gradually increase in size; rounded to angular periphery; later formed chambers, in some specimens, possess straight peripheries which result in test having angular rather than rounded profile; sutures flush and concave toward proloculum; small to moderately sized keel; poorly developed, radiate aperture at top of last septal face.

Specimens vary in length from 0.4 to 1.0 mm and in breadth from 0.35 to 0.70 mm.

Remarks. Specimens occur at all sections, but never in large numbers. The species was first described from the Cretaceous of Germany. The extent of its distribution in the Western Interior is uncertain due to the fact that its variability makes it difficult to recognize and to identify properly.

Figured specimen. UUM 2013

Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus MARGINULINOPSIS A. Silvestri, 1904
MARGINULINOPSIS AUSTINANA (Cushman)
Plate 1, figure 10

Marginulina austinana Cushman, 1937, p. 92, plate 13, figures 1 to 4; Peterson, 1953, p. 32, plate 1, figures 7 to 8.

Marginulina austinana Cushman var. *directa* Cushman. Peterson, 1953, p. 32, plate 1, figures 9 to 15.

Marginulinopsis frontierensis Young, 1951, p. 52, plate 11, figures 9 to 12; figures 5, 2 to 8; Green, 1959, p. 49, plate 2, figure 1.

Marginulinopsis ammonitiformis Young, 1951, p. 52, plate 11, figures 22 to 23; figures 5, 9 to 12. Green, 1959, p. 51, plate 2, figure 4.

Marginulinopsis amplaspira Young, 1951, p. 54, plate 11, figures 15, 17 to 21; plate 12, figures 1 to 4, 6, 8 to 14; figures 5, 14 to 16, 18 to 21; figures 6, 2 to 16, 20; Fox, 1954, p. 115, plate 25, figures 13 to 14; Green, 1951, p. 50, plate 2, figures 2 to 3; Lamb, 1968, p. 842.

Marginulinopsis n. sp. 1 Young, 1951, p. 57, plate 12, figure 5; figures 6 and 19.

Marginulinopsis n. sp. 2 Young, 1951, p. 57, figures 6, 17 to 18; Green, 1959, p. 52, plate 2, figure 5.

Marginulinopsis n. sp. 3 Young, 1951, p. 58, plate 11, figure 16; plate 12, figure 7; figures 1 and 6.

Marginulinopsis sp. Young, 1951, p. 58, figures 5, 24, 26 and 29.

Moderately compressed test with hyaline, calcareous walls; earlier portion coiled, later portion uncoiled and uniserial; coiled portion appears to decrease in size as uniserial stage grows longer; chambers gradually increase in size as added; convex-upward sutures flush in planispiral stage becoming depressed in uniserial stage; dorsal wall may be straight, slightly concave or convex; ventral wall may be convex or concave; umbo prominent or degenerate; prominent radiate aperture at terminus of dorsal side.

Test is longer than broad; specimens vary in length from 0.20 to 1.65 mm and in breadth from 0.1 to 0.4 mm.

Remarks. One of the most abundant of the Nodosariidae, the species occurs at all sections. Specimens vary greatly in appearance. Some of the variation appears to result from the ability of the species to resorb the calcium carbonate in the planispiral stage and to use it to construct the later chambers. An aberrant specimen (plate 1, figure 10b) illustrates the morphological similarities which exist between the genera *Lenticulina* and *Marginulinopsis* as pointed out by Gordon (1966, p. 326). The form is planispiral with a lenticulinian aperture on one end and the beginning of a marginulinian uniserial stage and aperture at the other end. As suggested by Gordon (1966, p. 329) such relationships might eventually result in the reevaluation and consolidation of these taxa, at least for Mesozoic forms. It occurs in the Austin Group of the Gulf Coast region and was reported from the Frontier Formation of southern Montana by Young, the Greenhorn Formation of South Dakota by Fox, the Allen Valley Shale and Frontier Formation of Utah by Green and Peterson, respectively, and the Graneros and lower Carlile Shale of northwestern New Mexico by Lamb.

Figured specimens. UUM 2014-2015

Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus PALMULA Lea, 1833
PALMULA PILULATA Cushman
Plate 1, figure 11

Palmula pilulata Cushman, 1938, p. 37, plate 6, figure 2.

Compressed test with hyaline, calcareous walls; early portion planispiral with seven chambers; later portion uniserial with chevron-shaped chambers, the chevrons becoming more distinct as new ones are added; chambers gradually increasing in size; sutures flush with surface; slightly raised nodes at end of each suture in planispiral stage; centrally located, low projecting radiate aperture.

The length of the larger specimen is 1.00 mm and its maximum breadth is 0.50 mm.

Remarks. Only two specimens were observed. They are from the Caineville section. The smaller possesses the nodes, which are indistinct on the larger. This form occurs in the Austin Group of the Gulf Coast region.

Figured specimen. UUM 2016

Family POLYMORPHINIDAE d'Orbigny, 1839
Subfamily RAMULININAE Brady, 1884
Genus RAMULINA Jones, *in* Wright, 1875
RAMULINA ARKADELPHIANA Cushman
Plate 2, figure 1

Ramulina arkadelphiana Cushman, 1938, p. 43, plate 7, figures 12 to 14; Peterson, p. 41, plate 2, figures 10 to 11.

Ramulina sp. Young, 1951, p. 62, plate 14, figures 9 to 10.

Aborescent test with hyaline, calcareous walls; conical tubes protruding from a central capsule; hispid surface; apertures are simple openings at end of tubes.

Average diameter of specimens is 0.75 mm.

Remarks. Although specimens occur at all measured sections, their numbers are always small. The species is found in the Frontier Formation of southern Montana and north central Utah as reported by Young and Peterson, respectively, as well as in the Navarro Group of the Gulf Coast region.

Figured specimen. UUM 2017

Family BULIMINIDAE Jones, 1875
Subfamily BULIMININAE Jones, 1875
Genus BULIMINA d'Orbigny, 1826
BULIMINA PROLIXA Cushman and Parker
Plate 2, figure 2

Bulimina prolixa Cushman and Parker, 1935, p. 98, plate 15, figure 5.

Bulimina kickapooensis Cole. Green, 1959, p. 61, plate 3, figure 4.

Neobulimina canadensis Cushman and Wickenden. Green, 1959, p. 62, plate 3, figure 6.

Neobulimina irregularis Cushman and Parker, Green, 1959, p. 62, plate 3, figure 7.

Praebulimina wyomingensis (Fox). Eicher, 1965, p. 903, plate 106, figure 4.

Triangular-shaped test with hyaline, calcareous walls; three chambers to a whorl with five to seven whorls per test; inflated chambers increase in size at a moderate rate; slightly depressed sutures are oblique to vertical axis; lower portion of test is sometimes slightly twisted; aperture is an elongated slit extending from the base of the last formed chamber towards its terminus.

Test is longer than broad; specimens vary in length from 0.15 to 0.30 mm and in breadth from 0.10 to 0.15 mm.

Remarks. Specimens occur in large numbers at all measured sections. Several tests were observed to go from a triserial to a biserial stage in the last formed whorl. This apparently would necessitate classifying the forms as *Neobulimina sp.* If this biserial stage results from the failure of the organism to add a final chamber before death, however, then the form should be classified as *Bulimina sp.* The latter condition is assumed applicable in the case of the Tununk specimens. Green reports this form as occurring in the Allen Valley Shale of Utah and Eicher from the Graneros Shale of Colorado. Fox (1954, p. 101) notes the occurrence of *Neobulimina canadensis* in the Greenhorn and Carlile formations of South Dakota while Lamb (1968, p. 842) indicates its abundant occurrence in the Carlile Shale of northwestern New Mexico. This could be the same species as identified in this paper, for the reason expressed. It also occurs in the Navarro and Taylor groups of the Gulf Coast region.

Figured specimen. UUM 2018

Family HETEROHELICIDAE Cushman, 1927
Subfamily GUEMBELITRIINAE Montanara Gallitelli, 1957
Genus GUEMBELITRIA Cushman, 1933
GUEMBELITRIA CRETACEA Cushman
Plate 2, figure 3

Guembelitria cretacea Cushman, 1933, p. 37, plate 4, figures 12a-b.

Test with hyaline, calcareous walls; triserial chamber arrangement; chambers globular, gradually increasing in size; aperture is a medium-sized arch at the base of the last septal face.

Test is longer than broad; specimens vary in length from 0.12 to 0.17 mm and in breadth from 0.10 to 0.15 mm.

Remarks. Specimens occur at all the measured sections and at some stations are extremely abundant. The Tununk forms are more closely aligned to *Guembelitria cretacea* than to *Guembelitria harrisi* Tappan. Forms described by Tappan (1940) are larger with a lower apertural opening. The difference in tests could be more of a response to environmental factors than to speciation, which would make *Guembelitria harrisi* a junior synonym of *Guembelitria cretacea.* Lamb (1968, p. 842) describes *Guembelitria harrisi* as occurring in the lower Carlile Formation of northwestern New Mexico. It also was reported from the Navarro Group of the Gulf Coast region.

Figured specimen. UUM 2019

Family DISCORBIDAE Ehrenberg, 1838
Subfamily DISCORBINAE Ehrenberg, 1838
Genus DISCORBIS Lamark, 1804
DISCORBIS AUSTINANA (Cushman)
Plate 2, figure 4

Planulina austinana Cushman, 1938, p. 68, plate 12, figures 2a-c.

Planulina dakotensis Fox, 1954, p. 119, plate 26, figures 19 to 21.

Anomalina ammonoides (Reuss) Chapman. Green, 1959, p. 65, plate 4, figure 1.

Anomalina cf. *A. Nelsoni* W. Berry. Green, 1959, p. 66, plate 4, figure 2.

Planulina kansasensis Morrow. Green, 1959, p. 66, plate 4, figure 4.

Planulina correcta (Carsey) Cushman. Peterson, 1953, p. 67, plate 4, figure 5.

Coarsely perforated, rotaloid test with hyaline calcareous walls; dorsal side evolute and flat; ventral side involute and convex; seven to eight chambers in final whorl; chambers gradually increase in size; the size of the last-formed chamber varies from specimen to specimen; depressed sutures on ventral side are straight to slightly curved; aperture is a slit extending from the umbilicus to the periphery.

Diameter of test varies from 0.2 to 0.5 mm.

Remarks. Specimens occur at all measured sections and are extremely numerous at many stations. Representatives are usually small. Cushman classified this taxon as *Planulina,* noting that the dorsal side was more evolute than the ventral side. The degree of ventral evoluteness depends on the size of the last-formed chamber which is described above as variable. The last chamber in the Tununk specimens is usually of sufficient size to cover the previously formed chambers. This, in addition to the position of the aperture, suggests that they should be placed into the genus *Discorbis* instead of *Planulina.* Fox reports the occurrence of the species in the Greenhorn Formation of South Dakota and Green cites its presence in the Allen Valley Shale of Utah. It also occurs in the Austin chalk of the Gulf Coast region.

Figured specimen. UUM 2020

Family HETEROHELICIDAE Cushman, 1922
Subfamily HETEROHELICINAE Cushman, 1927
Genus HETEROHELIX Ehrenberg, 1843
HETEROHELIX GLOBULOSA (Ehrenberg)
Plate 2, figure 5

Textularia globulosa Ehrenberg, 1840, p. 135, plate 4, figure 4b.

Gumbelina globulosa (Ehrenberg). Egger, 1899, p. 32, plate 14, figure 43; Morrow, 1934, p. 194, plate 29, figures 18a-b; Young, 1951, p. 63, plate 14, figures 12, 23 to 26; Green, 1959, p. 60, plate 3, figure 3.

Heterohelix globulosa (Ehrenberg). Montanara Gallitelli, 1957, p. 137, plate 31, figures 12 to 15; Eicher, 1965, p. 904, plate 106, figure 3; Wall, 1967, p. 102, plate 3, figures 26 to 37; Lamb, 1968, p. 842.

Test with finely perforated, hyaline calcareous walls; chamber arrangement either entirely biserial or with a small (compared to remainder of test) planispiral stage followed by a biserial stage; chambers globular, rapidly increasing in size and varying in number from 8 to 12; depressed sutures; aperture medium size, a centrally located arch at the base of the last septal face.

Test is longer than broad; specimens vary in length from 0.2 to 0.4 mm and in breadth from 0.1 to 0.3 mm.

Remarks. Specimens are abundant in the lower portion of each section and rare to absent in the upper portion. It is considered a planktonic form because of its worldwide Late Cretaceous distribution pattern and its common association with other planktonic forms. It was reported from the Greenhorn Formation of New Mexico and Colorado by Lamb, the Greenhorn Formation of Kansas by Morrow, the Graneros Shale of Wyoming and Kansas by Eicher, the Allen Valley Shale of Utah by Green and from the Vimy Member of the Blackstone Formation in the Rocky Mountain Foothills of Canada as well as the plains region of northwestern Alberta by Wall.

Figured specimen. UUM 2021

Family ROTALIPORIDAE Sigal, 1958
Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961
Genus HEDBERGELLA Bronnimann and Brown, 1958
HEDBERGELLA DELRIOENSIS (Carsey)
Plate 2, figure 6

Globigerina cretacea d'Orbigny var. *delrioensis* Carsey, 1926, p. 43.

Globigerina cretacea d'Orbigny. Morrow, 1934, p. 198, plate 10, figures 7 to 8, 10a-b; Young, 1951, p. 65, plate 14, figures 1 to 3; Peterson, p. 45, plate 2, figures 15a-b; Green, 1959, p. 64, plate 3, figures 11 to 14.

Hedbergella delrioensis (Carsey). Loeblich and Tappan, 1961, p. 275, plate 2, figures 11 to 13; Eicher, 1965, p. 904, plate 106, figures 2 and 6; Wall, 1967, p. 105, plate 3, figures 1 to 12, plate 13, figures 13 to 21; Lamb, 1968, p. 842.

Specimens vary in diameter from 0.35 to 0.50 mm.

Remarks. Specimens occur in large numbers at all measured sections. Approximately 95 percent of the forms demonstrate dextral coiling. This species is reported as occurring in the Graneros, Greenhorn and Carlile formations of Kansas by Morrow, in the Frontier Formation of southern Montana by Young, in the Frontier Formation of north central Utah by Peterson, in the Allen Valley Shale of Utah by Green, in the Graneros Shale of Kansas and Colorado by Eicher, in the Vimy Member of the Blackstone Formation by Wall and in the Greenhorn Limestone and Carlile Shale of northwestern New Mexico by Lamb.

Figured specimens. UUM 2022 and 2033

Family GLOBOTRUNCANIDAE Brotzen, 1942
Genus GLOBOTRUNCANA Cushman, 1927
GLOBOTRUNCANA MARGINATA (Reuss) Thalmann
Plate 2, figure 7

Rosalina marginata Reuss, 1845, p. 36, plate 1, figures 54 and 74.

Globotrunca marginata (Reuss). Thalmann, 1934, p. 414; Lamb, 1968, p. 842.

Rotaloid test with hyaline calcareous walls; dorsal side evolute, slightly convex with chambers that overlap; sutures on the dorsal side are beaded; ventral side involute with slightly compressed chambers; five chambers in last formed whorl; umbilical vestibule with remnants of tegilla; double keeled aperture opens into umbilical vestibule.

Specimens vary in diameter from 0.35 to 0.85 mm.

Remarks. Specimens were observed only in a few samples from the Ferron and Coal Bed Mesa sections. Forms appear worn due to the decrystallization of the original test material. Various stages of decrystallization were observed. Lamb lists this species as occurring in the Tocito Sandstone of northwestern New Mexico. It also occurs in the Navarro, Taylor and Austin groups of the Gulf Coast region.

Figured specimen. UUM 2023

Family LOXOSTOMIDAE Loeblich and Tappan, 1962
Genus LOXOSTOMUM Ehrenberg, 1854
LOXOSTOMUM TEGULATUM (Reuss)
Plate 2, figure 8

Virgulina tegulata Reuss, 1845, p. 40, plate 13, figure 81.

Loxostomum tegulatum (Reuss). Cushman, 1931, p. 51, plate 8, figure 8; Young, 1951, p. 64, plate 14, figure 13; Green, 1959, p. 63, plate 3, figure 8.

Finely perforated test with hyaline calcareous walls; biserial throughout; test is slightly twisted about its axis; chambers gradually increase in size with the last chamber being the largest and giving the test the appearance of becoming uniserial; sutures slightly depressed and entering axis at a moderate to slight angle; elongated aperture along edge and extending from the base of the last septal face to its terminus.

Test is longer than broad; specimens vary in length from 0.31 to 0.65 mm and in breadth from 0.10 to 0.15 mm.

Remarks. Specimens were not observed at the Silvagni Ranch section. Numbers vary at the remaining sections, becoming numerous at some stations. The tests are frequently filled with iron oxide or sulfide and internal molds composed of these substances are common. Green indicates that this species is present in the Allen Valley Shale of Utah and Young reports its occurrence in the Frontier Formation of southern Montana.

Figured specimen. UUM 2024

Subclass OSTRACODA
Family PARACYPRIDIDAE Sars, 1923
Genus PARACYPRIS Sars, 1866
PARACYPRIS WEATHERFORDENSIS Vanderpool
Plate 2, figure 9

Paracypris weatherfordensis Vanderpool, 1928, p. 104, plate 14, figures 11 to 12.

Paracypris cf. *p. tenuicula* Alexander. Peterson, 1953, p. 48, plate 3, figures 3a-c.

Remarks. Although specimens occur at all but the Coal Bed Mesa section, they never occur in significant numbers. They are characterized by their elongated wedge shape and strongly convex dorsal border. Peterson reported the species from the Frontier Formation of north central Utah.

Figured specimen. UUM 2025

Family BRACHYCYTHERIDAE Puri, 1954
Genus ALATACYTHERE Murray and Hussey, 1942
ALATACYTHERE PONDEROSANA (Israelsky)
Plate 2, figure 10

Cytheropteron ponderosana Israelsky, 1929, p. 2, plate 2, figures 1a-c.
Cythereis thomasi (Israelsky) Alexander. Peterson, 1953, p. 49, plate 3, figures 5 to 9; Green, 1959, p. 69, plate 4, figure 9.
Alatacythere ponderosana Butler and Jones, 1957, p. 29, plate 2, figures 4a-c.

Remarks. This form was common in the Tununk sea and specimens occur at all measured sections. It is distinguished by its prominent alae and spines. The average length of specimens is 0.9 mm. The species is reported as occurring in the Frontier Formation of north central Utah by Peterson and in the Allen Valley Shale of Utah by Green.

Figured specimen. UUM 2026

Family CYTHERIDEIDAE Sars, 1925
Subfamily CYTHERIDEINAE Sars, 1925
Genus HAPLOCYTHERIDEA Stephenson, 1936
HAPLOCYTHERIDEA SP.
Plate 2, figure 11

Remarks. Specimens are rare and were observed only at the Coal Bed Mesa and Silvagni Ranch sections.

Figured specimen. UUM 2027

Family CYTHERIDEIDAE Sars, 1925
Subfamily EUCYTHERINAE Puri, 1954
Genus EUCYTHERE Brady, 1868
EUCYTHERE BROWNSTONENSIS Alexander
Plate 2, figure 12

Eucythere brownstonensis Alexander, 1936, p. 690, plate 93, figure 4; Peterson, 1953, p. 49, plate 3, figures 4a-c.

Remarks. Representatives are fairly common and were observed at all but the Coal Bed Mesa section. They are characterized by their blunt wedge shape and strongly convex dorsal border. The species occurs in the Frontier Formation of Utah as reported by Peterson.

Figured specimen. UUM 2028

Family CYTHERURIDAE G. W. Muller, 1894
Genus ORTHONOTACYTHERE Alexander, 1933
ORTHONOTACYTHERE HANNAI (Iraelsky)
Plate 2, figure 13

Cytheridea ? hannai Israelsky, 1929, p. 12, plate 2A, figure 10a-b.
Orthonotacythere hannai Alexander, 1933, p. 200, plate 25, figures 1a-c; plate 26, figures 6a-b; plate 27, figures 14a-b.
Orthonotacythere sp. Peterson, 1953, p. 49, plate 3, figures 10a-b.

Remarks. Two specimens were observed from samples taken at the Silvagni Ranch section. Peterson reports that this species occurs in the Frontier Formation of north central Utah.

Figured specimen. UUM 2029

Family TRACHYLEBERIDIDAE Sylvester-Bradley, 1948
Genus CYTHEREIS Jones, 1849
CYTHEREIS CF. C. ARBENZI Skinner
Plate 2, figure 14

Cythereis arbenzi Skinner, 1956, p. 195, plate 4, figures 10a-b.

Remarks. The form is rare with only five specimens from the Harley Dome and Ferron sections observed.

Figured specimen. UUM 2030

Family TRACHYLEBERIDIDAE Sylvester-Bradley, 1948
Genus CYTHEREIS Jones, 1849
CYTHEREIS WRIGHTII Jones and Hinde

Cythereis wrightii Jones and Hinde, 1890, p. 25, plate 4, figure 18.

Remarks. A total of six specimens were observed. These are from the Harley Dome and Coal Bed Mesa sections.

Specimen. UUM 2031

Family CYTHERELLIDAE Sars, 1866
Genus CYTHERELLA Jones, 1849
CYTHERELLA NAVARROENSIS Alexander
Plate 2, figure 15

Cytherella navarroensis Alexander, 1929, p. 53, plate 2, figures 1 to 2.
Cytherella ? unilacuna Morrow, 1934, p. 202, plate 31, figures 12a-b and 13a-b.
Cytherella bullata Alexander. Peterson, 1953, plate 3, figures 2a-c.

Remarks. Representatives of this species are numerous in the Tununk and are found at all measured sections. It is characterized by its ovate form with maximum thickening in the middle of the test. Peterson describes it as occurring in the Frontier Formation of north central Utah and Morrow from the Greenhorn Formation of Kansas.

Figured specimen. UUM 2032

REFERENCES

Alexander, C. I., 1929, Ostracoda of the Cretaceous of north Texas: Texas Univ. Bull. 2907, 137 p.

————1933, Shell structure of the ostracode genus *Cytheropteron* and fossil species from the Cretaceous of Texas: Jour. Paleon., v. 7, no. 2, p. 181-214.

————1936, Ostracodes of the genera *Eucythere, Cytherurs, Eucytherura* and *Loxoconcha* from the Cretaceous of Texas: Jour. Paleon., v. 10, no. 8, p. 689-694.

Bandy, O. L., 1960, The geologic significance of coiling ratios in the foraminifer *Globigerina pachyderma* (Ehrenberg): Jour. Paleon., v. 34, no. 4, p. 671-681.

Beissel, Ignaz, 1886, Der Aachener Sattel und die aus demselben vorbrechenden Thermalquellen: Aachen, Naturw. Ges. Aachen, Abh. 1, p. 1-178.

————1891, Die Foraminiferen der Aachener Kreide: K. Preuss. Geol. Landesanst., Abh., N. F., no. 3, p. 1-78 (in atlas).

Benson, R. H. and others, 1961, Treatise on invertebrate paleontology, part Q, Arthropoda 3 (Moore, ed.): Geol. Soc. Am. and the Univ. of Kansas Press, 442 p.

Butler, E. A. and D. E. Jones, 1957, Cretaceous ostracoda of Prothro and Rayburns salt domes, Bienville Parish, Louisiana: La. Geol. Survey Geol. Bull., no. 32, 65 p.

Carman, K. W., 1929, Some foraminifera from the Niobrara and Benton formations of Wyoming: Jour. Paleon., v. 3, no. 3, p. 308-315.

Carsey, E. O., 1926, Foraminifera of the Cretaceous of central Texas: Univ. of Texas Bull., no. 2612, 56 p.

Cloud, P. E., Jr., 1955, Physical limits of glauconite formation: Am. Assoc. Petrol. Geol. Bull., v. 39, no. 4, p. 482-492.

Coleman, J. M. and S. M. Gagliano, 1965, Sedimentary structure Mississippi River deltaic plain, *in* Middleton, ed., Primary sedimentary structures and their hydrodynamic interpretation–a symposium: Soc. Econ. Paleontologists and Mineralogists, Spec. Publ., no. 3, p. 133-148.

Craig, L. C., 1961, Comments by Lawrence C. Craig, *in* Dakota Group of Colorado Plateau–discussion: Am. Assoc. Petrol. Geol. Bull., v. 45, no. 9, p. 1582-1584.

Cushman, J. A., 1931, A preliminary report on the Foraminifera of Tennessee: Tenn. Div. Geol. Bull. 41, p. 1-62.

————1933, Some new foraminiferal genera: Cushman Lab. Foram. Res., Contr., v. 9, pt. 2, p. 32-38.

————1936, Notes on some American Cretaceous *Frondicularias*: Cushman Lab. Foram. Res., Contr., v. 12, pt. 1, p. 11-22.

————1937, Some notes on Cretaceous species of *Marginulina*: Cushman Lab. Foram. Res., Contr., v. 3, pt. 4, p. 91-99.

————1938, Additional new species of American Cretaceous Foraminifera: Cushman Lab. Foram. Res., Contr., v. 14, pt. 2, p. 31-50.

————1938, Some new species of rotaliform Foraminifera from the American Cretaceous: Cushman Lab. Foram. Res., Contr., v. 14, pt. 3, p. 66-71.

————1946, Upper Cretaceous Foraminifera of the Gulf Coastal region of the United States and adjacent areas: U. S. Geol. Survey Prof. Paper 206, 241 p.

Cushman, J. A. and F. L. Parker, 1935, Some American Cretaceous *Buliminas*: Cushman Lab. Foram. Res., Contr., v. 11, pt. 4, p. 96-101.

Egger, J. G., 1899, Foraminiferen and Ostrakoden aus den Kreide-Mergeln der Oberbayerisch Alpen: K. Bayer. Akad. Wiss., Munchen, Math.-Phys. Cl., Abh., v. 21, pt. 1, p. 1-230.

Ehrenberg, C. G., 1840, Uber die Bildung der Kreidefelsen und des Kreidemergels durch unsichtbara Orgenismen: K. Akad. Wiss. Berkin, Physik. Abh., Berlin (Jahrg. 1838), p. 59-147.

Eicher, E. L., 1965, Foraminifera and biostratigraphy of the Graneros Shale: Jour. Paleon., v. 39, no. 5, p. 875-909.

————1969, Paleobathymetry of Cretaceous Greenhorn sea in eastern Colorado: Am. Assoc. Petrol. Geol. Bull., v. 53, no. 5, p. 1075-1090.

Fox, S. K., 1954, Cretaceous Foraminifera from the Greenhorn, Carlile and Cody formations, South Dakota, Wyoming: U. S. Geol. Survey Prof. Paper 254-E, p. 97-124.

Gilbert, G. K., 1877, Report on the geology of the Henry Mountains: U. S. Geog. and Geol. Survey of the Rocky Mountain region, 160 p.

Glissmeyer, C. H., 1959, Microfauna of the Funk Valley Formation, central Utah: Unpubl. M. S. thesis, Univ. of Utah.

Gordon, W. A., 1966, Variation and its significance in classification of some English Middle and Upper Jurassic nodosariid Foraminifera: Micropaleon., v. 12, no. 3, p. 325-333.

Green, P. R., 1959, Microfauna of the Allen Valley Shale, central Utah: Unpubl. M. S. thesis, Univ. of Utah.

Hintze, L. F. and W. L. Stokes, 1964, Geologic map of southeastern Utah: William and Heintz Map Corp.

Israelsky, M. C., 1929, Upper Cretaceous ostracodes of Arkansas: Ark. Geol. Survey Bull. 2, 29 p.

Jones, D. J., 1953a, Cretaceous stratigraphy of northern Utah and southwestern Wyoming, *in* Jones, ed., Microfossils of the Upper Cretaceous of northeastern Utah and southwestern Wyoming: Utah Geol. and Mineralog. Survey Bull. 47, p. 5-18.

———1953b, Evidence from the microfossils, *in* Jones, ed., Microfossils of the Upper Cretaceous of northeastern Utah and southwestern Wyoming: Utah Geol. and Mineralog. Survey Bull. 47, p. 19-28.

Jones, T. R. and G. J. Hinde, 1890, A supplementary monograph of the Cretaceous *Entomostraca* of England and Ireland: Paleontographical Soc. London, v. 43, p. 1-70.

Katich, P. J., Jr., 1954, Cretaceous and early Tertiary stratigraphy of central and south central Utah with emphasis on the Wasatch Plateau area: Intermtn. Assoc. Petrol. Geol. Guidebook, 5th Ann. Field Conf., p. 42-54.

Lamb, G. M., 1968, Stratigraphy of the lower Mancos Shale in the San Juan Basin: Geol. Soc. Am. Bull., v. 79, p. 827-854.

Lawrence, J. C., 1965, Stratigraphy of the Dakota and Tropic formations of Cretaceous age in southern Utah: Utah Geol. Soc. Guidebook, no. 19, p. 71-91.

Loeblich, A. R., Jr., 1946, Foraminifera from the type Pepper Shale of Texas: Jour. Paleon., v. 20, no. 2, p. 130-139.

Loeblich, A. R., Jr., and others, 1957, Studies in Foraminifera: U. S. Natl. Mus. Bull. 215, 323 p.

Loeblich, A. R., Jr., and H. Tappan, 1961, Cretaceous planktonic foraminifera, part 1—Cenomanian: Micropaleon., v. 7, no. 3, p. 257-304.

———1964, Treatise on invertebrate paleontology, part C—Protista 2 (Moore, ed.): Geol. Soc. Am. and the Univ. of Kansas Press, 2 vol., 900 p.

McCubbin, D. G., 1961, Basal Cretaceous of southwestern Colorado and southeastern Utah: Unpubl. Ph. D. thesis, Harvard Univ.

Montanaro Gallitelli, E., 1957, A revision of the foraminiferal family Heterohelicidae: U. S. Natl. Mus. Bull. 215, p. 133-154.

Morrow, A. L., 1934, Foraminifera and Ostracoda from the Upper Cretaceous of Kansas: Jour. Paleon., v. 8, no. 2, p. 186-205.

Peterson, R. H., 1953, Microfauna of the Frontier, *in* Jones, ed., Microfossils of the Upper Cretaceous of northeastern Utah and southwestern Wyoming: Utah Geol. and Mineralog. Survey Bull. 47, p. 29-50, 112-117, 128-129.

Phleger, F. B. and F. L. Parker, 1951, Ecology of Foraminifera, northwest Gulf of Mexico: Geol. Soc. Am. Mem. 46, 154 p.

Reuss, A. E., 1845, Die Versteinerungen der bohmischen Kreide formation: Stuttgart, I. Schweizerbart, Abh. 1, p. 1-58.

———1855, Ein Beitrag zur genaueren Kenntniss der Kreidegebilde Mecklenburgs: Deutsch Geol. Gessell., Zeitschr., v. 7, no. 1, p. 261-292.

———1860, Die Foraminiferen der Westphalischen Kreideformation: K. Akad. Wiss. Wien, Math.—Naturw. cl., p. 5-100.

———1863, Die Foraminiferen die norddeutschen Hils und Gault: K. Akad. Wiss. Wien, Math.—Naturw. cl., Sitzber., Wien, Bd. 46 (Jahrg. 1862), Abh. 1, p. 5-100.

Scruton, P. C., 1955, Sediments of the eastern Mississippi delta, *in* Hough and Menard, eds., Finding ancient shorelines—a symposium: Soc. Econ. Paleontologists and Mineralogists, Spec. Publ., no. 3, p. 21-51.

Sealy, G., Jr., 1950, Paleontology of the Upper Cretaceous Tropic Formation of Utah: Senior thesis, Princeton Univ. Univ.

Sears, J. D., C. B. Hunt and T. A. Hendricks, 1941, Transgressive and regressive Cretaceous deposits in southern San Juan Basin, New Mexico: U. S. Geol. Survey Prof. Paper 193-F, p. 11, 101-121.

Shawe, D. R., 1961, Comments by Daniel R. Shawe, *in* Dakota Group of Colorado Plateau—discussion: Am. Assoc. Petrol. Geol. Bull., v. 45, no. 9, p. 1587-1589.

Skinner, H. C., 1956, Ostracodes from basal Arkadelphia Marl exposures near Hope, Arkansas: Sixth Ann. Meeting of Gulf Coast Assoc. Geol. Societies, v. 6, p. 179-204.

Spieker, E. M. and J. B. Reeside, Jr., 1925, Cretaceous and Tertiary formations of the Wasatch Plateau, Utah: Geol. Soc. Am. Bull., v. 36, no. 3, p. 435-454.

Stokes, W. L., J. A. Peterson and M. D. Picard, 1955, Correlation of Mesozoic formations of Utah: Am. Assoc. Petrol. Geol. Bull., v. 39, no. 10, p. 2003-2019.

Tappan, H. E., 1940, Foraminifera from the Grayson Formation of northern Texas: Jour. Paleon., v. 14, no. 2, p. 93-126.

Thalmann, H. E., 1934, Die regional-stratigraphische Verbreitung der oberkretagischen Foraminiferen-Gatlung Globotruncana Cushman: Eclogae Geol. Helv., Lausanne, v. 27, p. 413-428.

Vanderpool, H. C., 1928, Fossils from the Trinity Group (Lower Comanchean): Jour. Paleon., v. 2, no. 2, p. 95-107.

Walker, G. J. and E. Jacob, 1798, Adam's essays on the microscope, 2nd ed., *in* F. Kanmacher: London, Dillon and Keating, 712 p.

Wall, J. H., 1967, Cretaceous Foraminifera of the Rocky Mountain foothills, Alberta: Res. Council of Alberta Bull. 20, 185 p.

Wegemann, C. H., 1915, The Coalville coal field, Utah: U. S. Geol. Survey Bull. 581-E, p. 161-187.

Weimer, R. J., 1960, Upper Cretaceous stratigraphy, Rocky Mountain area: Am. Assoc. Petrol. Geol. Bull., v. 44, no. 1, p. 1-20.

Young, K. P., 1951, Foraminifera and stratigraphy of the Frontier Formation (Upper Cretaceous), southern Montana: Jour. Paleon., v. 25, no. 1, p. 35-68.

Young, R. G., 1960, Dakota Group of Colorado Plateau: Am. Assoc. Petrol. Geol. Bull., v. 44, no. 2, p. 156-194.

———1966, Stratigraphy of coal-bearing rocks of Book Cliffs, Utah-Colorado *in* Central Utah coals: Utah Geol. and Mineralog. Survey Bull. 80, p. 7-21.

UTAH GEOLOGICAL AND MINERAL SURVEY

103 Utah Geological Survey Building
University of Utah
Salt Lake City, Utah 84112

THE UTAH GEOLOGICAL AND MINERAL SURVEY, a Division of the Utah Department of Natural Resources, operates with a professional staff under the guidance of a policy-making Board appointed by the Governor of Utah from various representatives of industry and the public as specified by law.

The Survey is instructed to investigate areas of geologic and topographic hazards, to survey the geology and mineral occurrences, and to collect and distribute reliable information concerning the mineral industry and mineral resources, topography and geology of the state so as to contribute to the effective and beneficial development of the state. The *Utah Code, Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-1 through 12,* describes the Survey's functions.

Official maps, bulletins, and circulars about Utah's resources are published. (Write to the Utah Geological and Mineral Survey for the latest list of available publications.)

THE LIBRARY OF SAMPLES FOR GEOLOGIC RESEARCH is a library for stratigraphic sections, drill cores, well cuttings, and miscellaneous samples of geologic significance. Initiated by the Utah Geological and Mineral Survey in cooperation with the departments of geology of the universities in the state, the Utah Geological Society, and the Intermountain Association of Petroleum Geologists, the library was made possible in 1951 by a grant from the University of Utah Research Fund and is maintained by donations of collections from mineral resource companies operating in Utah. It collects, catalogs, and systematically files geologically significant specimens for library reference, comparison, and research, particularly cuttings from important wells and exploratory holes drilled in Utah, and from strategic wells in adjacent states. For catalogs, facilities, hours and service fees, contact the Utah Geological and Mineral Survey.

THE SURVEY'S BASIC PHILOSOPHY is that of the U. S. Geological Survey, i. e., our employees shall have no interest in lands within Utah where there is a conflict of interest deleterious to the goals and objectives of the Survey; nor shall they obtain financial gain by reason of information obtained through their work as an employee of the Survey. For permanent employees this restriction is lifted after a two-year absence; for consultants employed on special problems, there is a similar time period which can be modified only after publication of the data or after the data have been acted upon. For consultants, there are no restrictions beyond the field of the problem, except where they are working on a broad area of the state and, here, as for all employees, we rely on their inherent integrity.

Directors:
William P. Hewitt, 1961-
Arthur L. Crawford, 1949-1961