STRATIGRAPHY AND MICROPALEONTOLOGY OF THE MANCOS SHALE (CRETACEOUS), BLACK MESA BASIN, ARIZONA

by

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I hereby recommend that this dissertation prepared under my direction by George Cordery Hazenbush entitled Stratigraphy and Micropaleontology of the Mancos Shale (Cretaceous), Black Mesa Basin, Arizona be accepted as fulfilling the dissertation requirement of the degree of Doctor of Philosophy

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ABSTRACT

Five outcrop sections of the Mancos Shale in Black Mesa Basin, Arizona, were measured and sampled at close intervals. The samples were broken down, screen washed, and the contained microfossils picked and mounted to determine the vertical distribution of microfossils through the Mancos.

On the basis of its contained microfossils, three gross vertical biostratigraphic units, or assemblage zones, can be recognized in all five sections of the Mancos Shale that were measured around the perimeter of Black Mesa. Each assemblage zone comprises about one-third of the section. These are, in ascending order, a lower unit containing planktonic and benthonic foraminifera, a middle unit which is nearly barren except for plant megaspores, and an upper unit containing an exclusively arenaceous foraminiferal fauna. These three assemblage zones have been informally designated, from bottom to top, the *Hedbergella delrioensis* zone, the megaspore zone, and the *Gaudryina bentonensis* zone.

The *Hedbergella delrioensis* zone is named for this planktonic foraminifer, which occurs in large numbers throughout this lower unit. This zone contains abundant foraminifera, both planktonic varieties and calcareous and arenaceous benthonics, and is interpreted to have been deposited in an estuary or embayment which was at times partially cut off from the open seaway to the east. The lower part of the *Hedbergella delrioensis* zone contains the Cenomanian-Turonian boundary, as it is

presently recognized in the western interior, Gulf Coast, and California areas of the United States, and as established by concurrent ranges of planktonic foraminifera.

The megaspore zone contains two types of megaspores based on form and is interpreted to have been deposited in a marginal marine mudflat under near-subaerial conditions approximating those of modern Dystichlis-Salicornia mudflats.

The Gaudryina bentonensis zone is named for this distinctive, predominantly Carlile (middle Turonian) species, which occurs in abundance in this upper assemblage zone but has not been found in either of the subjacent zones. Compared to the underlying megaspore zone, the G. bentonensis zone shows an increase in numbers of individuals and species of foraminifera, all of which are arenaceous. Slightly more flooding during deposition is postulated for the G. bentonensis zone than for the underlying megaspore zone, possibly as the result of a slight decrease in the incoming supply of sediment or a slight increase in rate of subsidence of the basin.

Faunal evidence indicates that the entire Mancos Shale of Black Mesa was deposited in a partially restricted embayment on the western shore of the western interior seaway, beginning in late Cenomanian time. Marine conditions persisted into the early Turonian. The embayment gradually filled with mud, becoming a nearly subaerial mudflat and later a partially flooded mudflat by mid-Carlile (middle Turonian) time. Maximum water depth probably did not exceed 20 fathoms, and may have been less than 10 fathoms.

INTRODUCTION

Black Mesa is a roughly circular area of Cretaceous rocks about 60 miles in diameter located in the central part of Black Mesa Basin, a well-defined structural basin in the Colorado Plateaus Province in northeastern Arizona. The Cretaceous rocks, which include the Mancos Shale, are an isolated remnant of larger areas of rocks of correlative age which occur on the Kaiparowitz Plateau of southern Utah and in the San Juan Basin of northwestern New Mexico.

This study involves an investigation of the occurrence and distribution of the microfossils in the Mancos Shale in the Black Mesa area and their use to determine the age and environments of deposition of the Mancos.

Location

The area of Cretaceous outcrop is located entirely on portions of the Navajo and Hopi Indian Reservations, mostly in Navajo County, but extending into Coconino and Apache Counties as well (Figure 1).

The top of Black Mesa ranges in altitude from more than 8,000 feet above sea level on the northern and northeastern edges to about 6,000 feet along the southern edge. Areas surrounding Black Mesa range from 5,000 to 6,000 feet above sea level. Topographic relief to the top of the mesa from surrounding valleys ranges from about 2,000 feet at Kayenta and Yale Point on the north and east sides to less than 200 feet along the southern and western sides.

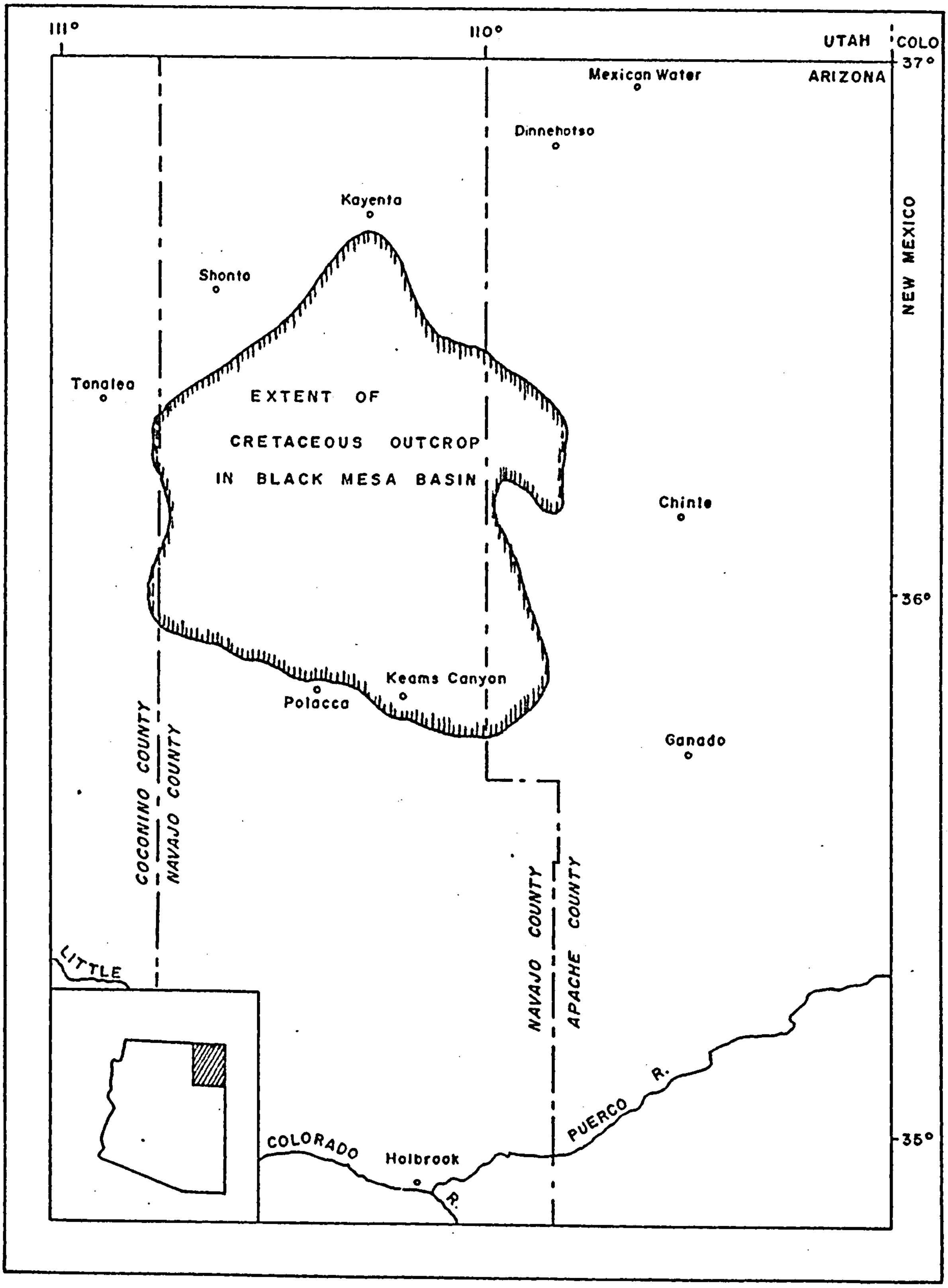

Figure 1. Index Map Showing Extent of Cretaceous Outcrop in Black Mesa Basin

Access to the northwestern and southern portion of Black Mesa is provided by State Highways 164 and 264, respectively. The interior, northeastern, and eastern sides are accessible by various dirt roads, most unimproved.

Purpose and Scope of the Investigation

The Mancos Shale of Black Mesa overlies the Dakota(?) Sandstone, is overlain by and intertongues with the Mesa Verde Group, and appears to pinch out to the west and south. In northern Arizona, these Cretaceous units represent the westernmost known limits of the transgression of the Late Cretaceous seaway of the western interior.

Marine microfossils, particularly foraminifera, have been known to occur in the Mancos of Black Mesa for many years, but they have hitherto remained unstudied.

The purpose of this investigation is multifaceted: (1) to define the vertical and horizontal distribution of microfossils through the Mancos Shale, (2) to establish its detailed stratigraphy in relation to similar units in neighboring areas, and (3) to infer whatever paleoecologic factors are possible on the basis of its contained microfossils.

Foraminifera are the principal subjects of investigation, but other microfossil groups have been encountered, such as ostracods, minute gastropods, and plant megaspores. The megaspores are present in the middle portion of the Mancos where other microfossils are few or absent, and in this paper have simply been designated as "Megaspores species A" or "species B," based on form. These, together with other palynomorphs which doubtless occur with them, will probably be the subjects of further graduate study at this department.

Only microfossils from the Mancos Shale have been treated in this investigation. The underlying Dakota(?) Sandstone and units of the overlying Mesa Verde Group have been only superficially examined.

Methods of Investigation

Field

Five outcrop sections of Mancos Shale were measured and sampled in detail: at Howell Mesa, Blue Canyon, Longhouse Valley, Kayenta, and Lohali Point. The locations of the sections are shown in Figure 2 (in pocket).

Sections were measured with a Brunton compass used as a hand level. Sample intervals were thus determined by eye height. Approximately the lower 30 feet of each section was sampled every 5 feet to determine the lowest occurrence of microfossils. Above this level, samples were taken at approximately every 11 feet. A total of 262 samples were collected for all sections.

Because it was suspected that a large portion of the upper part of the Mancos might be barren or nearly so, large samples were taken and broken down in order to increase the probability of finding sparsely occurring microfossils. As far as the foraminifera are concerned, this suspicion turned out to be justified, except for the lower one-third to one-half of the section, where microfossils, mostly foraminifera, are prolific.

Laboratory

In the laboratory, samples were broken down using the following procedure. About 250 ml of sample, broken into fragments of 1/2 inch or less, were placed in a 1000 ml beaker and dried overnight in an oven set at 400°F. Upon removal from the oven, the hot sample was covered with Stoddard Solvent (a petroleum solvent resembling kerosene) and allowed to soak for about one hour. The solvent was then decanted off and reclaimed, and the sample was gently boiled in about 800 ml of water containing a small amount of detergent for another two hours.

This treatment was generally sufficient to reduce the sample to a loose mud, which was washed through a series of 20-, 80-, and 150-mesh Tyler screens (850, 180, and 106 microns). The three separate fractions were rinsed, dried, and individually stored in labeled vials for later examination.

From each sample, microfossils were picked, identified to species, and mounted on assemblage slides in numbers roughly approximating their relative abundances in the sample. Enough additional material from each sample was examined to preclude missing possible sparsely occurring species.

All of the information concerning the occurrence of foraminifera and other microfossils in each measured section is presented graphically on the faunal distribution charts (Figs. 3, 4, 5, 6, and 7, in pocket). The relative abundances shown are semiquantitative, the size of the dots referring to numbers of specimens of a species on the assemblage slides: "rare" for less than 5, "common" for 5 to 19, and "abundant" for over 19 specimens. These designations are, however, believed to reflect closely the relative abundances in the samples.

Supplemental plots on the faunal distribution charts include planktonic-to-benthonic ratios and total numbers of benthonic species at each sample site. Planktonic-to-benthonic ratios were estimated from each sample by counting the first 100 forams encountered, 50 from the 80-mesh fraction and 50 from the 150-mesh.

Total number of benthonic species are plotted as an indication of benthonic species diversity. Absolute numbers of benthonic species were chosen to plot instead of one of the statistical indices of diversity, such as Simpson's modified index (L. B. Gibson, 1966) or the information function (Buzas and T. G. Gibson, 1969), because benthonic species are few. A plot of absolute numbers of species provides a curve parallel to one of the statistical plots, with the advantage that one can refer to the species chart above to determine what particular species are involved.

Photographs of the microfossils were taken with a Honeywell Pentax H-2 35 mm single lens reflex camera mounted on a Spencer AO Cycloptic binocular microscope with a Pentax microscope adapter. With the microscope eyepiece and camera lens removed, photographs were taken through the 3X objective lens only. Kodak Panatomic-X film was used, with exposure times of 1/8 to 1/30 second.

Previous Work in Black Mesa Basin and Neighboring Areas

The first published account of Cretaceous rocks in Black Mesa Basin was written more than one hundred years ago (Newberry, 1861).

Present nomenclature used in the Black Mesa area was established in 1911 by Campbell and Gregory, who compared the Black Mesa units with those near Gallup, New Mexico, and described them as including the Dakota Sandstone and Mesa Verde Formation separated by a thin Mancos Shale. This usage was amplified by Gregory in 1917, who added much detail. These same units have been recognized with variations by most subsequent workers in the vicinity, including Reeside and Baker (1929), Williams (1951), Repenning and Page (1956), Page and Repenning (1958), and Beaumont and Dixon (1965). The only notable deviation from this terminology was by Reagan (1925, 1926).

Correlative units have recently been studied in neighboring areas. Lamb (1968) has published on the stratigraphy of the Lower Mancos Shale in the San Juan Basin of New Mexico. J. E. Peterson (U.S. Geological Survey, Denver Federal Center, Denver, Colorado) has studied the Tropic Shale on the Kaiparowitz Plateau of southern Utah. Lessard (1970) has reported on the Tununk Member of the Mancos Shale of eastern Utah, and Sarmiento (1957) has reported on the microfossils of the Mancos Group, including the Tununk Shale, in the Book Cliffs of eastern Utah. Finally, Eicher (1965, 1966, 1967, 1969a, 1969b; Eicher and Worstell, 1970a, 1970b) has published prolifically on the stratigraphy and micropaleontology of correlative units in Utah, Colorado, Kansas, Wyoming, and Montana.

GENERAL GEOLOGY OF THE CRETACEOUS UNITS

The following section is a brief summary of the general stratigraphic, lithologic, and regional aspects of the Cretaceous rocks of Black Mesa. More detailed discussions of these features can be found in Williams (1951), Repenning and Page (1956), Page and Repenning (1958), and Beaumont and Dixon (1965).

Lower Boundary of the Cretaceous Rocks

Within the Black Mesa area, the lower boundary of the Cretaceous rocks is disconformable on the Jurassic. Although no angular relationship can be seen between the Dakota(?) Sandstone and underlying units in any single outcrop, stratigraphic relationships in surrounding areas show that the Dakota(?) overlies progressively older rocks from north to southwest and south.

In southwestern Colorado the Dakota Sandstone overlies the Lower Cretaceous Burro Canyon Sandstone. At Yale Point in northeastern Black Mesa, the Dakota(?) Sandstone overlies the upper part of the Upper Jurassic Morrison Formation. In southern Black Mesa at Polacca Wash, the Dakota(?) rests on the middle part of the Jurassic Entrada Formation. Near Show Low, about 70 miles south of the Black Mesa area, the Dakota(?) lies on the Chinle Formation of Upper Triassic age, and further south at McNary, Arizona, it lies on rocks of Paleozoic age (Harshbarger, Repenning, and Irwin, 1957, p. 157). Within the Black Mesa area, however, the unconformity below the Dakota(?) Sandstone is developed wholly on rocks of Jurassic age.

These relationships suggest a shorter time value for the pre-Dakota unconformity in the northeast than in the south and southwest. On the other hand, evidence from lithologic and thickness investigations made on rocks belonging to this missing time interval in neighboring areas indicate that these rocks were once deposited and have since been removed by erosion. Thus, although the unconformity represents greater erosion toward the south, it does not necessarily represent greater time of erosion (Page and Repenning, 1958, p. 115).

The surface of the unconformity is rolling and channeled, with channels having a maximum relief of about 5 feet within the Black Mesa area, although channels with a relief as great as 40 feet and as much as 100 yards wide have been observed in other areas (Repenning and Page, 1956, p. 259). The channels are filled with conglomeratic sands and finer material, and locally with carbonaceous shale and coal.

The Dakota(?) Sandstone

In its type locality in northeastern Nebraska, the Dakota Sandstone is of Early Cretaceous age (Cobban and Reeside, 1952). However, the name has been used widely over the Colorado Plateaus for many years and was introduced into Black Mesa by Gregory (1917, p. 71) on the basis of the lithologic and positional similarity of the unit to the "Dakota" as it was then recognized in the San Juan Basin of New Mexico. Following a long-time practice, the unit is therefore designated as "Dakota(?)" to indicate that it is not continuous with, nor the same age as the Dakota in its type locality.

In Black Mesa, as in many other localities, the Dakota(?) may be divided into three informal members: a basal sandstone, a middle carbonaceous shale, and an upper sandstone member. These units intergrade, and one or more commonly are missing in local sections.

The lower sandstone member is very pale orange (10YR 8/2) (Goddard, 1948), fine- to medium-grained quartzose sandstone. Grains are subangular to dominantly subround. Bedding is irregular with many sets of low-angle, small- to medium-scale cross beds. Locally, there is a basal conglomerate, and pebble lenses and streaks are common. The basal contact is the pre-Dakota(?) unconformity, and upward the unit grades into the carbonaceous shale unit.

The middle member consists of interbedded sandstone, siltstone, carbonaceous shale, claystone, and coal. Bedding is flat and thin, and commonly discontinuous in the clastic beds. Silicified logs are locally abundant; preserved plant megafossils are present at many localities.

The upper sandstone, where present, rests with a sharp, undulating, disconformable contact upon the middle unit and resembles the lower in composition and lithology. This upper sandstone differs from the lower in that it is generally finer grained and contains thin beds of silt and shale. The upper unit grades upward into the basal portion of the Mancos Shale. The upper unit is present in the northern half of Black Mesa but is mostly absent in the southern part (Page and Repenning, 1958, p. 116).

Taken as a whole, the Dakota(?) averages about 80 feet thick in the Black Mesa area, ranging from about 50 to 120 feet. Thickness variations appear to be unrelated to direction.

Based on marine invertebrates found within a portion of the middle member of the Dakota(?) at one locality, marine invertebrates at the base of the overlying Mancos at many localities, and the stratigraphic rise of the base of the Dakota(?) to the south and west, Page and Repenning (1958, p. 116) interpreted the age of the unit to be Late Cretaceous. Agasie (1969), working with spores and pollen from the middle carbonaceous unit at Coal Canyon, has recently confirmed the Late Cretaceous age and has assigned the middle carbonaceous unit to the Cenomanian. Coal Canyon is about 10 miles northwest of the Howell Mesa section of this study.

During the course of this study the late Cenomanian ostracod *Cythereis eaglefordensis* Alexander was found in the basal portion of the Mancos Shale directly overlying the Dakota(?) in all sections sampled. This further corroborates the Cenomanian age of the Dakota(?) in Black Mesa.

The Dakota(?) of this area is considered to be the equivalent of the Dakota of the Kaiparowitz Plateau of Utah and, in part, the equivalent of the Dakota of the San Juan Basin of New Mexico. *C. eaglefordensis* has also been found in the lower part of the Tropic Shale overlying the Dakota in southern Utah (Hazel, 1969; J. E. Peterson, personal communication).

The Mancos Shale

Regionally, the Mancos Shale of Black Mesa occupies an intermediate position between its type area in the Durango region of Colorado and its ultimate pinchout near Show Low, Arizona, to the south. In the Show Low area, the overlying units of the Mesa Verde Group coalesce with the underlying Dakota(?). In Black Mesa, the Mancos represents only a portion of the type section and is essentially only a southwestward-extending tongue of the main body of the Mancos further to the east. The name is retained here because of long-accepted usage in the area, and because the Mancos of Black Mesa was moreover probably originally continuous with a portion of the type Mancos.

The Mancos is predominantly dark gray (N 4) to shades of olive gray (5Y 3/2) in the lower part, grading to dusky yellow (5Y 6/4) in its upper part. The lower part weathers to a bluish gray. The unit is thinly bedded, fissile shale with thin (1/4 to 4 inch) beds of bentonitic shale interbedded haphazardly through it. Due to sliding, slumping, and cover, however, none of the individual bentonites seem to be continuously traceable for more than a few hundred feet. Thin, discrete, fine-grained sandstones, some with ripple marks, occur throughout and are particularly prominent in the middle part of the formation. These sandstone beds increase in number in the upper part of the section. Gypsum is common and occurs in small veins and as selenite crystals sporadically through the section.

The base of the Mancos is gradational with the underlying Dakota(?) but is easily delineated. In this study, the contact was selected immediately above the top of the uppermost Dakota-looking sandstone. The upper contact with the Toreva Sandstone of the Mesa Verde Group is somewhat arbitrary due to the intertonguing of the two units. In this study, it was placed at the base of the first thick platy sandstone overlying the shale at the base of the nearly vertical cliff formed by the Mesa Verde. The thickness of the Mancos ranges from

478 feet at Howell Mesa to 711 feet at Kayenta. Thicknesses measured are dependent partly on the presence or absence of the upper sandstone of the Dakota(?) and partly on intertonguing with the overlying Toreva.

Throughout the Black Mesa area, the Mancos Shale shows evidence of large-scale sliding and slumping, and over many large areas of its outcrop it is covered with debris from the overlying Mesa Verde. Most of its outcrops are less than ideal for the measuring and sampling of complete stratigraphic sections.

Previous workers in the Black Mesa area have established the time relationships of the Mancos here with correlative rocks of the western interior on the basis of megafossils. Reeside and Baker (1929, p. 35) on the basis of its contained ammonites recognized it as being equivalent to a portion of the Benton Shale, to a small portion of the type Mancos Shale of Colorado, and its age as essentially Turonian in terms of European Stages. In its type locality near Durango, Colorado, the Mancos Shale is a much thicker unit containing strata ranging in age from Cenomanian to well into the Campanian in terms of the European Stages or from Belle Fourche to the lower third of the Pierre Shale in terms of the western interior reference section. Repenning and Page (1956, p. 266) and Page and Repenning (1958, Fig. 3, p. 120) have equated the Black Mesa Mancos in part with the Greenhorn and lower Carlile of the western interior reference section (Cobban and Reeside, 1952). They considered the largely unfossiliferous upper portion to be probably equivalent to the upper Carlile. The results of this study confirm the interpretations of these earlier workers.

The Mesa Verde Group

The three formations comprising the Mesa Verde Group overlie the Mancos Shale and are the youngest Cretaceous units in the area. The entire Mesa Verde Group in Black Mesa is older than any part of the Mesa Verde at its type locality in Colorado and is the time equivalent of the upper part of the Mancos Shale in the San Juan Basin of New Mexico. The Mesa Verde was first treated as a group in Black Mesa by Williams (1951).

The Toreva Formation

The lowest formation of the Mesa Verde Group is the Toreva Formation. This unit consists of a lower sandstone, a middle carbonaceous member of variable lithology, and an upper sandstone. To the northeast, the middle carbonaceous member pinches out and is missing, and the Toreva consists of the lower and upper sandstones superimposed. To the south and southwest the contact between the lower sandstone and the Mancos Shale drops stratigraphically in the section. Based on megafossils and stratigraphic relationships, the Toreva in its type section in southwest Black Mesa is believed to be equivalent to the upper Carlile and to the upper Carlile plus basal Niobrara in the northeastern part of Black Mesa (Page and Repenning, 1958, p. 119). The total thickness of the Toreva is about 300 feet.

The Wepo Formation

The Wepo Formation overlies and intertongues with the Toreva over most of the Black Mesa area. The Wepo is a series of interbedded continental shales and sandstones, including some marine sands. Its contact with the Toreva is gradational. The upper part of the Wepo has been removed by erosion from the southern half of Black Mesa, but it seems to thin to the northeast by reason of tonguing into both the underlying Toreva and the overlying Yale Point Sandstone. Its thickness varies from 743 feet at Cow Springs to 318 feet near Rough Rock. Coal beds are common in the Wepo, especially in the siltstones in close proximity to major sandstone units (Page and Repenning, 1958, p. 121).

The Yale Point Sandstone

The Yale Point Sandstone overlies the Wepo Formation on a surface of minor unconformity and appears to intertongue southward with the Wepo. The Yale Point forms a continuous cliff along the northeast and northwest sides of Black Mesa. The area of Yale Point outcrop is small, and the unit thins rapidly southward, both by reason of erosion and by intertonguing with the underlying Wepo. The maximum thickness of the unit is a little more than 300 feet near Marsh Pass just west of Kayenta and less than 50 feet thick near Pinon, 20 miles to the southeast. The Yale Point is a coarse- to medium-grained quartz sandstone and is considered to be of middle Niobrara age (Page and Repenning, 1958, p. 121). The upper surface of the unit is a surface of recent erosion, and no younger rocks occur in the Black Mesa area except the Bidahochi Formation (Pliocene?) which overlies the Dakota(?), Mancos, Toreva, and Wepo Formations in the southern part of the area.

STRATIGRAPHY

Three basic systems of time-stratigraphic nomenclature for the Cretaceous are in use in North America (Fig. 3). While the objectives of this investigation do not include an exhaustive discussion of stratigraphic nomenclature, some mention of these three schemes should be made. Also included in this section is a discussion of some recent examples of the use of planktonic foraminifera in the definition of some of these Cretaceous "stages."

Discussion of Time-stratigraphic Units Used in the American Upper Cretaceous

The Western Interior Reference Section

The western interior reference section was established by Cobban and Reeside (1952) as part of a series of correlation charts of North American sedimentary formations compiled by the Committee on Stratigraphy of the National Research Council. The names used are formational (rock-stratigraphic) names from widely separated areas of the western interior. These names have been used in the time-stratigraphic sense, a practice not recommended by the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961), although admittedly the Code postdates the western interior reference section by some nine years. These "stages" are designated by zonal "index" fossils, principally ammonites, with ranges of other important associated fossils included, and have long been loosely tied into the European Stages.

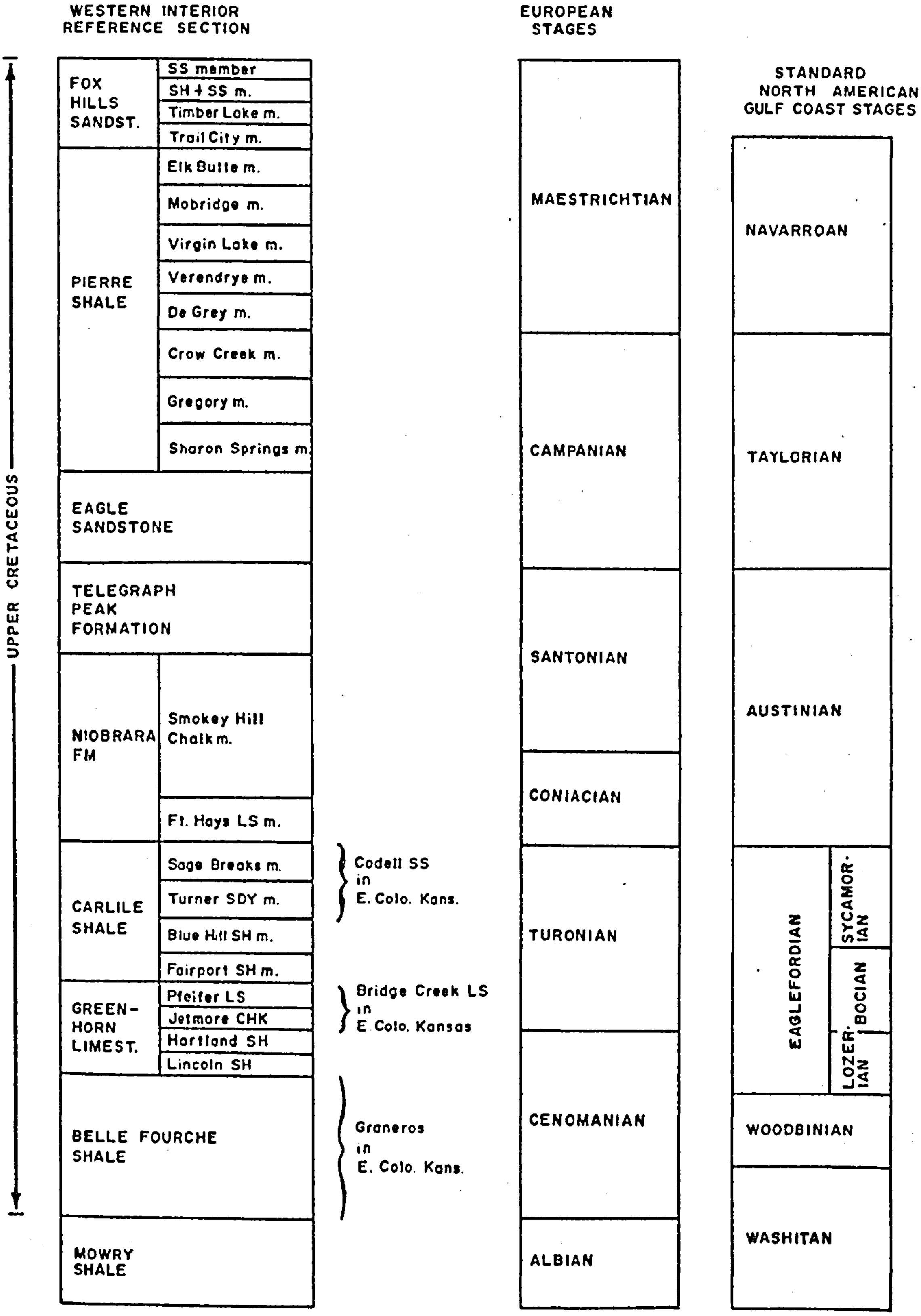

Figure 8. Time-rock Nomenclature Used in North America

The Standard Gulf Coast Section

Another system of time-stratigraphic nomenclature is the standard Gulf Coast section (Murray, 1961). The names used in this system are also formational or group names which have been transformed by usage over a period of many years into time-stratigraphic units or stages.

The European Stages

The European Stages of the Cretaceous System were originally defined by D'Orbigny(1852) in the 1840's and 1850's, in the type area of the Cretaceous previously designated by d'Omalius d'Halloy in 1822, in the Paris Basin of France. D'Orbigny was the first to introduce the concept of stages as time-stratigraphic units, based upon fossil assemblages and independent of lithology. However, he unfortunately used the term "stage" and "zone" more or less interchangeably.

Oppel (1856-1858), a few years later, was the first to use the word "zone" in a biostratigraphic and chronologic sense. Although Oppel did not strictly define the term, his usage of zone was based on a fauna which could be recognized over a large area or province without regard to lithology, and which he named after a species which was a characteristic member of that fauna but not necessarily restricted to it. He also clearly used zone as a subdivision of a stage, by grouping his 33 Jurassic zones into 8 stages. Although Oppel did not seem to specify overlapping ranges, he certainly implied it by stating that the taxa used in defining and naming his zones did not have to be confined to them.

The presently used "world standard" of the Cretaceous System (Muller and Schenck, 1943), with a few modifications, is based on

D'Orbigny's (1852) stages and in general retains his stage names. The zones which are the building blocks of the stages are basically Oppelian zones, the direct descendents of which are the Concurrent Range zones of the American Code of Stratigraphic Nomenclature (1961, Article 23). The species selected to be the name-bearers of the zones of this "world standard" of the Cretaceous System are all megafossils, principally ammonites.

The validity of extending the European Stages to North America has been questioned by some workers, many of whom prefer to use the so-called North American Standard Stages (Pessagno, 1969). Others use the European Stages freely and without apology, while recognizing that the stage boundaries may move up or down in the section as the results of later work become available. There is somewhat of a paradox in that the same general sequence of zones can be recognized in the Upper Cretaceous of Europe and North America, regardless of whether megafossils or microfossils are used to define the zones, but precise correlations of stage boundaries are not yet possible except in a tentative way.

Correlation by Foraminifera

The foraminifera, particularly the planktonic varieties, provide potentially precise instruments for correlation at the local and interregional levels, and even for intercontinental correlations. However, there are two basic problems which affect the precision of their use in correlations at the stage level between North American Cretaceous units and the type European. First, there is a certain amount of imprecision in the definitions of the European Stages themselves in their type areas. Second, the foraminiferal faunas contained in the stages in their type areas have not yet been completely studied. The first of these problems can probably only be solved by the International Commission on Stratigraphy. The final solution to the second problem is dependent on the first. A partial solution can be accomplished, however, by detailed sampling of type European sections by foraminiferal workers and the establishment by them of foraminiferal zonations integrated with the ammonite zones used to define the stages. Work of this nature is currently being done (Butt, 1966).

Much intensive work has been done on foraminifera in the Cretaceous of North America in the 1950's and 1960's, including many investigations of the foraminifera from the Upper Cretaceous of the western interior of the United States (Young, 1951; Fox, 1954; Loeblich and Tappan, 1961, 1964; Eicher, 1965, 1966, 1967, 1969a, 1969b; Eicher and Worstell, 1970a, 1970b). Pessagno (1967, 1969) has made detailed studies of the Upper Cretaceous planktonic foraminifera and stratigraphy of the western Gulf Coast area. As a result of these studies many species, particularly among the planktonics, have become recognized as having worldwide distribution and as being valuable for interregional and even intercontinental correlation. The extension of the European Stages to North America, which has been done by many workers on the basis of ammonites, has thus been strengthened by these supporting data.

Three schemes for the zonation of all or parts of the Cretaceous using the planktonic foraminifera have recently been published (Bandy, 1967; Pessagno, 1967, 1969; Eicher, 1969b). All are based on concurrent range zones as defined by the American Code of Stratigraphic

Nomenclature (1961, Article 23) and are established by overlapping ranges of planktonic foraminifera.

Pessagno, whose scheme covers the Upper Cretaceous, refers his zonation primarily to the standard Gulf Coast section and loosely to the European Stages. Pessagno's monograph (1967) includes detailed studies of external and internal morphology and phylogenetic relationships of Upper Cretaceous planktonic foraminifera, which have resulted in some major taxonomic and phylogenetic changes in the classification of these animals. He has erected two new families of foraminifera and has reorganized other groups at the subfamily, generic, and specific level. Some of these taxonomic and phylogenetic regroupings are in conflict with, or at least at variance with, those of other workers.

Bandy's (1967) zonation is a more generalized system and covers the entire Cretaceous Period. On the basis of the phylogenetic development of major groups of planktonic foraminifera and in an attempt to balance the temporal disparity indicated for the divisions of the Cretaceous by the radiometrically based time scale of Kulp (1961), Bandy suggests a threefold division of the Cretaceous. This scheme may have merit, but the most common practice is a twofold division of the Cretaceous System into two Series, Upper and Lower. Many European and British geologists, incidentally, do recognize a threefold division of the Cretaceous, but the boundaries are different than those proposed by Bandy.

Eicher's zonation (1969b, Fig. 3, p. 166) deals only with the Cenomanian and Turonian distributions as presently recognized in the western interior of the United States and is based on occurrences of foraminifera in rocks deposited in the central, deeper parts of the western interior seaway, where stratigraphic ranges are the most complete. The species are arranged in order of appearance. Twenty-seven planktonic species (decreased to 25 species in a revised nomenclatural note, dated February 1970, contained within the cited article) are used to establish the zonation, which is well tied into "index" ammonite occurrences. Two concurrent range zones, the "Rotalipora zone" and the "Praeglobotruncana zone", are recognized, which represent the late Cenomanian and the early and middle Turonian, respectively.

All three of these proposed zonations agree except in detail. Eicher's "Rotalipora zone" and "Praeglobotruncana zone", with few exceptions, contain the same planktonic foraminiferal assemblages as Pessagno's "Rotalipora cushmani—R. greenhornensis" and "Marginotruncana sigali" subzones, respectively, or what Pessagno has named the "Lozerian" and "Bocian" substages of the Eaglefordian. All three schemes place the boundary between the Cenomanian and Turonian in the same place. Differences between the three systems are largely taxonomic.

Eicher's scheme was followed in this study as the species used in his zonation are clearly recognizable in the Mancos Shale of Black Mesa, although about twelve of his species are missing. Unfortunately, some of the missing species include many which provide close time resolution, and their absence affects the precision of determining the Cenomanian—Turonian boundary in Black Mesa to some extent. The missing species in the Black Mesa Mancos are the result of the westward attrition of planktonic species away from the axial portion of the seaway. Possible causes of this phenomenon will be discussed in a later section. Figure 9 (adapted from Eicher, 1969b, Fig. 3, p. 166) shows the ranges of planktonic species in the Mancos Shale of Black Mesa.

The Western Interior Region and Black Mesa Basin

In the western interior of the United States, the Cenomanian and Turonian were a time of a great transgression and regression of the large interior seaway which extended from the Gulf of Mexico in the south to the Arctic Ocean in the north. The axial portion of the seaway passed through eastern Colorado or western Kansas (Eicher, 1969b, Fig. 4, p. 171), where the sediments deposited during this transgressive-regressive cycle include, in ascending order, the uppermost beds of the Dakota and overlying Graneros Shale (Belle Fourche equivalent) and the Greenhorn and Carlile Formations. Maximum flooding took place in late Cenomanian and early Turonian during the deposition of the upper Greenhorn (Bridge Creek) and lower Carlile (Fairport) Shale (Eicher and Worstell, 1970b, p. 271). Regressive deposits overlying the Fairport in this axial area include the upper Carlile (Blue Hill and Codell Members).

The Mancos Shale of Black Mesa Basin in Arizona represents the farthest known westward occurrence of this Greenhorn—Carlile (Cenomanian—Turonian) transgression in Arizona. While the cyclic nature of this Cenomanian—Turonian) sequence in eastern Colorado and western Kansas is reflected in lithologic as well as in faunal changes (Eicher, 1969b), p. 163), in Black Mesa the faunal changes only are recognizable, as the lithologic changes are quite subtle.

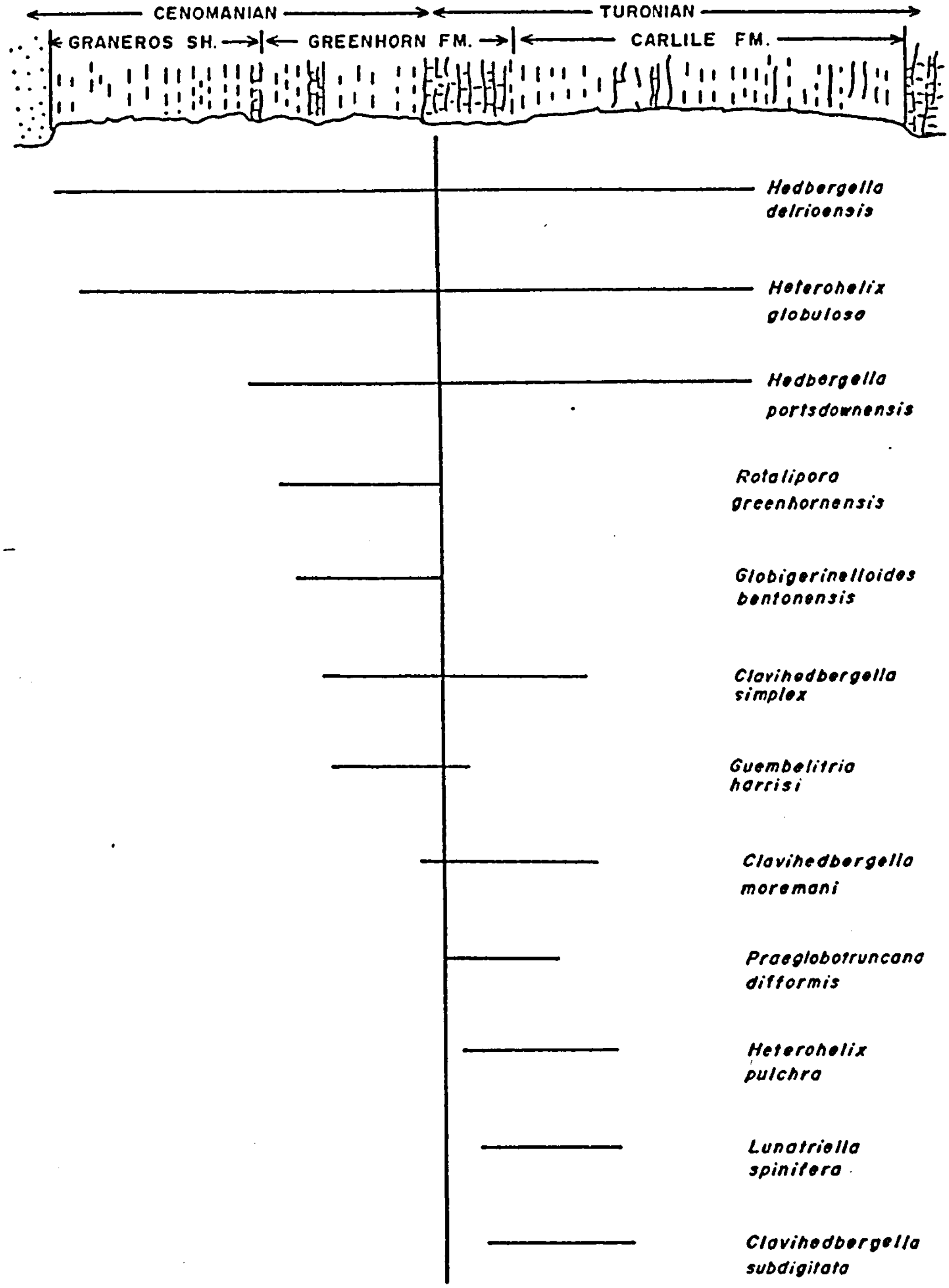

Figure 9. Ranges of Cenomanian and Turonian Planktonic Foraminifera in the Western Interior of the United States and the Mancos Shale of Black Mesa.--Adapted from Eicher, 1969b, fig. 3, p. 166.

BIOSTRATIGRAPHY OF THE MANCOS SHALE

The vertical distributions of microfossils in each of the five sections are shown on Figures 3, 4, 5, 6, and 7 (in pocket). These distributions show certain aspects common to all five sections.

General Relationships

On the basis of the contained microfossils, three gross biostratigraphic subdivisions or informal assemblage zones can be recognized, each comprising approximately one-third of the local Mancos section. These are, in ascending order, a lower zone containing a marine foraminiferal fauna, a middle zone characterized by megaspores, and an upper unit with a somewhat sparse, exclusively arenaceous foraminiferal assemblage. These three units are herein referred to as the "*Hedbergella delrioensis* zone," the "megaspore zone," and the "*Gaudryina bentonensis* zone," respectively. These names are probably not ideal, but for the purposes of discussion are useful to designate the three broad subdivisions of the Mancos. Figures 10 and 11 (in pocket) are isometric fence diagrams showing the spatial distribution of these zones around the area of outcrop.

The *Hedbergella delrioensis* Zone

The *Hedbergella delrioensis* assemblage zone is named for the planktonic foraminifer *Hedbergella delrioensis*, which occurs throughout this lower biostratigraphic unit.

The basal portion of the Hedbergella delrioensis zone everywhere contains the ostracod Cythereis eaglefordensis Alexander. C. eaglefordensis is considered to be the guide fossil for the latest Cenomanian in the western interior and the Gulf Coast regions of the United States (Hazel, 1969). Associated with C. eaglefordensis in this basal portion of the Hedbergella delrioensis zone are the ostracod Cytheropteron cf. C. castorense Butler and Jones, various planktonic and benthonic foraminifera, and scattered glauconite grains. Foraminifera increase rapidly upward both in species and numbers of individuals, although nowhere can the fauna be called rich in species.

In Black Mesa transition from the late Cenomanian Rotalipora concurrent range zone to the Turonian Praeglobotruncana concurrent range zone lies within the Hedbergella delrioensis zone about 60 to 70 feet above the Dakota(?). Although species of Rotalipora and Praeglobotruncana are scarce or even absent themselves in some sections, the transition can still be picked by the presence of other planktonic foraminifera which are associated with one or the other of these species. Fewer diagnostic species are present in the western sections (Howell Mesa and Blue Canyon) than in the eastern ones (Kayenta and Lohali Point) which affects the precision to some extent.

In the lower half of the Hedbergella delrioensis zone, planktonic-to-benthonic ratios are low, in the order of 3 to 1 or less; and benthonic forms, both calcareous and arenaceous, are represented in sufficient numbers of species and individuals to indicate that bottom conditions were at least reasonably favorable to the existence of these animals. However, in the upper half, planktonic-to-benthonic ratios increase sharply, often exceeding 100 to 1, and benthonic forms decrease in species and numbers of individuals. Species of Hedbergella and Heterohelix, which dominate the planktonic fauna throughout the Hedbergella delrioensis zone, become particularly dominant in the upper half of this zone and in many samples comprise very nearly 100 percent of the assemblage. This upward increase to anomalous planktonic-to-benthonic ratios, with concurrent decrease in the numbers of individuals and species of benthonic forms, is doubtless related to such worsening environmental conditions as shallowing, increasing runoff, decreasing aeration of the bottom waters, or a combination of the three, which may have immediately preceded the regression which took place before deposition of the next overlying zone. Many planktonic specimens from the upper part of the marine zone are corroded and etched as if they had been subaerially weathered before burial.

Megafossils found in the Hedbergella delrioensis zone are mostly Gryphaea newberryi. These are most abundant in the basal part of the unit and locally form biohermal banks. A tooth of the shark Isurus (Isurus cf. I. desorii) was found in the Hedbergella delrioensis zone at Lohali Point, and teeth of a shell-crushing shark of the genus Ptychodus together with a single vertebra of a hybodont shark were found in this zone at Kayenta (shark remains identified by Norman A. Tessman, Department of Geosciences, The University of Arizona, Tucson, Arizona). Scattered molds of some miscellaneous gastropods and a pelecypod, probably Inoceramus, are locally present.

The Megaspore Zone

The rather abrupt disappearance of marine foraminifera about one-third of the way up the Mancos section marks the top of the Hedbergella delrioensis zone. Above this the shale is barren of foraminifera except for rare etched and weathered planktonic individuals or sporadic Trochammina. After a barren interval of a few feet, plant megaspores make their appearance and become abundant higher in the section. Based upon form, these megaspores seem to be of two types, although a certain amount of intergradation probably exists. The type designated as species "A" on the range charts (Figs. 3, 4, 5, 6, and 7, in pocket) is circular in outline, while species "B" is elliptical shaped with rather sharp ends. Neither shows any particular surface features of ornamentation, but the palynological maceration, staining, and mounting techniques which provide the clean-up necessary for detailed observation of this type of microfossil were not done in this investigation. The megaspores are large, attaining sizes of more than 180 microns (80 mesh). Species "A" occurs lower in the section and extends higher stratigraphically than species "B" and is everywhere more numerous. Doubtless other palynomorphs occur with them but have been lost during the sample preparation followed in this study.

The meaning of the presence of the megaspores is unknown, but the abundance and state of preservation of such delicate microfossils after the somewhat rigorous sample preparation suggest that they have not been transported far. A frankly speculative suggestion is that they represent the presence of a spore-bearing plant or plants which in this part of the Upper Cretaceous occupied the niche in marine marsh or mudflat environments which is today occupied by Dystichylis, Salicornia, Juncus, or the like. Locally associated with them are the molds of small gastropods, minute bone fragments, and small iron oxide (?) concretions, which may also indicate a mudflat type of depositional environment. Scarce Oligostegina (Pithonella), a spherical calcareous microfossil of probable algal affinities, also occur locally.

Megafossils are largely absent in this zone. Notable exceptions are ammonite molds which are commonly in thin, locally ripple-marked, fine sandstone beds in the cliff-forming unit of the lower middle portion of the Mancos Shale but locally are also within shale laminae. These ammonite molds have been identified as Collignoniceras woolgari Mantell (Page and Repenning, 1958, p. 118), a guide fossil for the lower Carlile. This species has been referred to other genera by many workers. Shimer and Shrock (1944, p. 596) refer it to Prionotropis Meek 1876, a practice followed by many writers. Lamb (1968, p. 845) refers it to Selwynoceras, although Arkell, Kummel, and Wright (in "Treatise on Invertebrate Paleontology," Moore (ed.), 1957, L80-L437) consider Selwynoceras to be a subgenus of Collignoniceras. The name Collignoniceras is retained herein as this was the name used by Cobban and Reeside (1952) for this zonal "index" fossil in their western interior reference section, and it seems to be the most commonly recognized name for this animal. Occurrences of Collignoniceras noted during the course of this study have been indicated on the vertical distribution charts. Nearly all of these occurrences are in the otherwise barren megaspore zone. Collignoniceras woolgari may have been nektonic and became stranded on the mudflats during deposition of the unit. Reeside (1957, p. 522) also speculated on the possible nektonic habit of this animal.

The Gaudryina bentonensis Zone

Gradationally overlying the megaspore zone is a zone containing an exclusively arenaceous assemblage of foraminifera. The plant megaspores disappear upsection, and their place is taken by the gradual appearance of Trochammina wickendeni, a form that is also present below in the Hedbergella delrioensis zone. Still farther upsection, other arenaceous species appear, most of which, like T. wickendeni, are also present in the Hedbergella delrioensis zone. This upper biostratigraphic unit is herein called the Gaudryina bentonensis zone after this distinctive Carlile species which is present everywhere in large numbers higher in this zone. G. bentonensis has not been found in either of the two subjacent assemblage zone. Associated with T. wickendeni and G. bentonensis are Haplophragmoides sp. cf. H. gilberti, Saccammina alexanderi, and species of Reophax, Ammobaculities, and Ammomarginulina. This assemblage continues to the top of the Mancos Shale. Lowermost sandstones of the overlying Toreva Formation were sampled but were found to be barren of microfossils.

With the exception of G. bentonensis, the bulk of these arenaceous forms are crushed and broken, making specific identification difficult. This is also true to a somewhat lesser extent of the arenaceous species in the Hedbergella delrioensis zone, although preservation of the calcareous forms is generally good.

Biostratigraphy of Individual Sections

Similarities and unifying features of the five stratigraphic sections have been discussed in the previous section. The following are brief discussions of the five individual sections.

Howell Mesa

The vertical distribution of fauna in the section at Howell Mesa is shown in Figure 3 (in pocket). This section is the one most southwesterly and has a total Mancos thickness of only 478 feet due to intertonguing of the overlying Toreva into the Mancos Shale to the southwest. This section is one of the sections closest to the shoreline.

The *Hedbergella delrioensis* zone extends from the Dakota(?) Sandstone to about 225 feet above. Much of the base of the section is covered, making a precise determination of the Cenomanian-Turonian boundary impossible. The base is in the Cenomanian, as *Cythereis eaglefordensis* is found just above the Dakota(?) together with several species of marine foraminifera. Above the covered interval, only long-ranging species of *Hedbergella* and *Heterohelix* are present as high as 124 feet above the Dakota(?) where *Heterohelix pulchra*, a Turonian form, first appears. Such typically Cenomanian planktonic species as *Guembelitria harrisi*, *Rotalipora greenhornensis*, and *Globigerinelloides bentonensis* are absent in this lower interval. The boundary between the Cenomanian and Turonian is therefore imprecise but is probably lower in the section than the first appearance of *Heterohelix pulchra*. The general paucity of the fauna of the marine zone at Howell Mesa indicates that the shoreline was probably not far away. Many of the planktonic forms providing closer age resolution were probably animals restricted to offshore water masses or were depth stratified and thus did not get this close inshore.

At about 225 feet above the Dakota(?), planktonic species disappear and a short distance above this the remaining benthonics belong to a few species of arenaceous forms, which also disappear further upsection. This is taken as the base of the megaspore zone, although the lowest megaspores are about 398 feet above the Dakota(?). The megaspore zone at Howell Mesa is nearly barren. Ammonite molds (Collignoniceras woolgari) are present at 305 and 308 feet above the Dakota(?) in this barren interval.

The approximate base of the Gaudryina bentonensis zone is about 430 feet above the Dakota(?), where arenaceous species, including G. bentonensis appear. The Gaudryina bentonensis zone is only about 76 feet thick at Howell Mesa. This is probably due in part to intertonguing of the basal units of the overlying Toreva Formation with the upper part of the Mancos Shale.

Blue Canyon

The Mancos Shale section at Blue Canyon (Figure 4, in pocket) is complete, with no covered intervals, and is 677 feet thick. This section, like Howell Mesa, is one of the furthest shoreward.

A few more age-diagnostic planktonic species occur at Blue Canyon than at Howell Mesa, but environmental conditions were apparently similar in that normal marine water masses may not have reached this far westward. Sparse marine foraminifera are found 15 feet above the Dakota(?), and Cythereis eaglefordensis is present 40 feet above.

The *Hedbergella delrioensis* zone of the Mancos Shale is Cenomanian in age up to at least 62 feet above the Dakota(?) as indicated by the presence of the dominantly Cenomanian species *Guembelitria harrisi*. At 117 feet above the Dakota(?) the presence of *Heterohelix pulchra* and *Clavihedbergella simplex* indicate a Turonian age from this level upwards. The Cenomanian-Turonian boundary is somewhere in between, where only long-ranging planktonic forms occur in the samples. The plots of planktonic-to-benthonic ratio and number of benthonic species show a rude cyclic behavior, which is seen in most other sections in the upper portion of the marine zone.

The base of the megaspore zone is about 275 feet above the base of the Dakota(?), where planktonic foraminifera disappear and the remaining benthonics belong to a few arenaceous species. After a barren interval, the megaspores appear at 388 feet and persist to 455 feet above the Dakota(?). Numerous ammonite (*Collignoniceras*) molds occur in this zone.

The base of the *Gaudryina bentonensis* zone is at about 500 feet above the Dakota(?), where the ubiquitous *Trochammina wickendeni* makes its appearance in considerable numbers, followed upsection by *Gaudryina bentonensis* and several other species. The topmost 10 feet or so seem to be barren. Iron oxide nodules are present at several places in this zone.

Longhouse Valley

The distribution of Mancos microfossils at Longhouse Valley is shown in Figure 5 (in pocket). This section is nearly complete, the top

60 feet being covered, with two shorter covered intervals below in the megaspore zone. The total thickness of the Mancos Shale at this locality is 689 feet.

Marine microfossils, including Hedbergella delrioensis, appear immediately above the Dakota(?), and Cythereis eaglefordensis ranges from 10 feet to 20 feet above. The Cenomanian-Turonian boundary can be estimated fairly closely on the basis of the planktonic foraminifera. The predominantly Cenomanian Guembelitria harrisi extends to about 90 feet above the Dakota(?). The Turonian planktonics Heterohelix pulchra and Clavihedbergella first appear at 80 feet above. As G. harrisi extends slightly into the Turonian, the stage boundary is tentatively placed at about 75 feet above the Dakota(?), but it could be slightly higher. The top of the Hedbergella delrioensis zone is at 315 feet above the Dakota(?). The plots of planktonic-to-benthonic ratio and number of benthonic species show the rude cyclic behavior observed in other sections in the upper part of the Hedbergella delrioensis zone before subaerial conditions ensue.

The base of the megaspore zone is placed at 315 feet above the Dakota(?) where the planktonic forms disappear. While some benthonic forms extend a short distance above this point, most are arenaceous, and these disappear upsection. The megaspores appear at about 355 feet above the Dakota(?) and extend upward to 528 feet. One ammonite (Collignoniceras) mold was found within this zone at 410 feet above the Dakota(?)

The Gaudryina bentonensis zone begins at 557 feet above the Dakota(?) with the appearance of Trochammina wickendeni, and G. bentonensis appears at about 588 feet above the base of the Mancos. This assemblage continues up to the covered interval at 630 feet above the Dakota(?), and probably up to the top of the Mancos at 689 feet. Iron oxide concretions are found at scattered intervals through both of the upper biostratigraphic zones.

Kayenta

The vertical distribution of microfossils in the Mancos Shale at Kayenta is shown in Figure 6 (in pocket). The total Mancos thickness at this locality is 711 feet, of which the basal 15 feet and a total of 129 feet at or near the top are covered. This section is one of the two farthest seaward in Black Mesa.

The Hedbergella delrioensis zone extends from just above the Dakota(?) to about 260 feet above. Marine foraminifera and Cythereis eaglefordensis are present immediately above the 15-foot covered interval above the Dakota(?). The Cenomanian-Turonian boundary is tentatively placed at 50 feet above the Dakota(?) and is marked by the last appearance of Guembelitria harrisi and the first appearance of Heterohelix pulchra. Above this level only Turonian species appear, together with the ubiquitous long-ranging species of Hedbergella and Heterohelix. In the upper portion of the Hedbergella delrioensis zone, the plots of planktonic-to-benthonic ratio and number of benthonic species exhibit the same peculiar rough cyclic behavior as in other sections. Three teeth of the shell-crushing shark Ptychodus were found 100 feet above the Dakota(?), together with a single vertebra of a hybodont shark.

The base of the megaspore zone is placed at about 260 feet above the Dakota(?), where the planktonic forms disappear and megaspores first make their appearance. Trochammina wickendeni seems to continue from the Hedbergella delrioensis zone through the megaspore zone and on into the overlying Gaudryina bentonensis zone at Kayenta, indicating that some flooding was always present during the entire Mancos deposition at this locality. The spores persist upsection to 460 feet above the Dakota(?). Two horizons of ammonite molds (Collignoniceras) are in the megaspore zone, at 407 feet and 447 feet above the Dakota(?).

The base of the Gaudryina bentonensis zone is placed at about 460 feet above the Dakota(?); G. bentonensis is found in abundance at 490 feet. Flooding must have been more persistent at Kayenta than at most other localities during the deposition of the G. bentonensis zone, as the number of arenaceous species increases upsection to ten species. Unfortunately, a covered interval obscures the details and the order of their appearance. The top 54 feet are covered with Mesa Verde debris, but the G. bentonensis zone probably persists up to the Toreva Sandstone at 711 feet above the Dakota(?).

Lohali Point

Figure 7 (in pocket) shows the vertical distribution of Mancos microfossils at Lohali Point. This section is only 428 feet thick and is short because the upper portion has been planed off by a low-angle slide. Lohali Point along with Kayenta is one of the farthest seaward sections.

The Hedbergella delrioensis zone at Lohali Point extends from the Dakota(?) Sandstone to about 225 feet above. Marine foraminifera occur immediately above the Dakota(?), together with Cythereis eaglefordensis, which ranges as high as 45 feet above the base of the Mancos. The Cenomanian-Turonian boundary is tentatively placed at about 57 feet above the Dakota(?), halfway between the highest appearance of

Globigerinelloides bentonensis and the lowest appearance of Heterohelix pulchra and Clavihedbergella subdigitata. The boundary may be slightly higher, as Guembelitria harrisi persists up to 75 feet above the base of the Mancos. G. harrisi is a predominantly Cenomanian planktonic form, which continues for a short time into the Turonian. Both the Cenomanian and Turonian portions of the Hedbergella delrioensis zone at Lohali Point are of interest because of the presence of planktonic species not found in the other sections. The Cenomanian portion contains specimens of Rotalipora greenhornensis and Globigerinelloides bentonensis. Both of these species are considered to be confined to the Cenomanian by most workers. The Turonian portion of the marine zone at this locality contains specimens of Lunatriella spinifera. L. spinifera is a distinctive planktonic species recently described by Eicher and Worstell (1970a) from early Turonian strata of South Dakota, Colorado, and Kansas. Its presence at Lohali Point extends its known geographic range into northeastern Arizona.

Planktonic species disappear and benthonic numbers drop to zero at about 225 feet above the Dakota(?). The base of the megaspore zone is placed at this point. Megaspores appear at 244 feet above the Dakota(?) and persist as high as 413 feet, thus overlapping somewhat into the Gaudryina bentonensis zone.

The base of the Gaudryina bentonensis zone is placed somewhat arbitrarily at 402 feet above the Dakota(?), the first occurrence of arenaceous foraminifera (Trochammina wickendeni) above a barren interval. As at Kayenta, T. wickendeni persists sporadically through the megaspore zone and into the Gaudryina bentonensis zone, indicating some flooding during deposition. G. bentonensis itself makes its appearance directly under the Toreva.

The thickness of the Gaudryina bentonensis zone at the Lohali Point locality is only about 26 feet. An unknown but considerable amount of the upper part of the zone has been removed by a low-angle slide involving the upper part of the Mancos Shale and units of the overlying Toreva. Sliding is indicated both by the shorter than normal Mancos section for this part of Black Mesa and by the nature of the Mancos-Toreva contact.

The contact between the Mancos and the Toreva at the Lohali Point locality is not the usual gradational alternation of Mancos-like and Toreva-like units but is very abrupt. A broken, massive unit of the Toreva Sandstone rests directly upon silty Mancos Shale, the upper three feet of which has been rolled into a jumbled mass of pillowlike balls about two feet in diameter.

The amount of missing section is estimated to be in the order of 200 feet or more. The Gaudryina bentonensis zone is about 177 feet thick at Longhouse Valley and more than 250 feet thick at Kayenta. The total thickness of the Mancos Shale measured by Cooley, Akers, and Stevens (1964) in a nearby section also in the vicinity of Lohali Point is 640 feet, compared to the total of 428 feet measured in the locality of this study.

AGE OF THE MANCOS SHALE IN BLACK MESA

The three assemblage zones in the Mancos Shale of Black Mesa will probably not be recognized outside the area, especially the upper two, which are based on plant spores and arenaceous foraminifera. The upper two are environmental zones and probably cross time lines if extended far. However, they are useful stratigraphically, and within the confines of Black Mesa Basin the boundaries are probably nearly time parallel.

The planktonic foraminifera in the Hedbergella delrioensis zone of the Mancos provide a good means for the establishment of its age. The planktonic foraminifera in this lower portion are dominated by such long-ranging forms as Hedbergella delrioensis, H. portsdownensis, and Heterohelix globulosa. However, sufficient other planktonic species with overlapping time ranges are present to allow the extension of the Cenomanian to Turonian transition as presently recognized in the western interior and the Gulf Coast into the Mancos Shale of Black Mesa with a fair degree of confidence. This boundary is marked by the upward disappearance of such Cenomanian forms as Rotalipora greenhornensis, Globigerinelloides bentonensis, and Guembelitria harrisi, and the appearance of such Turonian species as Praeglobotruncana difformis (P. marginata), Clavihedbergella moremani, C. subdigitata, Heterohelix pulchra, and Lunatriella spinifera.

The age of that part of the Black Mesa Mancos above the Hedbergella delrioensis zone is more difficult to establish on the basis of the foraminifera. Planktonic foraminifera are missing, except for rare weathered individuals that were probably washed in by high tides or blown in by winds during deposition. Most of these are individuals or fragments of one of the long-ranging species of Hedbergella. In the Blue Canyon section, one weathered but recognizable specimen of Praeglobotruncana difformis (P. marginata) was found in the Gaudryina bentonensis zone, 100 feet below the Toreva. This would indicate the age of this part of the Gaudryina bentonensis zone is still in the Turonian, or Carlile equivalent.

Gaudryina bentonensis itself, like many other arenaceous foraminifera, is a temporally long-ranging species. It has been previously reported from widely separated localities in the Upper Cretaceous of the Gulf Coast and the western interior. This species is characteristic of the Blue Hill Member of the Carlile, which seems to be its lower temporal limit, but it extends upward through beds of Austin and Taylor age in the Gulf Coast (Cushman, 1946; Frizzell, 1954). Mello (1969, p. 30) reported it from throughout the Virgin Creek Member and the lower half of the Mobridge Member of the Pierre Shale in South Dakota. The upper temporal limit of G. bentonensis therefore seems to extend at least to the end of the Campanian (Taylorian) and possibly into the Maestrichtian (Navarroan). The same is probably true of other associated arenaceous species in the Gaudryina bentonensis zone, although less is known of their ranges. The presence of all these arenaceous species is dictated more by environment than time.

Previous workers using megafossils have established that the basal Toreva overlying the Mancos in Black Mesa is equivalent to the upper Carlile (p. 14). This evidence, together with the presence of *G. bentonensis* and other associated arenaceous foraminifera typical of the Blue Hill Member of the Carlile, indicates that the upper part of the Mancos Shale is probably no younger than Blue Hill, or middle Turonian.

PALEOECOLOGY

A major environmental change appears to have taken place during the deposition of the Mancos Shale of Black Mesa, from marine conditions at the bottom to a possibly subaerial environment at the top. Environmental boundary conditions were thus very different and will be treated separately.

The *Hedbergella delrioensis* Zone

The widespread appearance of marine planktonic and benthonic foraminifera immediately above the Dakota(?) indicates a rapid initial transgression of the sea. Using the plots of total numbers of benthonic species present as an indicator, this transgression seems to have reached its peak near or slightly above the Cenomanian-Turonian boundary. Even at the greatest extent of the transgression, the Mancos Shale in this area is not rich in species. The planktonic species indicate a connection with normal, well-ventilated marine waters, but the dearth of benthonic species, even at the greatest extent of the transgression, indicates that bottom conditions were somewhat less than ideal for the support of many species present elsewhere in deeper, more normal marine portions of this seaway.

Planktonic Relationships

Planktonic foraminiferal distributions in today's oceans are controlled largely by salinity, water depth, latitude, and major water mass distributions. Probably the distributions of the Cretaceous species were controlled by similar mechanisms. The effects of latitude on various Cretaceous planktonic groups have been discussed elsewhere (Bandy, 1967; Eicher, 1969b; Pessagno, 1969) and do not enter into the problem here.

Eicher (1969b, p. 170 and Fig. 4), investigating the planktonic foraminiferal distributions of the Cenomanian and Turonian of the western interior, noted the attrition of planktonic species which takes place from the axial portion of the seaway in eastern Colorado and western Kansas toward the west. Proceeding west from eastern Colorado, species of Ticinella disappear first, then Rotalipora and Globigerinelloides, leaving species of Hedbergella and Heterohelix the only planktonic representatives as the shoreline is approached (Fig. 12). Considering all Cretaceous planktonic foraminiferal species to have been stenohaline like those of today, Eicher reasoned that lowered salinity to the west would limit the total planktonic population in this direction rather than just certain groups and therefore other explanations than lowered salinity were responsible for the observed distributions. He considered the missing species either to be indicators of a southern water mass which extended northward from the Gulf or to be depth stratified and confined to the deeper axial portions of the seaway.

In one explanation for the observed planktonic distributions, Eicher (1969b, p. 172) proposed the possible existence of a southward-moving boreal current down the westward margin of the seaway. Such a current may have had an effect on the planktonic distributions by inhibiting the westward spread of warm-water species from the Gulf water mass. This implies that species of Hedbergella and Heterohelix were

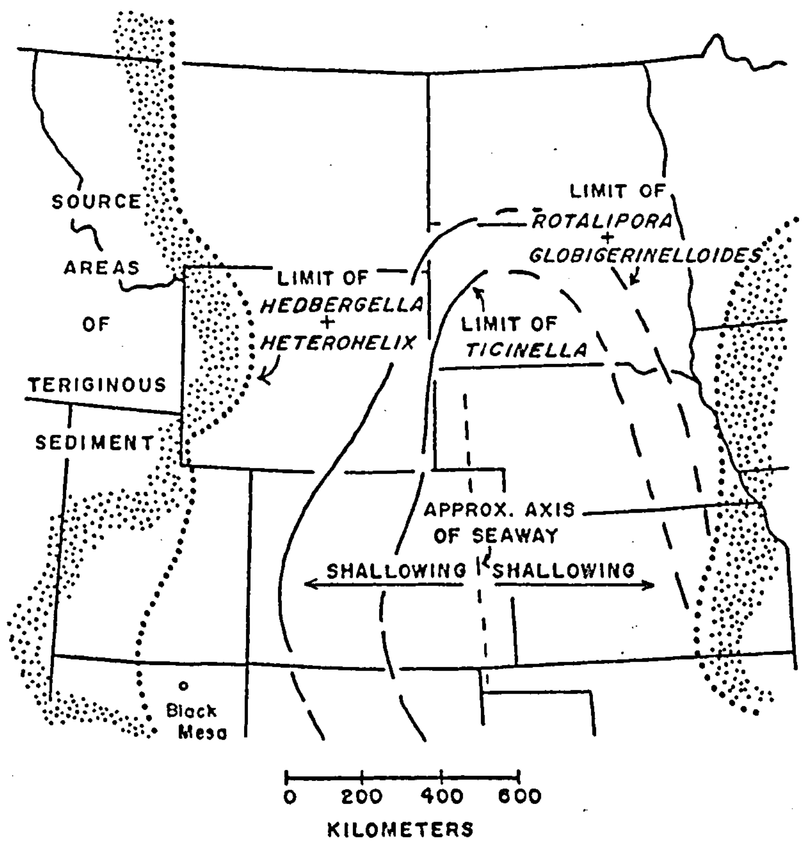

Figure 12. Geographic Distributions of the Genera Hedbergella, Heterohelix, Rotalipora, Globigerinelloides, and Ticenella in Cenomanian and Turonian Rocks of the Western Interior of the United States.--Adapted from Eicher, 1969b, fig. 4, p. 171.

hardier animals able to adapt to these colder waters as well as to the warmer waters of the Gulf.

By and large, the distributions of planktonic foraminifera found at Black Mesa fit with the geographic distributions as noted by Eicher. Species of Hedbergella and Heterohelix dominate in all samples in the Hedbergella delrioensis zone, and the somewhat scarce occurrences of other planktonics fit either with the depth stratification concept or the mixing of unlike water masses. However, if species of Hedbergella and Heterohelix were able to adapt to cold- and warm-water masses, they may likewise have been able to adapt to less than normal salinity. Thus, the possibility that lowered salinities due to land runoff existed to the west cannot be definitely ruled out.

Rotalipora greenhornensis and Globigerinelloides bentonensis both occur sparingly in the Lohali Point section, the one farthest seaward. If their presence is the result of depth stratification, the water depth at this locality was probably near the upper limit of the occurrence of these animals in the water column, and the contour drawn by Eicher showing the westward limit of these two species must be redrawn farther to the west to include the eastern part of Black Mesa. However, if an opposing Gulf and boreal current circulation system existed, the possibility is strong that the indicated positions of Eicher's lines limiting species are essentially correct and the Lohali Point occurrences are depositional freaks resulting from detached gyres of mixing currents. Such things are not uncommon in today's oceans.

At any rate, planktonic species distributions in the Mancos Shale of Black Mesa compared to contemporary distributions to seaward indicate that conditions unfavorable to many planktonic species prevailed in the Black Mesa area at the time of deposition. Shallowing water, with resultant dilution by land runoff and larger variations in both diurnal and seasonal temperature ranges, could have been a cause. A boreal current moving southward along the western shore could have been another.

Benthonic Relationships

The benthonic foraminifera, after their "peak" at the time of maximum transgression, decline both in numbers of individuals and species. As is evident from the number of benthonic species plots on the vertical distribution charts, there seems to be some sort of rude cyclicity in this, possibly connected with the breaking down of some barrier and temporarily improving environmental conditions. The overall trend, however, is toward worsening environment for the benthonic species. Concurrent with this trend is the tendency toward abnormal planktonic to benthonic ratios, indicating further that while a connection to well-ventilated marine waters existed, bottom conditions were becoming marginal first for the calcareous benthonic forms, then for the arenaceous ones. In all five sections, the same upsection trends are evident. The diversity of the benthonic fauna (faunal diversity) decreases, and the dominance of individuals of a single species (faunal dominance) increases until nearly all individuals left are of one arenaceous species, usually a Trochammina, indicating a regression that becomes essentially complete in the overlying megaspore zone.

Based on the contained foraminifera, the depositional environment of the Hedbergella delrioensis zone of the Mancos Shale must have been in relatively shallow water, close to shore, the depth of which became progressively shallower upsection. The abundant planktonic foraminifera present in the Hedbergella delrioensis zone probably provide no clue for estimation of water depth. In modern marine environments, planktonic-to-benthonic ratios generally increase proceeding from shallow nearshore waters to the shelf edge, but so many exceptions are known that it is concluded that this parameter is of limited value in the establishment of precise depth estimates (Phleger, 1960a, p. 242). Much the same can be said of the use of individual species, genera, or families of benthonic foraminifera as "depth indicators." This requires the study of the evolutionary history and limiting environmental factors of modern species and genera back through geologic time, and comparisons with Cretaceous forms may be possible only in a general way (Phleger, 1960a, p. 261).

General ecological principles based on the studies of modern foraminiferal distributions may shed light on this matter. In modern seas the numbers of benthonic species show an inverse relationship to the variability of the environment. The variability of the environment in turn is related to the distance from the shoreline, or water depth. As the shoreline is approached, the depth shoals and the environment (including such factors as temperature, salinity, pH, turbidity, and oxygen content) becomes more variable. The increasing dominance of any one species shows a direct relationship in the same direction.

Walton (1964, p. 217) has attempted to quantify these relationships between water depth, faunal diversity, and faunal dominance. According to his figures, 100 percent of all faunas with less than 30 species occur in water less than 20 fathoms (120 feet) deep, and 100 percent of all faunas with less than 20 species occur in water less than 10 fathoms (60 feet) deep. The Mancos Shale of Black Mesa, even at the interpreted maximum of the transgression, contains less than 15 benthonic species, indicating a water depth of possibly less than 10 fathoms. The possibility exists that the number of benthonic species was originally greater and that delicate thin-walled forms once present have since been dissolved. Ample evidence of chemical attack is recognized on some of the planktonic tests found in the upper part of the Hedbergella delrioensis zone. However, several delicate thin-walled forms are found in the lower part of the Hedbergella delrioensis zone, and it is thus felt that any substantial removal of species due to the selective dissolution of tests is negligible.

Walton's relationships are based on occurrences in the northeast Gulf of Mexico, which may not be typical of the Cretaceous western interior seaway, but the ecologic principles governing nearshore marginal marine faunal distributions and their relations to water depth were probably as valid in the Cretaceous as they are now.

Other evidence for shallow water is given by Scott (1940, p. 310), who cited evidence that Gryphaea newberryi lived in water less than 20 fathoms deep in the Texas area. G. newberryi occurs abundantly in the lower Hedbergella delrioensis zone of the Mancos.

The fauna of the Hedbergella delrioensis zone of the Black Mesa Mancos seems to be even more impoverished in species than would be expected for a marginal marine environment of maximum depth of perhaps 20 fathoms facing an open seaway (Walton, 1964, p. 217).

Furthermore, there is a very high incidence of arenaceous foraminifera compared to calcareous ones. These factors indicate an even more extreme nearshore environment. The depth could have been less than 10 fathoms. An alternate possibility is that the unit was deposited in an embayment or estuary that was partially cut off from the open sea by a physical or hydrodynamic barrier. The rude cyclic increases and decreases of the benthonic species upsection could represent periods of breaching or movement of the barrier, thus temporarily "ventilating" the bottom as the embayment gradually filled with sediment. These conclusions agree with those of Repenning and Page (1956, p. 282-287), who also interpreted the depositional environment of the Black Mesa Mancos as a restricted embayment or estuary based largely on litho-stratigraphic evidence.

Estimates of the total depth of the axial portion of the Greenhorn-Carlile seaway have been made by others. Eicher (1969a), using two independent lines of evidence, one based on foraminiferal faunal relationships (planktonic-to-benthonic ratios) and the other on physiographic speculations, showed that it is possible to postulate depths of 2,000 to 3,000 feet. Lessard (1970), on the basis of the microfauna and sediments in the Tununk Member of the Mancos Shale in eastern Utah, suggests a maximum depth of 300 to 600 feet for this same seaway. The results of this study shed no light on depth relationships basinward. The fauna found here simply indicate shallow marginal marine waters close to the shoreline.

The Megaspore Zone

The two overlying zones containing plant megaspores and *Gaudryina bentonensis* are interpreted as marine mudflat or marsh.

Upsection from the lower *Hedbergella delrioensis* zone, marine foraminifera disappear rather abruptly, and there is a barren interval of a few feet before the appearance of the first spores. This is interpreted as the accumulation of mud in a filled-in embayment at nearly subaerial conditions and before plants could establish themselves. The appearance of the spores is gradual, with species "A" appearing first and persisting higher in the section than species "B", and always more abundant than species "B". This portion of the section is interpreted as possibly being the Cretaceous equivalent of the *Salicornia-Spartina* zone in modern marine marshes.

In modern marginal marine areas in the temperate zone, these borderlands between land and estuary or bay are colonized by halophytic marsh plants, which occur in a rough zonation related largely to height of the marsh above water (Hedgepeth, 1957, p. 718). Although the generic and specific constituents of the plants occupying this niche may vary somewhat due to other factors, there are remarkable regional and worldwide similarities. In California and the Gulf Coast, the plants involved are mainly species of *Spartina* and *Salicornia*, although species of *Dystichlis* may be present. *Spartina* occupies the lower areas of the marsh, while *Salicornia* and *Dystichlis* occur slightly higher above mean tide. In other regions, these plants may be replaced by, or supplemented by, species of *Juncus*, *Batis*, or other halophytes. To place specific figures relating height above sea level to these zones is difficult, as this is largely governed by local tidal variations. Animal populations inhabiting this environment, with the exception of a few species of foraminifera and the locally common burrowing crab, Uca, tend to be small, active, and transitory. Modern estuarine and neighboring salt marsh areas are utilized as nurseries by the juvenile and larval stages of many animals from surrounding marine and land environments, particularly shrimp and several species of fish (McHugh, 1967, p. 614).

That environmental conditions in these nearshore marshes and mudflats are extreme has been attested by many workers (Emery and Stevenson, 1957; Phleger, 1960a, p. 177; Phleger, 1960b, p. 278). Phleger and Bradshaw (1966) recently published information on diurnal and seasonal variations of some of the physico-chemical parameters of this environment. Their results indicate that many are even more extreme than previously thought. Using self-recording devices placed in a Spartina-Salicornia marsh at Mission Bay, California, Phleger and Bradshaw attempted to obtain continuous and simultaneous recordings of salinity, air and water temperature, pH, Eh, light intensity, wind velocity, tide level, plus several other parameters, over a period of one year.

Diurnal variations were found to be mainly related to tidal fluctuations. Salinity varied from 34 parts per mil at high tide to more than 42 parts per mil at the end of low tide. The high salinities of water draining from the marsh are attributed in part to evaporation and in part to the metabolism of the halophytes during which excess salt is excreted. Diurnal pH and oxygen ranged from 6.9 to 8.3 and from 30 percent to 130 percent air saturation, respectively. Oxygen and pH were both highest in daylight hours while marsh plants produce oxygen. Both were also higher during flood tides when normal marine water came in from the bay and lower at low tide when low-pH and low-oxygen water drained from the marsh. Diurnal variation of water temperature was from 12°C to 20°C.

Of greater interest are the seasonal variations. Water temperature had an extreme annual range of from 5°C to 33°C. For only about 40 percent of the year was the temperature within the 19- to 32-degree range established by Bradshaw (1961, p. 88) in defining the temperature range within which the species Ammonia beccarii can reproduce. Ammonia beccarii is a benthonic foraminiferal species commonly found in these marginal marine environments. Oxygen had a 9-month range of from 0 to 275 percent air saturation and was less than 100 percent saturation for 75 percent of the time. The pH values ranged from 6.7 to 8.5 over a 7-month period, with most values in excess of 7.0 but nearly always less than those of the bay. Salinity values were only recorded for two months, but during this time showed an extreme range from less than 30 parts per mil to more than 50 parts per mil. Salinities were found to be in excess of bay salinities 75 percent of the time and were more than 40 parts per mil 37 percent of the time.

All or any one of these parameters show ranges which could be limiting for organisms. The consistently low pH values indicate an overall marsh chemistry which could limit the life and preservation of calcareous forms. The temperatures are mainly outside of ranges which allow most foraminiferal species to reproduce and are probably even in excess of life tolerance for many.

Preservation of organic remains in such an environment would probably be minimal and confined largely to the arenaceous foraminifera and palynomorphs from the plants. Odum and de la Cruz (1967, p. 386), studying the rate of decay of particulate organic matter in a Spartina marsh in Georgia, found that debris from the burrowing crab Uca disappeared within 180 days, much less time than that taken by the bulk of the plant material.

The megaspore zone of the Mancos Shale of Black Mesa is largely barren of fossil material except for the megaspores themselves and a few arenaceous foraminifera. Ammonite molds, rare finely comminuted bone fragments, scales, small simple teeth, and occasional molds of minute gastropods are also found. Small concretions of iron oxide or iron hydroxide were also observed in this portion of the section. Such concretions or nodules have also been noted by workers studying modern salt marshes and marine mud flats. They are considered to be among the diagnostic features of these environments by some (Bouma, 1963, p. 127; Coleman, Gagliano, and Webb, 1964, p. 252).

The Gaudryina bentonensis Zone

The increase in numbers of species and individuals of arenaceous foraminifera, together with the disappearance of spores in the overlying Gaudryina bentonensis zone shows a slight transgressive tendency. This does not necessarily imply a vertical rise in sea level or subsidence of the basin. If sea level remains constant, apparent transgressions and regressions of a shore can take place as a result of changes in the supply of sediment. Such a mechanism is postulated for the slight environmental changes which took place during the deposition of this upper zone of the Black Mesa Mancos. A small decrease in the rate of sediment supply would allow a slight encroachment of the sea over a previously established "high" marsh allowing more extensive flooding. This would probably inhibit or eliminate the "high" marsh plants, with concurrent introduction of more foraminiferal species. The absolute value of the difference in elevation from "high" to "low" marsh would not have to be much, probably in the order of a few inches to a few feet, depending on the local tidal regime. Such a small change seems to be more easily explained by a slight decrease in sediment influx than by a miniscule rise in sea level.

That the depositional environment of this zone was still a marsh is indicated by the numbers and character of the species present. All are arenaceous and occur in variable numbers, probably reflecting the microenvironments in which they lived. They compare with Phleger's (1960a, p. 258; 1960b, p. 280) "marine marsh" fauna, except that there seem to be fewer species and the dominant genera are not the same.

Environmental conditions prevalent during deposition of this unit were probably also extreme but not so much so as in the "high" marsh environment of the megaspore zone. Ranges in temperature, salinity, and pH were probably damped out to some extent, and periods of extreme dry conditions were reduced, thus opening a few more niches for other foraminiferal species.

SYSTEMATIC PALEONTOLOGY

A total of 49 species of foraminifera representing 15 families were found in the Mancos Shale of Black Mesa. Twenty-two species are arenaceous (agglutinated) and 27 are calcareous; 14 species are planktonic. The classification of the foraminifera used in this paper is essentially that of Loeblich and Tappan in "Treatise on Invertebrate Paleontology," Part C (1964).

In addition to the foraminifera, which are the principal objects of investigation, other microfossils were found. These include ostracods, plant megaspores, small gastropods, and a conglomeration of small bone fragments, simple teeth, spines, and scales which are probably of vertebrate origin and are inferred to have been derived mostly from small fish. No attempt was made to classify these latter objects. The gastropods are almost exclusively internal or external molds with all or most of the shell material dissolved away.

Only two ostracods, *Cythereis eaglefordensis* Alexander and *Cytheropteron* cf. *C. castorense* Butler and Jones, are present in quantities sufficient to warrant description and illustration. Both of these occur together in the lowermost samples of the Mancos just above the Dakota(?). Classification of the ostracods follows that of Benson and others in "Treatise on Invertebrate Paleontology," Part Q (1961).

In the following sections, no claim is made to complete synonymies. Reference is made to pertinent name changes and, where known, to more complete synonymies.

Subclass Ostracoda
Family Cytheruridae G. W. Miller, 1894
Genus Cytheropteron Sars, 1866
Cytheropteron cf. C. castorense Butler and Jones
Figure 13E-H

Cytheropteron castorensis Butler and Jones, 1957, p. 20, pl. 5, fig. 5a,b. Howe and Laurencich, 1958, p. 297, text fig.
Cytheropteron castorense Butler and Jones. Crane, 1965, p. 205, pl. 3, fig. 1.

Description. Carapace subovate with distinct ventral alae; posterior with upturned caudal process; venter shows three or four fine ridges or striations which roughly parallel the outer margin of alae. Hingement of right valve has two elongate crenulate projections separated by a short crenulate groove; hingement of left valve complements that of right valve.

Remarks. This species is distinguished from Cytheropteron navarroense Alexander by having faint reticulations on the dorsal surface of the alae, whereas C. navarroense has smooth alae. In the Mancos specimens, these features are unclear and hence have been designated Cytheropteron cf. C. castorense. They may be C. navarroense.

Dimensions. Length, about 0.55 mm.

Occurrence. All specimens occur associated with Cythereis eaglefordensis Alexander in the basal part of the Mancos Shale in all sections. Crane (1965) lists this species from the Lower Taylor Marl of Texas, Annona Chalk and Saratoga Chalk of Arkansas, Ripley Formation of Georgia and Alabama, Nacatoch Sand of Arkansas, and the lower Prairie Bluff Chalk of Alabama.

Figure 13. Ostracoda

A-C. Cythereis eaglefordensis Alexander: A, right valve; B, left valve; C, dorsal; D, ventral. X50.

E-H. Cytheropteron cf. C. castorense Butler and Jones: E, right valve exterior; F, right valve interior; G, left valve exterior; H, left valve interior. X50.

Figure 13. Ostracoda

Family Trachyleberididae Sylvester-Bradley, 1948
Genus Cythereis Jones, 1849
Cythereis eaglefordensis Alexander
Figure 13A-D

Cythereis eaglefordensis Alexander, 1929, p. 98, pl. 9, figs. 9, 12. Howe and Laurencich, 1958, p. 194, text fig. Hazel, 1969, p. D157, fig. 2a-l.

Description. Carapace oblong, highest in front; anterior rounded, rimmed, denticulate; dorsal and ventral margins straight and converging; posterior compressed, short, angled below middle, denticulate below; valves convex, widest behind; surface prominently reticulate, with two low obscure nodes on median lateral line of carapace.

Remarks. This species is considered to be sufficiently widespread and time restricted to be used as a zonal marker for the Sciponoceras gracile zone, or latest Cenomanian, of the Gulf Coast and western interior of the United States (Hazel, 1969).

Dimensions. Length, about 0.75 to 0.80 mm.

Occurrence. Widespread and common in the basal part of the Black Mesa Mancos, associated with Cytheropteron cf. C. castorense Butler and Jones. Widespread in strata of middle Eagle Ford age (latest Cenomanian) of the Gulf Coast, Florida, and Georgia.

Order Foraminiferida
Family Saccamminidae Brady, 1884
Subfamily Saccammininae Brady, 1884
Genus Saccammina M. Sars, 1869
Saccammina alexanderi (Loeblich and Tappan)
Figure 14A-B

Proteonina alexanderi Loeblich and Tappan, 1950, p. 5, pl. 1, figs 1,2.
Proteonina cf. P. alexanderi Loeblich and Tappan. Stelck and Wall, 1955, p. 52, pl. 1, figs. 5, 6.
Saccammina alexanderi (Loeblich and Tappan). Eicher, 1960, p. 55, pl. 3, figs. 1, 2. Eicher, 1965, p. 891, pl. 103, fig. 1. Eicher and Worstell, 1970b, p. 280, pl. 1, fig. 7.

Description. Test consisting of one slightly elongate, bulbous chamber with an elongate neck; aperture terminal on elongate neck; wall arenaceous, medium- to coarse-grained.

Remarks. Specimens are usually flattened in preservation. The neck is very prominent and tapering in some specimens and short and abrupt in others.

Dimensions. Length, from about 0.18 mm to 0.50 mm; width from about 0.10 mm to 0.25 mm.

Occurrence. Common in all sections at Black Mesa. This species has been previously reported from Kiowa, Thermopolis, Skull Creek, Graneros, Belle Fourche and Blue Hill Shales of the United States western interior, and from the Kaskapau Formation of Alberta, Canada.

Figure 14. Foraminiferida: Saccamminidae, Hormosinidae, Lituolidae

A-B. Saccammina alexanderi (Loeblich and Tappan); two individuals, somewhat crushed. X65.

C-D. Reophax inordinatus Young; two individuals, D is somewhat crushed. X65.

E. Reophax recta (Beissel); side. X65.

F-H. Haplophragmoides cf. H. gilberti Eicher; side view of three individuals. X65.

I. Haplophragmoides collyra Nauss; side view of crushed individual. X65.

J. Ammobaculites impexus Eicher; side view of crushed specimen. X65.

K. Ammomarginulina carlilensis Lamb; side view of crushed specimen. X65.

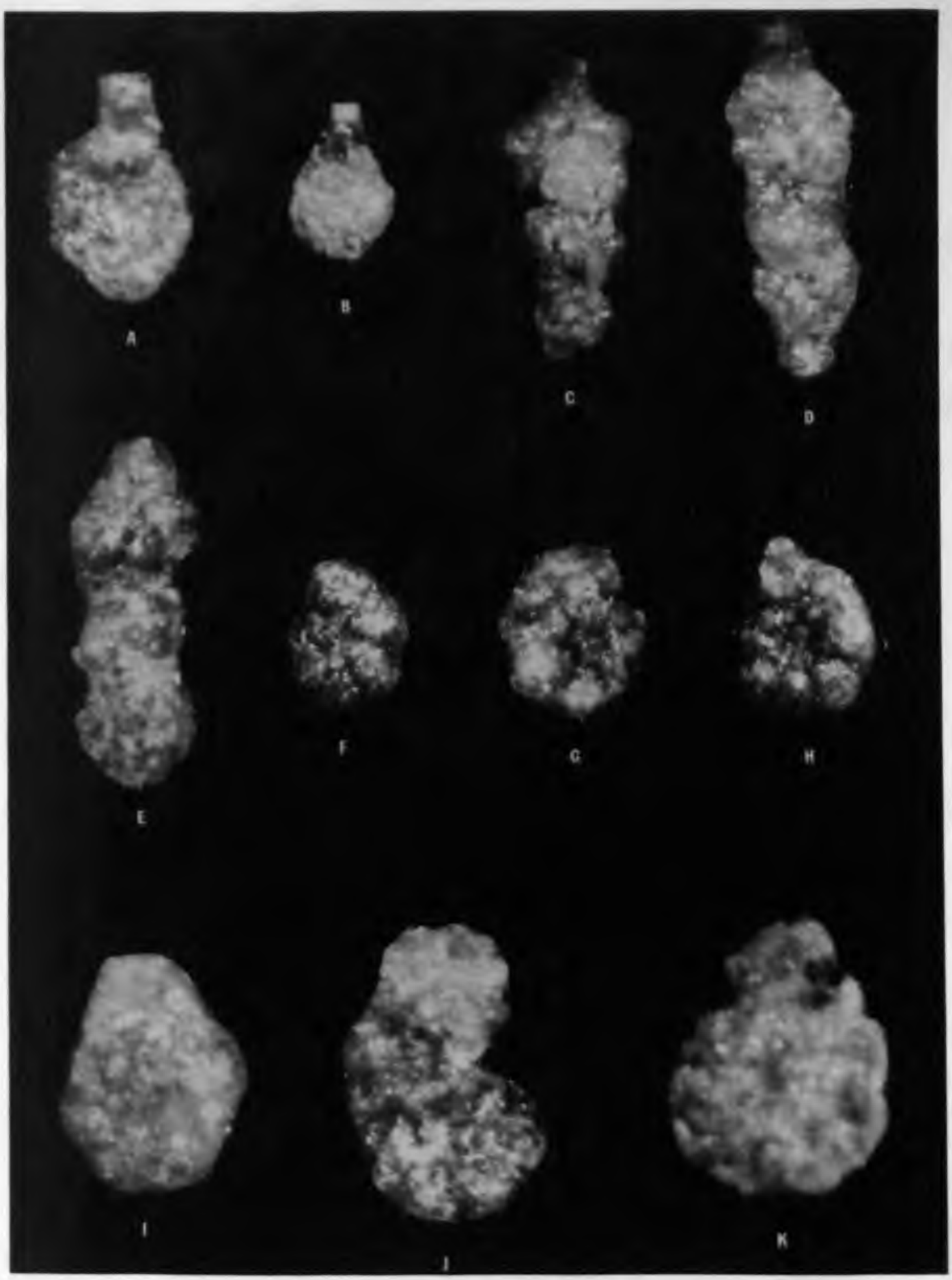

Figure 14. Foraminiferida: Saccamminidae, Hormosinidae, Lituolidae

Family Hormosinidae Haeckel, 1894
Subfamily Hormosininae Haeckel, 1894
Genus Reophax Montfort, 1808
Reophax inordinatus Young
Figure 14C-D

Reophax inordinatus Young, 1951, p. 48, pl. 11, figs. 1, 2. Eicher, 1966, p. 21, pl. 4, figs. 3, 4.

Description. Test elongate, tapering from center of last chamber to initial chamber and tapering rapidly from center of last chamber toward aperture; two to five uniserial chambers, usually three; sutures straight, depressed; wall coarsely arenaceous; aperture terminal, round, at end of prominent tapering neck.

Remarks. Specimens are usually flattened in preservation.

Dimensions. Length, from about 0.40 mm to over 1.0 mm; width, from 0.20 to 0.50 mm.

Occurrence. Locally common in all sections at Black Mesa. The species was originally described from Greenhorn equivalents from southern Montana and has been reported from the Blue Hill and Codell Members of the Carlile.

Reophax minuta Tappan

Reophax minuta Tappan, 1940, p. 94, pl. 14, fig. 4. Tappan, 1943, p. 480, pl. 77, fig. 4. Frizzell, 1954, p. 57, pl. 1, fig. 11. Tappan, 1962, p. 132, pl. 30, fig. 10. Eicher, 1965, p. 892, pl. 105, fig. 12.

Description. Test elongate, cylindrical when uncrushed, sides gently tapering; up to eight uniserial inflated chambers, slightly wider than high, increasing gradually in size; sutures depressed; wall arenaceous, medium- and coarse-grained; aperture terminal, rounded.

Remarks. Most specimens are crushed. The main difference between R. minuta and R. pepperensis Loeblich is in size; R. minuta is the larger. None are well enough preserved to illustrate.

Dimensions. Length, about 0.5 mm; width, about 0.18 mm.

Occurrence: Rare, only in the Blue Canyon and Lohali Point sections at Black Mesa. This species has previously been reported from the Graneros of Kansas, the Duck Creek and Grayson Formations of Oklahoma and Texas, and the Topagoruk and Oumalik Formations of Alaska.

Reophax pepperensis Loeblich

Reophax pepperensis Loeblich, 1946, p. 133, pl. 22, fig. 1. Frizzell, 1954, p. 58, pl. 1, fig. 12. Tappan, 1962, p. 133, pl. 30, fig. 14. Eicher, 1965, p. 892, pl. 105, fig. 8. Eicher, 1967, p. 180, pl. 17, fig. 8.

Description. Test elongate, small, cylindrical when uncrushed, gently tapering; up to 9 uniserial chambers, slightly wider than high, increasing gradually in size; sutures straight, depressed; wall arenaceous, fine- to medium-grained, rough; aperture terminal, round.

Remarks. Most specimens are crushed. Specimens in the Black Mesa material may be small R. minuta Tappan. None are well enough preserved to illustrate.

Dimensions. Length about 0.20 to 0.40 mm; width, from about 0.05 mm to 0.10 mm.

Occurrence. Rare in Black Mesa, only recognized in Longhouse Valley and Kayenta sections. The species has been previously reported from the Pepper Shale of Texas, from Turonian beds in northern

Alaska, and from the Belle Fourche and Graneros of the U.S. western interior.

Reophax recta (Beissel)
Figure 14E

Trochammina recta Beissel, 1891, p. 22, pl. 5, figs. 1-3.
Reophax recta (Beissel). Franke, 1928, p. 19, pl. 2, fig. 3. Fox, 1954, p. 110, pl. 24, fig. 1 (additional synonymy). Eicher, 1967, p. 180, pl. 17, figs. 3, 4. Eicher and Worstell, 1970b, p. 280, pl. 1, fig. 11.

Description. Test elongate, large, nodose, two to six uniserial chambers; chambers inflated, about as wide as high, increasing little in size as added, initial chamber commonly larger than the succeeding ones; sutures distinct, depressed; wall coarsely arenaceous, rough; aperture terminal, rounded, on low neck.

Remarks. Most specimens are crushed. The large initial chamber makes this species distinctive. Many individuals have only two or three chambers.

Dimensions. Length, from about 0.50 to over 1.0 mm.

Occurrence. Locally common in Black Mesa, found in all sections but Lohali Point. This species has been previously reported from the Cody Shale of Wyoming, the Belle Fourche Shale in Montana and Wyoming, and from the upper part of the Greenhorn Formation in northeastern Wyoming.

Family Lituolidae de Blainville, 1825
Subfamily Haplophragmoidinae Mayne, 1952
Genus Haplophragmoides Cushman, 1910
Haplophragmoides collyra Nauss
Figure 14I

Haplophragmoides collyra Nauss, 1947, p. 337, pl. 49, figs. 2, 5. Wall, 1960, p. 16, pl. 3, figs. 16-19. Eicher, 1967, p. 180, pl. 17, figs. 7, 9.

Description. Test planispiral, umbilici fairly deep, involute, tending to become slightly evolute in later stages; chambers slightly inflated, increasing in size gradually, six to nine in last whorl; sutures depressed; wall arenaceous, fine- to medium-grained; aperture indistinct.

Remarks. Most specimens are crushed flat so that chambers are concave.

Dimensions. Greatest diameter from about 0.35 mm to about 0.90 mm.

Occurrence. Locally common in the Hedbergella delrioensis zone in all five sections at Black Mesa. This species has previously been reported from the Lloydminister Shale of Alberta and from all portions of the Belle Fourche and its equivalents in Montana, Wyoming, and northern Colorado.

Haplophragmoides cf. H. gilberti Eicher
Figure 14F-H

Haplophragmoides gilberti Eicher, 1965, p. 894, pl. 103, figs. 11, 13, 14. Eicher, 1967, p. 181, pl. 17, fig. 2.

Description. Test planispiral, periphery broadly rounded, partly evolute, umbilicus fairly deep; seven to eight chambers in last whorl, chambers somewhat inflated, increasing in size very gradually;

sutures straight, indistinct; wall arenaceous, medium-grained, rough; aperture indistinct at base of apertural face.

Remarks. This species seems to be coarser grained than the form described by Eicher, and the chambers are less distinct. It compares favorably with his illustrations, however, and is thus designated as *Haplophragmoides* cf. *H. gilberti* Eicher.

Dimensions. Greatest diameter about 0.20 to 0.40 mm.

Occurrence. Common in all sections at Black Mesa except Longhouse Valley. It is more typical of the *Gaudryina bentonensis* zone but also occurs in the *Hedbergella delrioensis* zone.

Haplophragmoides howardense Stelck and Wall

Haplophragmoides howardense Stelck and Wall, 1954, p. 25, pl. 1, fig. 20, pl. 2, figs. 5, 6. Eicher, 1966, p. 21, pl. 4, figs. 6, 7.

Description. Test planispiral, periphery broadly rounded, variably evolute; umbilicus wide and shallow to moderately deep and narrow; six to eight chambers in last whorl, chambers slightly inflated, increasing in size gradually; sutures thickened, flush; wall arenaceous, fine- to medium-grained, smooth; aperture obscure at base of apertural face.

Remarks. Distinguished from *H. gilberti* Eicher by having much smoother surface and less inflated chambers.

Dimensions. Greatest diameter about 0.25 mm.

Occurrence. Rare to locally common in all sections at Black Mesa, particularly in the *Gaudryina bentonensis* zone. Previously reported from the Blue Hill Member of the Carlile, the Graneros Shale, and the Kaskapau Formation of Alberta.

Genus Trochamminoides Cushman, 1910
Trochamminoides cf. T. apricarius Eicher

Trochamminoides apricarius Eicher, 1965, p. 894, pl. 103, figs. 7, 12. Eicher, 1966, p. 22, pl. 4, fig. 10. Eicher, 1967, p. 181, pl. 17, fig. 14.

Description. Test small, compressed, planispiral and evolute, 8 chambers in the last whorl; chambers slightly inflated, increasing in size gradually; wall finely arenaceous; aperture at base of apertural face, obscure.

Occurrence. Rare in the Black Mesa Mancos. Only one specimen was found at Kayenta, 174 feet above the Dakota(?). In Colorado and Wyoming this species constitutes an important part of the fauna in the upper part of the Graneros and Belle Fourche and has been found in the Blue Hill Member of the Carlile.

Subfamily Lituolinae de Blainville, 1825
Genus Ammobaculites Cushman, 1910
Ammobaculites impexus Eicher
Figure 14J

Ammobaculites impexus Eicher, 1965, p. 895, pl. 104, figs. 3-5. Eicher, 1967, p. 181, pl. 17, fig. 6.

Description. Test elongate, uniserial portion cylindrical in uncrushed specimens, coil evolute, protruding beyond one or both sides of uniserial portion; 4 to 7 chambers in last whorl of coil, up to 3 or 4 chambers in uniserial portion; sutures indistinct in early portions of coil, distinct in later portions and in uniserial portion. Wall coarsely arenaceous, large grains giving a jagged outline; aperture terminal.

Remarks. Most specimens smashed flat and are quite jagged and irregular. Many are broken, with coils and uniserial portions occurring separately.

Ammobaculites junceus Cushman and Applin

Ammobaculites junceus Cushman and Applin, 1946, p. 72, pl. 13, fig. 2. Frizzell, 1954, p. 62, pl. 2, fig. 22. Eicher, 1967, p. 181, pl. 17, figs. 11, 12. Eicher and Worstell, 1970b, p. 281, pl. 1, fig. 6ab.

Description. Test elongate, involute coiled portion wider than uniserial portion, coil umbilicate with four to seven slightly inflated chambers, uniserial portion with up to six moderately inflated chambers which are wider than high; sutures in coil indistinct except when dampened, distinct in uniserial portion; wall arenaceous, medium-grained; aperture terminal.

Remarks. Most specimens flattened and frequently broken. None was well enough preserved to illustrate.

Dimensions. Length, from about 0.50 mm to about 0.75 mm.

Occurrence. Locally common in the Gaudryina bentonensis zone in the Blue Canyon and Kayenta sections at Black Mesa, not recognized in the other sections. This species has previously been reported from the upper part of the Woodbine Formation of Texas and from the Belle Fourche and equivalents of the western interior of the United States.

Genus Ammomarginulina Wiesner, 1931
Ammomarginulina carlilensis Lamb
Figure 14K

Ammomarginulina carlilensis Lamb, 1969, p. 143, text fig. 1-3.

Description. Test large, compressed; early portion closely coiled and partly involute; nine or ten chambers in whorl, usually visible only in transmitted light, two or three chambers in uniserial portion; wall arenaceous, rough, fine- to medium-grained; last uniserial chamber rectangular in outline.

Dimensions. Length, up to 1.5 mm; diameter, about 0.3 mm.

Occurrence. Rare to locally common in Howell Mesa, Blue Canyon, and Kayenta sections at Black Mesa, in the *Hedbergella delrioensis* zone. First described from Blue Hill equivalents of the Mancos Shale of the San Juan Basin of New Mexico

Ammomarginulina cf. *A. paterella* Eicher

Ammomarginulina paterella Eicher, 1967, p. 182, pl. 17, figs. 15, 16

Description. Test comparatively large, compressed, early portion a faintly biumbilicate coil of about two whorls with about seven chambers in a whorl, followed by compressed uniserial portion of one to three chambers; chambers indistinct except when dampened, expanding slowly; sutures indistinct; wall arenaceous, coarse, rough finish; aperture indistinct.

Dimensions. Length, up to about 1.0 mm; diameter to about 0.8 mm.

Remarks. Many individuals consist of coil only. Coarser grained than *A. carlilensis* Lamb, and last uniserial chamber is less rectangular. None is well enough preserved to illustrate.

Occurrence. Recognized only in Blue Canyon sections at Black Mesa where it is common in some samples in the *Gaudryina bentonensis* zone. Previously reported from the upper part of the Belle Fourche and equivalents in Montana and Wyoming.

Ammomarginulina cf. A. perimpexus Eicher

Ammomarginulina perimpexus Eicher, 1966, p. 23, pl. 4, figs. 13-15

Description. Test planispiral, compressed, evolute, early portion of less than two complete whorls, five to seven chambers in last whorl, less in preceding whorl, chambers increasing in size gradually but somewhat inflated in some specimens; uniserial portion one or two chambers; sutures indistinct; wall coarsely arenaceous; aperture indistinct. None of the Black Mesa specimens were sufficiently well preserved to illustrate.

Dimensions. Length, up to 0.50 mm.

Occurrence. Recognized only in one sample in the Gaudryina bentonensis zone in the Longhouse Valley section at Black Mesa, where 19 specimens were found. Most were poorly preserved. Difficult to differentiate from A. cf. paterella Eicher, except smaller.

Genus Haplophragmium Reuss, 1860
Haplophragmium arenatum Lamb
Figure 15A

Haplophragmium arenatum Lamb, 1969, p. 143, text fig. 4-6

Description. Test large, early portion is an irregular streptospiral coil, later portion uniserial, straight to sometimes crooked; up to six chambers in uniserial portion, but many seem broken off; sutures slightly depressed; wall arenaceous, medium-grained; aperture round, terminal.

Remarks. Many specimens appear to be distorted. There seems to be quite a variation in the coiling, but all closely resemble Lamb's figures.

Figure 15. Foraminiferida: Lituolidae, Textulariidae, Trochamminidae, Ataxophragmiidae

A. Haplophragmium arenatum Lamb: front view showing streptospiral coiling. X50.

B. Coscinophragma? cf. C. codyensis (Fox): side view. X50.

C-E. Spiroplectammina acostai Tappan: side views of three individuals. X65.

F-I. Trochammina wickendeni Loeblich: F, dorsal, and G, ventral views of a crushed specimen H, dorsal, and I, ventral views of another somewhat crushed specimen. X65.

J-M. Gaudryina bentonensis (Carman): side views of four different individuals. X65.

Figure 15. Foraminiferida: Lituolidae, Textulariidae, Trochamminidae, Ataxophragmiidae

Dimensions. Length, to about 1.10 mm.

Occurrence. Rare to locally common in Hedbergella delrioensis zone of all Black Mesa sections. Previously reported from lower Greenhorn equivalent of the lower Mancos in the San Juan Basin, New Mexico.

Subfamily Coscinophragmatinae Thalmann, 1951
Genus Coscinophragma Thalmann, 1951
Coscinophragma ? cf. C. codyensis (Fox)
Figure 15B

Polyphragma codyensis Fox, 1954, p. 113, pl. 25, figs. 1-4.
Coscinophragma codyensis (Fox). Eicher, 1967, p. 183, pl. 18, figs. 5, 6.
Coscinophragma ? codyensis (Fox). Eicher and Worstell, 1970b, p. 281, pl. 1, fig. 14.

Description. Test, large, elongate, irregularly uniserial, all specimens broken, crushed, or distorted; chambers wider than high but variably shaped, very slightly inflated; some individuals show bifurcating branches; wall arenaceous, medium-grained; aperture obscure. It cannot be determined in the material available if chamber interiors are labyrinthic as illustrated by Loeblich and Tappan (1964, text fig. 162, fig. 7), and therefore the generic assignment is in doubt.

Remarks: All material in Black Mesa is represented by broken and crushed fragments, some of which show bifurcations.

Dimensions. Fragments range up to over 1 mm in length.

Occurrence. Generally rare, but locally common to abundant in the Hedbergella delrioensis zone of Howell Mesa, Blue Canyon, and Kayenta in the Black Mesa Mancos. Originally reported from parts of the Cody Shale of inferred Niobrara age in the Big Horn Basin of Wyoming. Subsequently reported from the uppermost Belle Fourche of Montana and from the upper Greenhorn in South Dakota and Colorado.

Family Textulariidae Ehrenberg, 1838
Subfamily Spiroplectammininae Cushman, 1927
Genus Spiroplectammina Cushman, 1927
Spiroplectammina acostai Tappan
Figure 15C-E

Spiroplectammina acostai Tappan, 1943, p. 484, pl. 77, fig. 30. Frizzell, 1954, p. 66, pl. 4, fig. 16. Eicher, 1966, p. 23, pl. 4, fig. 17, 20.

Description. Test small, compressed, flaring moderately from rounded base, periphery unevenly serrate; some specimens begin with a 4- or 5-chamber coil, others with a proloculus, followed by up to 12 biserial chambers; biserial chambers elongate, twice as wide as high, sloping downward to periphery, increasing gradually in size; sutures distinct, depressed; wall finely arenaceous; aperture obscure.

Remarks. Taper of test and degree of flatness is somewhat variable.

Dimensions. Length, about 0.25 mm.

Occurrence. This species is locally abundant in the Gaudryina bentonensis zone of Kayenta and present at Lohali Point at Black Mesa. Previously reported from the Duck Creek Formation of Texas and from the Blue Hill Member of the Carlile Shale of Colorado.

Family Trochamminidae Schwager, 1877
Subfamily Trochammininae Schwager, 1877
Genus Trochammina Parker and Jones, 1859
Trochammina cf. T. rutherfordi Stelck and Wall

Trochammina rutherfordi Stelck and Wall, 1955, p. 56, figs. 11, 12, 14, 16, pl. 3, figs. 20, 21. Eicher, 1965, p. 899, pl. 105, fig. 1 (additional synonymy).

Description. Test trochospiral, small, ventrally umbilicate, dorsally variably convex, consisting of three to four whorls with five to eight chambers in final whorl; chambers inflated, increasing in size gradually; sutures depressed; wall arenaceous, fine to medium.

Remarks. Two subspecies have been previously described (Eicher, 1965, p. 899), and considerable overlap in characteristics exists between the two subspecies and still another species, *T. ribstonensis* Wickenden. The material found in Black Mesa, although somewhat crushed, most closely resembles those in Eicher's (1965, pl. 105, fig. 1) illustration. None is good enough to illustrate.

Dimensions. Greatest diameter about 0.20 mm; height about 0.10 mm.

Occurrence. Found only in one sample at the base of the Longhouse Valley section in Black Mesa. Previously reported from the Graneros Shale and equivalents in the western interior of the United States, the Dunvegan and Kaskapau Formations of western Canada, and the Ninuluk Formation of northern Alaska.

Trochammina wetteri Stelck and Wall

Trochammina wetteri Stelck and Wall, 1955, p. 59, pl. 2, figs. 1-3, 6.
Eicher, 1967, p. 184, pl. 18, figs. 7, 9 (additional synonymy).
Eicher and Worstell, 1970b, p. 282, pl. 1, fig. 16.

Description. Test trochospiral, rather large, consisting of about two and one-half whorls, dorsally convex, ventrally umbilicate; four to six chambers in last whorl, chambers inflated; sutures depressed, radial ventrally and slightly slanted dorsally; wall arenaceous, medium- to fine-grained.

Remarks. Very similar to *T. wickendeni* Loeblich except for size, with *T. wetteri* being larger (Eicher, 1967, p. 185). These two forms may be the same species. Most specimens are crushed.

Dimensions. Diameter, about 0.30 mm.

Occurrence. T. wetteri is considered to be rare in the Black Mesa Mancos. It was recognized locally only in the Howell Mesa and Kayenta sections. This species is common in the Belle Fourche and equivalents of the U.S. western interior and has also been found in the Greenhorn. It is also quite common in the Kaskapau and Puskwaskau Formations of western Canada.

Trochammina wickendeni Loeblich
Figure 15F-I

Trochammina wickendeni Loeblich, 1946, p. 138, pl. 22, fig. 17. Frizzell, 1954, p. 79, pl. 7, fig. 24. Eicher, 1965, p. 900, pl. 105, fig. 13. Eicher, 1966, p. 24, pl. 4, fig. 22.

Description. Test trochospiral, low, consisting of about two complete whorls, with ventral umbilicus; four to six chambers in last whorl, chambers inflated; sutures depressed; wall arenaceous, medium- to fine-grained; aperture obscure, at inner ventral margin of last chamber opening into umbilicus.

Remarks. This species resembles T. wetteri in all characters, except smaller in size. Most specimens are smashed flat.

Dimensions. Diameter from about 0.15 mm to 0.30 mm.

Occurrence. Common to abundant throughout the Black Mesa Mancos, even occurring sparsely through the megaspore zone in some sections. Previously reported from the Pepper Shale of Texas and from the Graneros and Carlile of the U.S. western interior. Lamb (1968, p. 841) found it to be common in the Carlile equivalent portions of the lower Mancos Shale in the San Juan Basin of New Mexico.

Family Ataxophragmiidae Schwager, 1877
Subfamily Verneuilininae Cushman, 1911
Genus Gaudryina D'Orbigny, 1839
Gaudryina bentonensis (Carman)
Figure 15J-M

Spiroplectammina bentonensis Carman, 1929, p. 311, pl. 34, figs. 8, 9.
Gaudryina bentonensis (Carman). Cushman, 1932a, p. 96. Cushman, 1946, p. 33, pl. 7, figs. 15, 16 (additional synonymy). Frizzell, 1954, p. 70, pl. 5, fig. 14. Eicher, 1966, p. 24, pl. 5, figs. 3, 4. Mello, 1969, p. 48, pl. 4, fig. 11.

Description. Test elongate, rounded at base, somewhat compressed, edges parallel to gently tapering in side view, early triserial portion about as high as wide, usually with two or three whorls, biserial portion usually slightly twisted; chambers increasing rapidly in size in triserial portion but nearly uniform in biserial portion; sutures distinct in biserial part; wall finely arenaceous, smooth; aperture a high, narrow opening rising from the base of apertural face.

Remarks. Usually well preserved. This species is substantially larger and less sharply tapering than G. spiritensis Stelck and Wall.

Dimensions. Length, from about 0.20 mm to 0.70 mm, mostly about 0.50 mm.

Occurrence. Locally common to abundant in the Gaudryina bentonensis zone in all five sections at Black Mesa. It has not been found in the Hedbergella delrioensis zone or the megaspore zone. Previously reported from many Upper Cretaceous units in the Gulf Coast and the western interior. It is abundant in the Blue Hill Member of the Carlile Shale in Colorado.

Gaudryina spiritensis Stelck and Wall

Gaudryina spiritensis Stelck and Wall, 1955, p. 43, pl. 2, figs. 9, 10; pl. 3, figs. 8-12. Eicher, 1966, p. 24, pl. 5, figs. 1, 2.

Description. Test elongate, tapering markedly to a very narrow, rounded base, early one-fourth of test closely triserial, later portion slightly twisted and biserial; chambers inflated, increasing slightly; sutures distinct; wall arenaceous, fine- to medium-grained, smooth; aperture a high arch in apertural face.

Remarks. Smaller, more tapering, and slightly rougher finish than G. bentonensis. None well enough preserved to illustrate.

Dimensions. Length about 0.15 mm to 0.25 mm.

Occurrence. Generally rare in Black Mesa Mancos. Only found at base of Longhouse Valley section and in one sample in the Hedbergella delrioensis zone at Kayenta. Previously reported from the Kaskapau Formation of western Canada and from the Blue Hill and Codell Members of the Carlile in Colorado.

Family Miliolidae Ehrenberg, 1839
Subfamily Quinqueloculininae Cushman, 1917
Genus Quinqueloculina D'Orbigny, 1826
Quinqueloculina moremani Cushman
Figure 16A-B

Quinqueloculina moremani Cushman, 1937, p. 100, pl. 15, fig. 1. Cushman, 1946, p. 48, pl. 14, fig. 7. Frizzell, 1954, p. 77, pl. 6, fig. 34. Eicher and Worstell, 1970b, p. 283, pl. 2, fig. 7.

Description. Test longer than broad, oval, with apertural end projecting into a round apertural neck; chambers angular, distinct, sides flattened to slightly concave in some specimens, last formed chamber overlapping base; sutures distinct; wall smooth, porcelaneous; aperture round.

Figure 16. Foraminiferida: Miliolidae

A-B. Quinqueloculina moremani Cushman: side view of two individuals. X75.

C-D. Nodosaria bighornensis Young: side view of two individuals. X75.

E-F. Citharina kochii (Roemer): side view of two individuals showing range in variation. X75.

G. Dentalina gracilis D'Orbigny: side view. X75.

H-I. Frondicularia imbricata Young: side view of two individuals. X75.

J-K. Marginulinopsis amplaspira: side view of two individuals. X75.

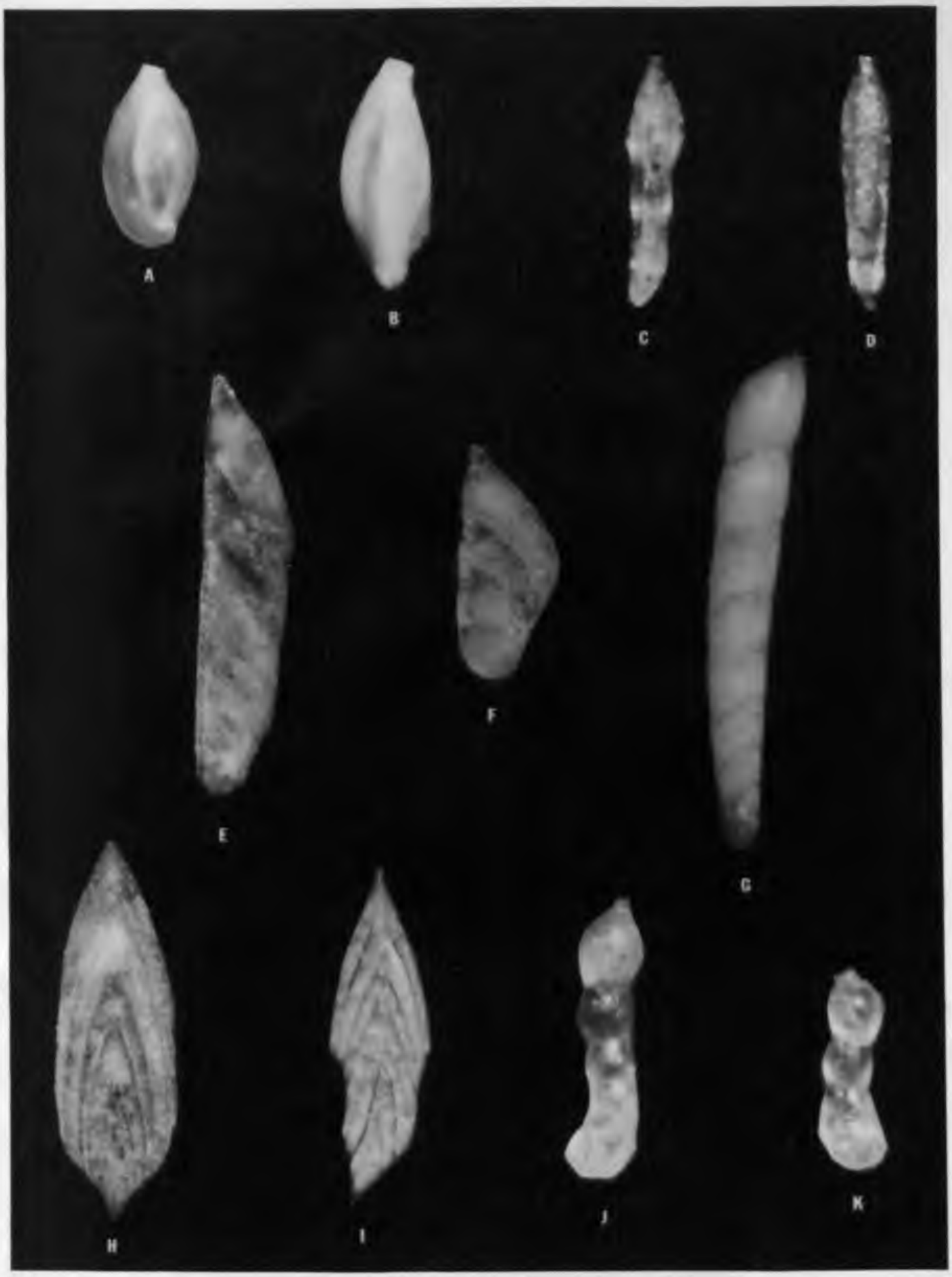

Figure 16. Foraminiferida: Miliolidae

Remarks. Generally well preserved. Characterized by angular chambers which results in angular ridge on side of test.

Dimensions. Length, from about 0.20 mm to 0.50 mm.

Occurrence. Not found in Blue Canyon or Kayenta sections but locally common in the Hedbergella delrioensis zone of the other three sections at Black Mesa. Previously reported from the Eagle Ford Formation of Texas and from the Greenhorn of the western interior.

Family Nodosariidae Ehrenberg, 1838
Subfamily Nodosariinae Ehrenberg, 1838
Genus Nodosaria Lamarck, 1812
Nodosaria bighornensis Young
Figure 16C-D

Nodosaria bighornensis Young, 1951, p. 58, pl. 12, figs. 17, 19.
Eicher and Worstell, 1970b, p. 287, pl. 3, figs. 21, 22.

Description. Test straight to slightly curved, long, variably tapering, composed of from four to eight chambers, ornamented with from four to eight raised, widely spaced, straight costae, which increase in number by intercalation; specimens with pointed base expand rather rapidly, those with large proloculus and rounded base remain nearly parallel through length of test; aperture terminal, on low neck at distal end of last chamber.

Dimensions. Length, from about 0.30 mm to 0.50 mm, broken individuals originally of still larger size.

Occurrence. Found in the Hedbergella delrioensis zone of all Black Mesa sections except Blue Canyon. Previously reported from the Frontier Formation of southern Montana and from widely scattered localities in the Greenhorn Formation of the western interior.

Genus Citharina D'Orbigny, 1839
Citharina kochii (Roemer)
Figure 16E-F

Vaginulina kochii Roemer, 1841, p. 96, pl. 15, fig. 10. Tappan, 1940, p. 109, pl. 17, figs. 2-4 (additional synonymy).
Citharina kochii (Roemer), Frizzell, 1954, p. 94, pl. 11, fig. 9 (additional synonymy). Eicher and Worstell, 1970b, p. 284, pl. 2, figs. 2, 3 (additional synonymy).
Vaginulina recta Reuss, 1863, p. 48, pl. 3, figs. 14, 15. Tappan, 1940, p. 110, pl. 17, figs. 7, 8 (additional synonymy). Cushman, 1946, p. 78, pl. 28, fig. 23 (additional synonymy).
Citharina recta (Reuss), Frizzell, 1954, p. 95, pl. 11, figs. 19-21 (additional synonymy).
Vaginulina sp. 1, Fox, 1954, p. 116, pl. 25, fig. 21.

Description. Test elongate, dorsal margin straight, ventral margin uneven, parallel to flaring sides; chambers distinct, up to eight but usually four to six; sutures limbate, gently curved, slightly raised; proloculus prominent, of variable size; surface smooth; aperture terminal on dorsal margin.

Remarks. Specimens show great variability in size of proloculus and in lateral profile. Characterized by rectangular cross section and limbate, raised sutures. Division between C. kochii and C. recta was originally on the basis of flaring versus parallel sides, but there is a gradation between the extremes, and the two species have been lumped together by Eicher and Worstell (1970b, p. 284). The Mancos specimens of Black Mesa show this same intergradation.

Dimensions. Length, from 0.50 to as much as 0.90 mm; width, about 0.30 mm.

Occurrence. Locally common in the Hedbergella delrioensis zone of all five sections in Black Mesa. Previously reported from widely separated Cretaceous localities under several local names. Common in the Greenhorn of the western interior.

Genus Dentalina Risso, 1826
Dentalina gracilis D'Orbigny
Figure 16G

Dentalina gracilis D'Orbigny, 1840, p. 14, pl. 1, fig. 5. Franke, 1928, p. 29, pl. 2, fig. 22. Cushman, 1946, p. 65, pl. 23, figs. 3-6 (additional synonymy). Frizzell, 1954, p. 88, pl. 9, figs. 49, 50.

Description. Test elongate, slender, curved; chambers gently inflated, forming a more or less smooth series without constrictions in early portion of test, becoming nodose in later portion; sutures flush in early portion, variably depressed in later portion, slightly oblique to axis; aperture terminal, radiate.

Remarks. This species shows considerable variation in length, curvature, and proportion of test which is smooth and flush in the early portion and nodose in the later portion. Most individuals are broken. This species may be the same as that Eicher and Worstell (1970b, p. 284, pl. 2, fig. 22) referred to D. basiplanata Cushman.

Dimensions. Variable, length to over 1.50 mm.

Occurrence. Locally common to abundant in the Hedbergella delrioensis zone of all Black Mesa section. Previously reported from widespread localities throughout the Upper Cretaceous.

Genus Frondicularia Defrance, 1826
Frondicularia imbricata Young
Figure 16H-I

Frondicularia imbricata Young, 1951, p. 61, pl. 13, figs. 4-6. Eicher, 1967, p. 185, pl. 19, fig. 4. Eicher and Worstell, 1970b, p. 285, pl. 2, figs. 17, 18.

Description. Test thin, perforate, elongate, of variable outline but usually broadly oval to wedge shaped; proloculus elongate, often protruding beyond proximal chambers; early chambers of some specimens added unevenly with later chambers added evenly, in normal specimens all chambers added evenly; sutures slightly limbate; ornamentation consists of light striations, which are most visible where they cross the sutures; aperture terminal, radial, on neck.

Remarks. Many specimens broken and most weathered or worn, so that striations are barely visible when dampened.

Dimensions: Variable, length from about 0.50 mm to over 1.50 mm.

Occurrence. Generally rare, but locally common in the *Hedbergella delrioensis* zone of all sections at Black Mesa. Previously reported from the Frontier Formation of southern Montana, and from the Greenhorn of South Dakota, Colorado, and Kansas.

Genus *Lenticulina* Lamarck, 1804
Lenticulina gaultina (Berthelin)

Cristellaria gaultina Berthelin, 1880, p. 49, pl. 3(26), figs. 15-19.
Lenticulina gaultina (Berthelin), Tappan, 1940, p. 101, pl. 15, figs. 13-15. Frizzell, 1954, p. 82, pl. 8, fig. 15 (additional synonymy). Eicher, 1965, p. 903, pl. 106, fig. 5 (additional synonymy). Eicher and Worstell, 1970b, p. 286, pl. 2, fig. 14.

Description. Test planispiral, involute, subrounded to tear-shaped in profile, keeled; chambers increasing in size gradually, usually seven to nine in last whorl; sutures indistinct in early chambers, thickened in later ones, straight; peripheral keel a series of nearly straight segments in later chambers; aperture radiate at peripheral angle.

Remarks. Most specimens somewhat corroded; none well enough preserved to illustrate.

Dimensions. Diameter about 0.15 to 0.30 mm.

Occurrence. Rare in the *Hedbergella delrioensis* zone of the Blue Canyon, Kayenta, and Lohali Point sections at Black Mesa. Previously reported from the upper part of the Graneros in Colorado and from the Greenhorn of South Dakota, Colorado, and Kansas. Also reported from the Gulf Coast Cretaceous and from Europe.

Genus *Marginulinopsis* Silvestri, 1904
Marginulinopsis amplaspira Young
Figure 16J-K

Marginulinopsis amplaspira Young, 1951, p. 54, pl. 11, figs. 15, 17-21, pl. 12, figs. 1-4, 6, 8-14, text fig. 5, nos. 14-16, 18-21, text fig. 6, nos. 2-16, 20. Fox, 1954, p. 115, pl. 25, figs. 13, 14. Eicher and Worstell, 1970b, p. 286, pl. 3, figs. 3, 4 (additional synonymy).

Description. Test short to long, smooth; coiled portion circular to polygonal in peripheral outline, many specimens showing marked angles at juncture of suture with periphery; sutures flush to raised in coil; uniserial series straight to arcuate, later chambers more or less inflated; aperture variable in position but situated on low neck below peripheral angle.

Remarks. The large amount of variability in nearly all characteristics found in this species led Eicher and Worstell (1960b, p. 286) to lump several of Young's (1951) species into *M. amplaspira*. The variability found in this form in the Black Mesa material tend to confirm the conclusions of these workers.

Dimensions. Length from about 0.40 mm to over 1.50 mm.

Occurrence. Widespread and locally common in the *Hedbergella delrioensis* zone in all sections at Black Mesa. Previously reported from the Frontier Formation of southern Montana and from the Greenhorn of Wyoming, South Dakota, and Colorado.

Family Turrilinidae Cushman, 1927
Subfamily Turrilininae Cushman, 1927
Genus Neobulimina Cushman and Wickenden, 1928
Neobulimina albertensis (Stelck and Wall)
Figure 17A-B

Guembelitria cretacea Cushman var. albertensis Stelck and Wall, 1954 p. 23, pl. 2, fig. 19.
Guembelitria cretacea Cushman var. spiritensis Stelck and Wall, 1955, p. 44, pl. 2, fig. 11.
Neobulimina albertensis (Stelck and Wall), Tappan, 1962, p. 184, pl. 48, figs. 3-6. Eicher, 1966, p. 26, pl. 5, figs. 5-8. Eicher and Worstell, 1970b, p. 290, pl. 4, figs. 2-4.
Bulimina wyomingensis Fox, 1954, p. 118, pl. 26, figs. 8-11.
Praebulimina wyomingensis (Fox), Eicher, 1965, p. 903, pl. 106, fig. 4. Eicher, 1967, p. 185, pl. 19, fig. 7.

Description. Test elongate, variably flaring, most of test triserial, with last two or three chambers loosely triserial or irregularly biserial; chambers inflated, globular, increasing in size slowly, closely packed at first, later becoming almost bulbous; sutures distinct, depressed; wall calcareous with finely roughened appearance; aperture an asymmetrical arch on one side of a depression in apertural face.

Remarks. Many specimens crushed, especially later chambers. Variable in size and degree of biseriality of later chambers.

Dimensions. Length, from about 0.15 mm to about 0.45 mm.

Occurrence. Widespread and locally common in the Hedbergella delrioensis zone in all Black Mesa sections. Previously reported in the Greenhorn and in the Fairport Member of the Carlile in many western interior localities.

Figure 17. Foraminiferida: Turrilinidae, Heterohelicidae, Planomalinidae

A-B. Neobulimina albertensis (Stelck and Wall): side views of two individuals. X75.

C-D. Guembelitria harrisi Tappan: C, side, and D, apertural view. X90.

E-F. Heterohelix globulosa (Ehrenberg): E, side, and F, apertural view. X75.

G-H. Heterohelix pulchra (Brotzen): side views of two individuals. X75.

I. Planoglobulina cf. P. glabrata (Cushman): side view. X75.

J-K. Lunatriella spinifera Eicher and Worstell: side view of two individuals. X90.

L-M. Globigerinelloides bentonensis (Morrow): L, side, and M, apertural view. X75.

Figure 17. Foraminiferida: Turrilinidae, Heterohelicidae, Planomalinidae

Genus Praebulimina Hofker, 1953
Praebulimina ovulum (Reuss)

Bulimina ovulum Reuss, 1844, p. 215. Reuss, 1845, p. 37, pl. 8, fig. 57, pl. 13, fig. 3 (non Bulimina ovula D'Orbigny).
Bulimina reussi Morrow, 1934, p. 195, pl. 29, fig. 12. Cushman, 1946, p. 120, pl. 51, figs. 1-5 (additional synonymy).
Bulimina reussi Morrow var. navarroensis Cushman and Parker, 1935, p. 100, pl. 15, fig. 11. Cushman, 1946, p. 121, pl. 51, fig. 6. Frizzell, 1954, p. 115, pl. 17, fig. 1 (additional synonymy). Mello, 1969, p. 75, pl. 9, fig. 1 (additional synonymy).
Bulimina reussi Morrow var. ovulum Reuss, Frizzell, 1954, p. 115, pl. 17, fig. 2 (additional synonymy).

Description. Test small, ovate, subglobular, nearly circular in transverse section, tapering rapidly to a sharply rounded initial end; chambers triserial throughout, slightly inflated, enlarging rapidly; sutures depressed, wall smooth; aperture small, subterminal.

Remarks. Differs from Neobulimina albertensis in that the test is triserial throughout, in its subglobular shape, and its smaller size.

Dimensions. Length, about 0.20 mm; breadth about 0.18 mm.

Occurrence. Found only in one sample in the Hedbergella delrioensis zone of the Kayenta section, represented by four specimens. Previously reported from many Upper Cretaceous localities in the Gulf Coast and throughout the world.

Family Discorbidae Ehrenberg, 1838
Subfamily Bagginінae Cushman, 1927
Genus Valvulineria Cushman, 1926
Valvulineria loetterlei (Tappan)

Gyroidina loetterlei Tappan, 1940, p. 120, pl. 19, fig. 10. Tappan, 1943, p. 512, pl. 82, fig. 9.
Valvulineria loetterlei (Tappan), Ten Dam and Schijfsma, 1944, p. 143. Tappan, 1962, p. 194, pl. 54, figs. 1-4. Eicher, 1966, p. 26, pl. 5, fig. 11 (additional synonymy). Eicher and Worstell, 1970b, p. 291, pl. 4, figs. 13, 14.

Description. Test small, thick, periphery rounded, gently convex dorsally, ventral umbilicus covered with flap; about seven chambers in final whorl, chambers gradually increasing in size; sutures flush, slightly curved dorsally, nearly straight ventrally; wall smooth, calcareous; aperture obscure.

Remarks. Specimens are somewhat corroded and coated with secondary material. None well enough preserved to illustrate.

Dimensions. Diameter, about 0.20 mm, and 0.10 mm thick.

Occurrence. A total of five specimens were found in two samples from the *Gaudryina bentonensis* zone at Blue Canyon. Previously reported from the Greenhorn and Carlile of the western interior and from Cretaceous strata of Texas, western Canada, and Alaska.

Family *Heterohelicidae* Cushman, 1927
Subfamily *Guembelitriinae* Montanaro-Gallitelli, 1957
Genus *Guembelitria* Cushman, 1933
Guembelitria harrisi Tappan
Figure 17C-D

Guembelitria harrisi Tappan, 1940, p. 115, pl. 19, fig. 2. Tappan, 1943, p. 507, pl. 81, figs. 13, 14. Frizzell, 1954, p. 110, pl. 15, fig. 46.
Guembelitria harrisi Tappan, Pessagno, 1967, p. 258, pl. 48, figs. 12, 13. Eicher and Worstell, 1970b, p. 296, pl. 8, figs. 1, 2.

Description. Test small, triserial throughout; chambers inflated, globular, increasing in size rapidly; sutures distinct, depressed; wall calcareous, perforate; aperture an interiomarginal arch at base of last chamber.

Remarks. Considered by Eicher (1969b, p. 167) and by Pessagno (1967, p. 258) to be typical of the "*Rotalipora*" Assemblage Zone (Cenomanian).

Dimensions. Length, about 0.12 mm.

Occurrence. Rare but widespread in the basal part of all Black Mesa sections except Howell Mesa. Previously reported from the lower part of the Greenhorn Formation in the western interior and from the Grayson Formation and Eagle Ford Group of the Gulf Coast, where it does not seem to occur above the Lozerian Substage of Pessagno.

Subfamily Heterohelicinae Cushman, 1927
Genus Heterohelix Ehrenberg, 1843
Heterohelix globulosa (Ehrenberg)
Figure 17E-F

Textularia globulosa Ehrenberg, 1840, p. 135, pl. 4, figs. 1B, 2B, 4B, 5B, 7B, 8B.
Gümbelina globulosa (Ehrenberg), Egger, 1900, p. 32, pl. 14, fig. 43. Cushman, 1946, p. 105, pl. 45, figs. 9-15 (additional synonymy). Frizzell, 1954, p. 109, pl. 15, figs. 24-27 (additional synonymy).
Heterohelix globulosa (Ehrenberg), Montanaro-Gallitelli, 1957, p. 137, pl. 31, figs. 12-15. Tappan, 1962, p. 196, pl. 55, figs. 1, 2 (additional synonymy). Eicher, 1965, p. 904, pl. 106, fig. 3. Eicher, 1966, p. 26, pl. 5, figs. 9, 10. Eicher, 1967, p. 185, pl. 19, fig. 11. Pessagno, 1967, p. 260, pl. 87, figs. 5-9 and 11-13 (additional synonymy). Mello, 1969, p. 70, pl. 8, fig. 5. Eicher and Worstell, 1970b, p. 296, pl. 8, figs. 3-6.

Description. Test biserial, tapering moderately to rapidly from pointed or broadly rounded base, greatest width at last pair of chambers; chambers globular, increasing in size fairly rapidly, four to seven pairs; sutures distinct, depressed; wall smooth, calcareous, finely perforate; aperture a low symmetrical arch at base of apertural face.

Remarks. Pessagno (1969, p. 260, and text fig. 3, p. 253) considers H. globulosa to be a Taylor-Navarro species and assigns similar species occurring in the Eagle Ford and Austin to H. moremani or H. reussi. Many other workers consider this species to be variable and long ranging, intergrading in characteristics with individuals which could reasonably be placed in H. moremani on the one hand and, through a tendency to multiply later chambers, into Planoglobulina on the other.

Most Black Mesa representatives are the more typical stubby forms usually assigned to H. globulosa and have been so designated, although considerable variation exists.

Dimensions. Specimens range in size from the very small individuals which would have passed through the 150-mesh screen (less than 105 microns), if not stuck to other foraminifera, to large ones about 0.50 mm in length.

Occurrence. Widespread and abundant throughout the Hedbergella delrioensis zone of all Black Mesa sections. An extremely widespread Cretaceous species.

Heterohelix pulchra (Brotzen)
Figure 17G-H

Gümbelina pulchra Brotzen, 1936, p. 121, pl. 9, figs. 2, 3.
Gümbelina tessera (Ehrenberg), Cushman, 1932b, p. 338, pl. 51, figs. 4, 5.
Gümbelina pseudotessera Cushman, 1938, p. 14, pl. 2, Figs. 19-21. Cushman, 1946, p. 106, pl. 45, figs. 16-20 (additional synonymy). Frizzell, 1954, p. 109, pl. 15, figs. 33, 34 (additional synonymy).
Heterohelix pulchra (Brotzen), Montanaro-Gallitelli, 1957, p. 137, pl. 31, fig. 20. Pessagno, 1967, p. 262, pl. 87, fig. 4. Eicher and Worstell, 1970a, p. 118, pl. 1, figs. 1-4. Eicher and Worstell, 1970b, p. 296, pl. 8, figs. 9, 10.

Description. Test biserial, compressed, about twice as long as broad, rapidly tapering, with greatest width at last pair of chambers; chambers inflated, increasing in size rapidly, late chambers reniform; sutures distinct, curved, depressed; wall smooth, calcareous; aperture a symmetrical arch with lateral flaps.

Remarks. This species is variable, grading from individuals with nearly globular chambers resembling small H. globulosa with only a tendency toward reniform shape of last chambers to individuals with most chambers reniform.

Dimensions. Smaller than H. globulosa; length from 0.15 mm to about 0.30 mm.

Occurrence. Locally common in the upper part of the Hedbergella delrioensis zone of all Black Mesa section. In the Gulf Coast, Pessagno (1967, p. 262) considers this species to be restricted to the Taylor and Navarro (Campanian-Maestrichtian), but it is considered to appear in the Turonian in the western interior (Eicher, 1969b, p. 167; Eicher and Worstell, 1970b, p. 296).

Genus Lunatriella Eicher and Worstell, 1970
Lunatriella spinifera Eicher and Worstell
Figure 17J-K

Lunatriella spinifera Eicher and Worstell, 1970a, p. 118, pl. 1, figs. 5-17. Eicher and Worstell, 1970b, p. 296, pl. 8, figs. 7, 8, 12.

Description. Test elongate, compressed, initial biserial portion consisting of up to four pairs of subglobular chambers, later chambers becoming elongate vertically with curved axes convex outward, final chambers may become irregularly uniserial; last chamber or two chambers may bear a large spinelike elongation which protrudes at a variable angle; sutures distinct, depressed; aperture a high arch bounded by lateral lips, which may join below aperture into a troughlike flange; wall calcareous.

Remarks. Many specimens not well preserved and have secondary material deposited in the sutures and apertures. This is a newly described species from strata of lower and middle Turonian age from Kansas, Colorado, and South Dakota (Eicher and Worstell, 1970a). Its presence in the Mancos Shale of Black Mesa extends its known geographic occurrence to northeastern Arizona.

Dimensions. Length, from about 0.20 mm to 0.35 mm.

Occurrence. Rare in Black Mesa material, being found only in the upper part of the Hedbergella delrioensis zone at Lohali Point.

Genus Planoglobulina Cushman, 1927
Planoglobulina cf. P. glabrata (Cushman)
Figure 17I

Ventilabrella eggeri var. glabrata Cushman, 1938, p. 26, pl. 4, figs. 15-17. Cushman, 1946, p. 111, pl. 47, figs. 20-22. Frizzell, 1954, p. 111, pl. 16, figs. 11, 12.
Ventilabrella eggeri Cushman, 1946, p. 111, pl. 47, figs. 17-19 (additional synonymy).
Ventilabrella eggeri Cushman var. eggeri Cushman, Frizzell, 1954, p. 111, pl. 16, fig. 10 (additional synonymy).
Planoglobulina glabrata (Cushman), Montanaro-Gallitelli, 1957, p. 141, pl. 32, figs. 10-12. Pessagno, 1967, p. 272, pl. 88, figs. 12, 13, 17 (additional synonymy).

Description. Test short and broad, flabelliform, early portion biserial, later chambers proliferate in plane of biseriality; chambers globular, increasing gradually in size; sutures depressed; wall calcareous, smooth; aperture multiple, obscure.

Remarks. The species designation is somewhat uncertain because of dearth of material. Specimens at hand seem to lack the longitudinal costae which ornament most P. glabrata. The material found in the Black Mesa Mancos may possibly be what Cushman (1946, p. 111) referred to P. austiniana Cushman.

Dimensions. Length, about 0.20 mm.

Occurrence. Rare in Black Mesa Mancos but occurs sporadically in the Hedbergella delrioensis zone of all sections except Blue Canyon.

Family Planomalinidae Bolli, Loeblich, and Tappan, 1957
Genus Globigerinelloides Cushman and Ten Dam, 1948
Globigerinelloides bentonensis (Morrow)
Figure 17L-M

Anomalina bentonensis Morrow, 1934, p. 201, pl. 30, fig. 4. Cushman, 1946, p. 154, pl. 63, fig. 7.
Globigerinelloides bentonensis (Morrow), Loeblich and Tappan, 1961, p. 267, pl. 2, figs. 8-10 (additional synonymy). Eicher, 1965, p. 904, pl. 106, fig. 10. Pessagno, 1967, p. 275, pl. 76, fig. 10, 11. Eicher and Worstell, 1970b, p. 297, pl. 8, figs. 17, 19, pl. 9, fig. 3.

Description. Test planispiral, involute to partly evolute, bi-umbilicate, six to eight chambers in final whorl, chambers increasing gradually in size, peripheral outline lobate; sutures distinct, radial, nearly straight; wall calcareous, finely perforate; aperture a broad, low, interiomarginal equatorial arch with narrow lip, lateral portions of previous apertures remaining uncovered by later chambers, so that relict supplementary apertures are preserved around umbilical region.

Dimensions. Greatest diameter, from about 0.25 mm to about 0.40 mm.

Occurrence. Rare in Black Mesa, only found in the lower part of the Hedbergella delrionensis zone at Lohali Point. This species is considered to be limited to the Cenomanian by Loeblich and Tappan (1961, p. 267), Eicher (1967, p. 167), Pessagno (1967, p. 275), and Bandy (1967, p. 12).

Family Rotaliporidae Sigal, 1958
Subfamily Hedbergellinae Loeblich and Tappan, 1961
Genus Hedbergella Bronniman and Brown, 1958
Hedbergella delrioensis (Carsey)
Figure 18A-C

Globigerina cretacea D'Orbigny var. delrioensis Carsey, 1926, p. 43.
Globigerina delrioensis Carsey, Frizzell, 1954, p. 127, pl. 20, fig. 1 (additional synonymy).
Hedbergella delrioensis (Carsey), Loeblich and Tappan, 1961, p. 275, pl. 2, figs. 11-13 (additional synonymy). Eicher, 1965, p. 904, pl. 106, figs. 2, 6. Eicher, 1966, p. 27, pl. 5, fig. 12. Eicher, 1967, p. 186, pl. 19, fig. 6. Pessagno, 1967, p. 282, pl. 48, figs. 1-5 (additional synonymy). Eicher and Worstell, 1970b, p. 302, pl. 9, figs. 10, 11.

Description. Test trochospiral, low, about two whorls, early whorl slightly raised to slightly depressed below final whorl on spiral side, ventral side umbilicate, peripheral outline lobate; chambers inflated, spherical, increasing rapidly in size, four to six in final whorl, most commonly five; sutures distinct, nearly straight; wall calcareous, perforate, with no keel or poreless margin; aperture an arch, interiomarginal and extraumbilical-umbilical in position, covered with spatulate flap.

Remarks. Individuals placed in this species show considerable variation, and many possibly should be referred to H. amabilis, whose diagnostic characteristics intergrade with those of H. delrioensis. Those individuals developing higher spires intergrade with H. portsdownensis.

Dimensions. Greatest diameter, from about 0.20 to 0.60 mm.

Occurrence. Abundant and widespread in the Hedbergella delrioensis zone of Black Mesa Mancos, where it was chosen as namebearer for the zone. A widespread and long-ranging Cretaceous species.

Figure 18. Foraminiferida: Rotaliporidae: Hedbergella, Clavihedbergella

A-C. Hedbergella delrioensis (Carsey): A, dorsal, B, edge, and C, ventral views. X85.

D-F. Hedbergella portsdownensis (Williams-Mitchell): A, dorsal, B, edge, C, ventral views. X85.

G. Clavihedbergella moremani (Cushman): dorsal view. X85.

H-J. Clavihedbergella simplex (Morrow): H, dorsal, I, edge, and J, ventral views. X85

Figure 18. Foraminiferida: Rotaliporidae: Hedbergella, Clavihedbergella

Hedbergella portsdownensis (Williams-Mitchell)
Figure 18D-F

Globigerina portsdownensis Williams-Mitchell, 1948, p. 96, pl. 8, Fig. 4.
Hedbergella brittonensis Loeblich and Tappan, 1961, p. 274, pl. 4, figs. 1-8. Pessagno, 1967, p. 282, pl. 52, figs. 9-12 (additional synonymy).
Hedbergella portsdownensis (Williams-Mitchell). Loeblich and Tappan, 1961, p. 277, pl. 5, fig. 3. Eicher and Worstell, 1970b, p. 304, pl. 10, figs. 1, 2.

Description. Test trochospiral, medium to high, two to three whorls, all visible on spiral side, only five to six chambers visible on umbilical side surrounding wide and deep umbilicus; chambers increasing in size gradually; sutures distinct, depressed; wall calcareous, perforate; aperture an arch opening into umbilicus, covered with flap.

Remarks. Because of the marked similarity of H. brittonensis to H. portsdownensis, most workers think that H. brittonensis is a junior synonym. Individuals with lower spires intergrade in characteristics with H. delrionensis.

Dimensions. Greatest diameter, from about 0.25 mm to 0.50 mm.

Occurrence. Common to abundant and widespread in the Hedbergella delrioensis zone of the Black Mesa Mancos. A widespread and long-ranging Cretaceous species.

Genus Clavihedbergella Banner and Blow, 1959
Clavihedbergella moremani (Cushman)
Figure 18G

Hastigerinella moremani Cushman, 1931 (part), p. 86, pl. 11, figs. 1a-c (not figs. 2, 3). Cushman, 1946 (part), p. 147, pl. 61, figs. 1a-c (not figs. 2, 3). Frizzell, 1954 (part), p. 127, pl. 20, fig. 11 (not fig. 12).
Clavihedbergella moremani (Cushman), Loeblich and Tappan, 1961, p. 279, pl. 5, figs. 12-16. Pessagno, 1967, p. 285, pl. 53, figs. 1, 2. Eicher and Worstell, 1970b, p. 304, pl. 10, fig. 5.

Description. Test trochospiral, low, early portion with globular chambers, about four or five per whorl, later chambers becoming elongate to clavate with final chamber greatly elongate with bulbous termination; sutures distinct, depressed; wall calcareous, perforate; aperture an interiomarginal arch with lip, umbilical to peripheral in position.

Remarks. Delicate and easily broken, especially the elongate last chamber.

Dimensions. Greatest diameter, to about 0.50 mm.

Occurrence. Rare to locally common in the Hedbergella delrioensis zone of Longhouse Valley and Lohali Point sections in Black Mesa. A somewhat uncommon but widely distributed upper Cenomanian-Turonian form.

Clavihedbergella simplex (Morrow)
Figure 18H-J

Hastigerinella simplex Morrow, 1934, p. 198, pl. 30, fig. 6. Cushman, 1946, p. 148, pl. 61, fig. 10. Frizzell, 1954, p. 127, pl. 20, fig. 13.
Clavihedbergella simplex (Morrow), Loeblich and Tappan, 1961, p. 279, pl. 3, figs. 11-14 (additional synonymy). Pessagno, 1967, p. 285, pl. 52, figs. 1, 2 (additional synonymy). Eicher and Worstell, 1970b, p. 308, pl. 10, figs. 4, 6, 7.

Description. Test trochospiral, low, early portion with about five globular chambers, final whorl with about four to six chambers, the last one to three being radially elongate to subclavate; sutures distinct, depressed; wall calcareous, finely perforate; aperture an interiomarginal arch from periphery to umbilicus, with narrow lip.

Remarks. Stouter and less clavate chambers than C. moremani, and no bulbous termination of final chamber.

Dimensions. Greatest diameter from about 0.15 mm to 0.55 mm.

Occurrence. Relatively common in the Hedbergella delrioensis zone of the Black Mesa Mancos. A fairly common and widely spread Cenomanian-Turonian planktonic form.

Clavihedbergella subdigitata (Carman)
Figure 19A-C

Globigerina subdigitata Carman, 1929, p. 315, pl. 34, figs. 4, 5.
Clavihedbergella simplex (Morrow). Eicher, 1966, p. 27, pl. 6, fig. 3.
Clavihedbergella subdigitata (Carman). Eicher and Worstell, 1970b, p. 306, pl. 10, figs. 3, 4.

Description. Test trochospiral, low, early portion with about five globular chambers, the last two or three becoming tangentially elongate to subclavate; sutures distinct, depressed; wall calcareous, finely perforate; aperture an interiomarginal arch from periphery to umbilicus, with lip.

Remarks. This species has previously been included in C. simplex by most workers. Eicher (1969b, p. 168) and Eicher and Worstell (1970b, p. 306) have recently separated the two species on the basis of the tangential versus radial alignment of the clavate later chambers, and the belief that they are derived from a different lineage. Douglas (1969, p. 163) has noted similar differences in California specimens. Eicher's usage has been followed in this study, as there seems to be a

Figure 19. Foraminiferida: Rotaliporidae: Clavihedbergella, Praeglobotruncana, Rotalipora

A-C. Clavihedbergella subdigitata (Carman): A, dorsal, B, edge, and C, ventral views. X85.

D-F. Praeglobotruncana difformis (Gandolfi): E, dorsal view; D and F edge views showing double keel. X85.

G-I. Rotalipora greenhornensis (Morrow): A, dorsal, B, edge, and C, ventral views; ventral side plugged. X85.

Figure 19. Foraminiferida: Rotaliporidae: Clavihedbergella, Praeglobotruncana, Rotalipora

stratigraphic significance, with C. subdigitata appearing somewhat higher in section than C. simplex.

Dimensions. Greatest diameter from about 0.20 mm to 0.45 mm.

Occurrence. Locally common in the upper portion of the Hedbergella delrioensis zone in all sections at Black Mesa.

Genus Praeglobotruncana Bermudez, 1952

Praeglobotruncana stephani (Gandolfi)

Globotruncana stephani Gandolfi, 1942, p. 130, pl. 3, figs. 4, 5, pl. 4, figs. 36, 37, 41, 45, pl. 6, figs. 4, 6, pl. 9, figs. 5, 8, pl. 13, fig. 5, pl. 14, fig. 2.

Praeglobotruncana stephani (Gandolfi). Bolli, Loeblich, and Tappan, 1957, p. 39, pl. 9, fig. 2. Loeblich and Tappan, 1961, p. 284, pl. 6, figs. 1-8 (additional synonymy). Eicher, 1966, p. 28, pl. 6, fig. 4. Pessagno, 1967, p. 287, pl. 50, figs. 9-11 (additional synonymy). Eicher and Worstell, 1970b, p. 308, pl. 10, fig. 9, pl. 11, figs. 2a-c, 3.

Description. Test trochospiral, convex; all chambers of two to three whorls visible on spiral side, five to six chambers visible on umbilical side; early chambers subround, later chambers becoming subangular, umbilicus narrow; sutures distinct, depressed, radial on umbilical side, curved backward on spiral side; wall calcareous, with a beaded single keel bordering early whorls, less distinct in last two or three chambers; aperture interiomarginal from umbilicus to halfway up to periphery, with lip.

Remarks. Considerable variability in spire height and degree of lobateness in outline. The few specimens at hand were plugged with foreign material, and none were sufficiently well preserved to illustrate.

Dimensions. Greatest diameter about 0.45 mm.

Occurrence. Rare in lower part of the Hedbergella delrioensis zone in the Lohali Point section, with Rotalipora greenhornensis and

Globigerinelloides bentonensis. The temporal range of this species is considered to terminate at the top of the Cenomanian.

Praeglobotruncana difformis (Gandolfi)
Figure 19D-F

Rosalina marginata Reuss, 1845, p. 36, pl. 13, fig. 68.
Globotruncana marginata (Reuss). Cushman, 1946, p. 150, pl. 62, figs. 1, 2 (additional synonymy).
Globotruncana (Globotruncana) intermedia Bolli subsp. difformis Gandolfi, 1955, p. 49, pl. 3, figs. 4, 5.
Globotruncana marginata (Reuss). Eicher, 1966, p. 29, pl. 6, figs. 5, 6 (additional synonymy).
Praeglobotruncana renzi (Thalmann). Eicher, 1966, p. 28, pl. 6, fig. 9 (additional synonymy). Douglas, 1969, p. 172, pl. 2, fig. 8 (additional synonymy).
Marginotruncana marginata (Reuss). Pessagno, 1967, p. 307, pl. 54, figs. 7-12, 16-18, pl. 56, figs. 10-12, pl. 99, figs. 5-7 (additional synonymy).
Praeglobotruncana difformis (Gandolfi). Eicher and Worstell, 1970b, p. 308, pl. 11, figs. 4, 5, 6.

Description. Test trochospiral, dorsally slightly to moderately convex, ventrally umbilicate, composed of up to three whorls with four to six chambers in final whorl, two closely spaced peripheral keels rimming the entire periphery, sometimes becoming less distinct in the final chamber; chambers moderately flattened dorsally, inflated ventrally; sutures curved, raised and beaded dorsally, depressed and radial ventrally; umbilicus wide and shallow; wall calcareous, perforate; aperture apparently extraumbilical-umbilical in position, plugged in all Black Mesa specimens.

Remarks. This distinctive species is regarded by most workers as having a wide geographic distribution and being restricted in time to the Turonian or some portion of it. Unfortunately, considerable taxonomic confusion surrounds this species, and its nomenclature is presently in a state of flux. The species has been previously, and is currently, referred to by different authors as Globotruncana marginata (Reuss), Praeglobotruncana marginata (Reuss), Praeglobotruncana renzi (Thalmann), Praeglobotruncana algeriana Caron, Globotruncana intermedia difformis Gandolfi, Marginotruncana marginata (Reuss), and Praeglobotruncana difformis (Gandolfi). An adequate treatment of the evolution of this nomenclatural tangle is beyond the scope of this investigation, and those interested are referred to discussions by Eicher (1966, p. 28-29; 1969b, p. 169), Douglas (1969, p. 172), Pessagno (1967, p. 306-310, and footnote, p. 306), and Eicher and Worstell (1970b, p. 308). In this study, the species is tentatively referred to Praeglobotruncana difformis (Gandolfi), following the usage of Eicher (1969b) and Eicher and Worstell (1970b).

Dimensions. Greatest diameter from about 0.40 mm to 0.60 mm.

Occurrence. Generally rare in the Black Mesa Mancos but occurs sparsely in the upper part of the Hedbergella delrioensis zone in the Howell Mesa, Blue Canyon, and Kayenta sections. Previously reported from Turonian strata of the western interior and Gulf Coast of the United States, Mexico, South America, and Europe.

Subfamily Rotaliporinae Sigal, 1958
Genus Rotalipora Brotzen, 1942
Rotalipora greenhornensis (Morrow)
Figure 19G-I

Globorotalia greenhornensis Morrow, 1934, p. 199, pl. 31, no. 1.
Planulina greenhornensis (Morrow). Cushman, 1946, p. 159, pl. 65, fig. 3.
Rotalipora greenhornensis (Morrow). Loeblich and Tappan, 1961, p. 299, pl. 7, figs. 5-10 (additional synonymy). Eicher, 1965, p. 906, pl. 106, fig. 11. Pessagno, 1967, p. 295, pl. 50, figs. 3, 4 (additional synonymy). Eicher and Worstell, 1970b, p. 312, pl. 12, fig. 2, pl. 13, fig. 3.

Description. Test trochospiral, biconvex, approximately two whorls, prominent peripheral keel, ventral side umbilicate; chambers nearly flat dorsally, inflated ventrally, about six in last whorl; sutures distinct, elevated curved and oblique dorsally, depressed to nearly flush ventrally; wall calcareous, finely perforate, surface rough on early chambers, smooth on later ones; primary aperture interiomarginal, extra-umbilical-umbilical in position, sutural secondary apertures arched with bordering lip, just beneath umbilical shoulder.

Remarks. Except for plugged umbilical sides, the specimens found in Black Mesa are fairly well preserved and recognizable, although smaller than some reference specimens from the Greenhorn of Colorado which were kindly furnished by D. L. Eicher.

Dimensions. Greatest diameter about 0.30 mm to 0.45 mm.

Occurrence. Generally rare in the Black Mesa Mancos. Found only in the lower part of the Hedbergella delrioensis zone at Lohali Point. This species is considered by most workers to be a distinctive, worldwide Cenomanian marker.

Family Caucasinidae N. K. Bykova, 1959
Subfamily Fursenkoininae Loeblich and Tappan, 1961
Genus Coryphostoma Loeblich and Tappan, 1962
Coryphostoma plaita (Carsey)
Figure 20A-B

Bolivina plaita Carsey, 1926, p. 26, pl. 4, fig. 2.
Loxostomum plaitum (Carsey). Cushman, 1946, p. 130, pl. 54, figs. 10-14 (additional synonymy).
Loxostomum plaitum var. plaitum (Carsey). Frizzel, 1954, p. 118, pl. 17, fig. 38 (additional synonymy).
Coryphostoma plaita (Carsey). Loeblich and Tappan, 1962, p. 111. Loeblich, Tappan, and others, 1964, p. C732-C733, pl. 600, figs. 8, 9.
Loxostoma plaita (Carsey). Mello, 1969, p. 82, pl. 9, figs. 9, 10.

Description. Test elongate, narrow, biserial throughout, three to four times as long as broad, compressed, rounded in section, slightly twisted to straight, later chambers tend to become uniserial; chambers numerous, slightly inflated, sutures depressed, curved toward proximal end; wall calcareous, finely perforate; aperture terminal, loop shaped, obscure in most specimens.

Remarks. The test is typically twisted and thus shows affinities to Cassidella, although there is no observable triserial stage. A certain amount of confusion exists in the literature regarding the taxonomic status of Cassidella, Coryphostoma, and Loxostomum, as has recently been pointed out by Kent (1967, p. 1450), and by Eicher and Worstell (1970b, p. 292). The specimens at hand are referred to Coryphostoma because they most closely resemble illustrations in the literature which depict Loxostomum plaitum (Carsey), and because Loeblich and Tappan (1962) used Bolivina (= Loxostomum) plaita Carsey as their genotype for Coryphostoma.

Dimensions. Length, from about 0.15 mm to 0.40 mm, mostly around 0.20 mm.

Figure 20. Foraminiferida: Caucasinidae, Anomalinidae

A-B. *Coryphostoma plaita* (Carsey): side views of two individuals. X75.

C-E. *Gavelinella dakotensis* (Fox): C, dorsal, D, edge, E, ventral views. X75.

Figure 20. Foraminiferida: Caucasinidae, Anomalinidae

Occurrence. Locally common in the Hedbergella delrioensis zone of all Black Mesa sections.

Family Anomalinidae Cushman, 1927
Subfamily Anomalininae Cushman, 1927
Genus Gavelinella Brotzen, 1942
Gavelinella dakotensis (Fox)
Figure 20D-F

Planulina dakotensis Fox, 1954, p. 119, pl. 26, figs. 19-21.
Gavelinella dakotensis (Fox). Eicher, 1966, p. 30, pl. 6, no. 7.
Eicher and Worstell, 1970b, p. 293, pl. 5, figs. 5, 6.

Description. Test small, compressed, spiral side evolute, ventral side nearly involute with small portion of preceding whorls showing in the center, periphery narrowly rounded, later chambers of many specimens lobate; chambers distinct, increasing in size gradually, eight to ten in final whorl; sutures distinct, gently curved, gently depressed, in some specimens limbate in early spiral-side chambers; wall calcareous, smooth, perforate; aperture a low peripheral slit extending from periphery to umbilical side.

Remarks. Variable in outline, the smaller individuals tending to be nearly circular and the larger ones more lobate.

Dimensions. Greatest diameter from about 0.12 mm to 0.35 mm.

Occurrence. One of the most widespread and frequently occurring species in the Black Mesa material. Common through the Hedbergella delrioensis zone in all sections. Also reported in abundance through the upper Greenhorn and the Fairport Member of the Carlile.

Genus Lingulogavelinella Malapris, 1965

Lingulogavelinella asterigerinoides (Plummer)

Valvulineria asterigerinoides Plummer, 1931, p. 190, pl. 14, no. 6. Tappan, 1940, p. 120, pl. 19, fig. 9. Tappan, 1943, p. 511, pl. 82, figs. 10, 11. Frizzel, 1954, p. 123, pl 18, fig. 34.
Lingulogavelinella asterigerinoides (Plummer). Eicher and Worstell, 1970b, p. 293, pl. 7, figs. 2, 4.

Description. Test planotrochospiral, but spire depressed, partly evolute, periphery rounded, outline slightly lobate, oral side nearly flat; chambers inflated, seven or eight in final whorl; sutures depressed, slightly curved on spiral side, sinuous on oral side and grooved where not covered by flaps; wall calcareous, perforate; aperture a peripheral arch opening into slit that extends partway around umbilicus under flaps.

Remarks. Most specimens are broken, none well enough preserved to illustrate.

Dimensions. Greatest diameter about 0.30 mm.

Occurrence. Very rare in Black Mesa, a total of three specimens were found in the basal part of the Hedbergella delrioensis zone at Longhouse Valley.

APPENDIX I

CONTENTS OF FAUNAL ASSEMBLAGE SLIDES

Numbers to the right of species name refer to numbers of individuals of that species on the slide for that particular sample.

P:B stands for planktonic to benthonic ratio, determined by actual count of the first 100 foraminifera encountered.

Location for slide numbers:

Howell Mesa	HM1-HM35
Blue Canyon	BC1-BC66
Longhouse Valley	LHV1-LHV64
Kayenta	K1-K54
Lohali Point	LP1-LP43

Howell Mesa

HM-1	Top of Dakota(?) Sandstone		
	Barren. No microfossils.		
HM-2	11.2 feet above Dakota(?)	P:B 1/5	
	Cythereis eaglefordensis Alexander		7
	Hedbergella delrioensis (Carsey)		4
	Citharina kochii (Roemer)		5
	Dentalina gracilis D'Orbigny		4
	Gavelinella dakotensis (Fox)		3
	Nodosaria bighornensis Young		4
	Haplophragmoides collyra Nauss		1
	Reophax inordinatus Young		1
	Saccammina alexanderi (Loeblich and Tappan)		1
	Miscellaneous--shark scale, glauconite		
HM-3	16.8 feet above Dakota(?)	P:B 2	
	Cythereis eaglefordensis Alexander		3
	Hedbergella delrioensis (Carsey)		10
	Hedbergella portsdownensis (Williams-Mitchell)		2
	Dentalina gracilis D'Orbigny		1
	Quinquiloculina moremani Cushman		1
	Reophax sp. cf. R. recta (Beissel)		1
	Haplophragmoides collyra Nauss		3
HM-4	95 feet above Dakota(?)	P:B 7/10	
	Hedbergella delrioensis (Carsey)		28
	Heterohelix globulosa (Ehrenberg)		1
	Dentalina gracilis D'Orbigny		6
	Frondicularia imbricata Young		1
	Gavelinella dakotensis (Fox)		11
	Reophax sp. cf. R. recta (Beissel)		1
	Trochammina wickendeni Loeblich		21
	Miscellaneous--simple tooth, bone fragments		
HM-5	100.8 feet above Dakota(?)	P:B 1/2	
	Hedbergella delrioensis (Carsey)		25
	Hedbergella portsdownensis (Williams-Mitchell)		2
	Clavihedbergella simplex (Morrow)		3
	Heterohelix globulosa (Ehrenberg)		3
	Dentalina gracilis D'Orbigny		13
	Gavelinella dakotensis (Fox)		13
	Neobulimina albertensis (Stelck and Wall)		1
	Reophax sp. cf. R. recta (Beissel)		10
	Trochammina wickendeni Loeblich		15
	Saccammina alexanderi (Loeblich and Tappan)		5

HM-6	112.0 feet above Dakota(?)	P:B 2	
	Hedbergella delrioensis (Carsey)		16
	Hedbergella portsdownensis (Williams-Mitchell)		5
	Clavihedbergella simplex (Morrow)		10
	Heterohelix globulosa (Ehrenberg)		7
	Planoglobulina sp. cf. P. glabrata (Cushman)		1
	Dentalina gracilis D'Orbigny		1
	Gavelinella dakotensis (Fox)		16
	Frondicularia imbricata Young		1
	Coryphostoma plaita (Carsey)		4
	Neobulimina albertensis (Stelck and Wall)		3
	Reophax sp. cf. R. recta (Beissel)		3
	Trochammina wickendeni Loeblich		8
	Haplophragmoides collyra Nauss		1
	Saccammina alexanderi (Loeblich and Tappan)		5
HM-7	123.2 feet above Dakota(?)	P:B 19	
	Hedbergella delrioensis (Carsey)		16
	Hedbergella portsdownensis (Williams-Mitchell)		5
	Clavihedbergella simplex (Morrow)		7
	Heterohelix globulosa (Ehrenberg)		5
	Heterohelix pulchra (Brotzen)		3
	Citharina kochii (Roemer)		6
	Frondicularia imbricata Young		5
	Gavelinella dakotensis (Fox)		9
	Dentalina gracilis D'Orbigny		1
	Coryphostoma plaita (Carsey)		3
	Neobulimina albertensis (Stelck and Wall)		3
	Reophax sp. cf. R. recta (Beissel)		1
	Ammomarginulina carlilensis Lamb		2
	Haplophragmium arenatum Lamb		2
	Saccammina alexanderi (Loeblich and Tappan)		4
	Reophax inordinatus Young		1
HM-8	162.4 feet above Dakota(?)	P:B 32	
	Hedbergella delrioensis (Carsey)		17
	Hedbergella portsdownensis (Williams-Mitchell)		14
	Clavihedbergella simplex (Morrow)		4
	Heterohelix globulosa (Ehrenberg)		4
	Heterohelix pulchra (Brotzen)		2
	Dentalina gracilis D'Orbigny		3
	Frondicularia imbricata Young		2
	Gavelinella dakotensis (Fox)		6
	Neobulimina albertensis (Stelck and Wall)		4
	Nodosaria bighornensis Young		1
	Coscinophragma ? cf. C. codyensis (Fox)		7
	Saccammina alexanderi (Loeblich and Tappan)		8
	Trochammina wickendeni Loeblich		5

HM-9 173.6 feet above Dakota(?) P:B 5

Hedbergella delrioensis (Carsey)	19
Hedbergella portsdownensis (Williams-Mitchell)	7
Heterohelix globulosa (Ehrenberg)	1
Dentalina gracilis D'Orbigny	2
Frondicularia imbricata Young	2
Gavelinella dakotensis (Fox)	1
Nodosaria bighornensis Young	3
Marginulinopsis amplaspira Young	6
Ammomarginulina carlilensis Lamb	6
Haplophragmium arenatum Lamb	3
Coscinophragma ? cf. _C. codyensis_ (Fox)	2
Trochammina wickendeni Loeblich	9
Saccammina alexanderi (Loeblich and Tappan)	6

HM-10 184.8 feet above Dakota(?) P:B over 100

Hedbergella delrioensis (Carsey)	24
Hedbergella portsdownensis (Williams-Mitchell)	14
Clavihedbergella simplex (Morrow)	6
Clavihedbergella subdigitata (Carman)	3
Heterohelix globulosa (Ehrenberg)	8
Heterohelix pulchra (Brotzen)	2
Planoglobulina sp. cf. _P. glabrata_ (Cushman)	1
Gavelinella dakotensis (Fox)	2
Marginulinopsis amplaspira Young	1
Reophax sp. cf. _R. recta_ (Beissel)	1
Trochammina wickendeni Loeblich	3
Saccammina alexanderi (Loeblich and Tappan)	5

HM-11 196.0 feet above Dakota(?) P:B 32

Hedbergella delrioensis (Carsey)	17
Hedbergella portsdownensis (Williams-Mitchell)	11
Clavihedbergella simplex (Morrow)	3
Clavihedbergella subdigitata (Carman)	7
Praeglobotruncana difformis (Gandolfi) (=_P. marginata_ (Reuss))	2
Heterohelix globulosa (Ehrenberg)	6
Heterohelix pulchra (Brotzen)	6
Gavelinella dakotensis (Fox)	7
Neobulimina albertensis (Stelck and Wall)	2
Marginulinopsis amplaspira Young	6
Trochammina wickendeni Loeblich	4
Saccammina alexanderi (Loeblich and Tappan)	2

HM-12 207.2 feet above Dakota(?) P:B 9

Hedbergella delrioensis (Carsey)	23
Hedbergella portsdownensis (Williams-Mitchell)	19
Clavihedbergella simplex (Morrow)	1

HM-12--*Continued*

Heterohelix globulosa (Ehrenberg)		7
Heterohelix pulchra (Brotzen)		1
Gavelinella dakotensis (Fox)		4
Coryphostoma plaita (Carsey)		2
Neobulimina albertensis (Stelck and Wall)		5
Nodosaria bighornensis Young		1
Trochammina wickendeni Loeblich		7

HM-13 218.4 feet above Dakota(?) P:B 1.5/1

Hedbergella delrioensis (Carsey)		33
Hedbergella portsdownensis (Williams-Mitchell)		12
Gavelinella dakotensis (Fox)		8
Marginulinopsis amplaspira Young		6
Haplophragmoides collyra Nauss		3
Trochammina wickendeni Loeblich		5

HM-14 229.6 feet above Dakota(?) P:B 1/5

Hedbergella delrioensis (Carsey)		8
Hedbergella portsdownensis (Williams-Mitchell)		2
Gavelinella dakotensis (Fox)		10
Reophax cf. *R. recta* (Beissel)		3
Haplophragmoides collyra Nauss		1
Haplophragmoides cf. *H. howardense* (Stelck and Wall)		1
Trochammina wickendeni Loeblich		32

HM-15 240.8 feet above Dakota(?) P:B --

Reophax recta (Beissel)		24
Trochammina wickendeni Loeblich		15
Trochammina wetteri Stelck and Wall		3
Saccammina alexanderi (Loeblich and Tappan)		10

HM-16 252.0 feet above Dakota(?)

Hedbergella delrioensis (Carsey)	weathered	2
Trochammina wickendeni Loeblich		8

HM-17 263.2 feet above Dakota(?)

Hedbergella delrioensis (Carsey)	weathered	2
Reophax recta (Beissel)		8
Trochammina wickendeni Loeblich		28
Miscellaneous--fish(?) scale, bone fragments		

HM-18	274.4 feet above Dakota(?)		
		Haplophragmoides cf. H. collyra Nauss	8
		Reophax recta (Beissel)	20
		Trochammina wickendeni Loeblich	32
		Saccammina alexanderi (Loeblich and Tappan)	3
HM-19	285.6 feet above Dakota(?)		
		Hedbergella delrioensis (Carsey), weathered, broken, and corroded	6
HM-20	296.8 feet above Dakota(?)		
		Hedbergella delrioensis (Carsey), badly weathered	5
		Miscellaneous--weathered shell hash and bone	
HM-21	308.0 feet above Dakota(?)		
		Gavelinella dakotensis (Fox)	4
		Trochammina wickendeni Loeblich	34
HM-22	319.2 feet above Dakota(?)		
		Barren--miscellaneous weathered shell and bone fragments	
HM-23	347.2 feet above Dakota(?)		
		Barren	
HM-24	364.0 feet above Dakota(?)		
		Barren	
HM-25	375.2 feet above Dakota(?)		
		Barren	
HM-26	386.4 feet above Dakota(?)		
		Barren	
HM-27	397.6 feet above Dakota(?)		
		Trochammina wickendeni Loeblich	19
		Megaspores, species A	7
		Miscellaneous--internal gastropod molds, fish(?) scale, bone fragments	

HM-28	408.8 feet above Dakota(?)	
	Megaspores, species A	20
	Megaspores, species B	9
	Miscellaneous--internal gastropod molds	
HM-29	420 feet above Dakota(?)	
	Haplophragmoides cf. *H. gilberti* Eicher	1
	Trochammina wickendeni Loeblich	11
	Megaspores, species A	11
	Megaspores, species B	7
HM-30	431.2 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	15
	Ammonbaculites impexus Eicher	1
	Trochammina cf. *T. wetteri* Stelck and Wall	4
	Trochammina wickendeni Loeblich	18
	Megaspores, species A	1
HM-31	442.4 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	2
	Trochammina wickendeni Loeblich	10
HM-32	453.6 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	1
	Trochammina wickendeni Loeblich	31
HM-33	464.8 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	30
	Trochammina wickendeni Loeblich	20
HM-34	476.0 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	1
HM-35	477.6 feet above Dakota(?). Base of Toreva Sandstone.	
	Barren	

Blue Canyon

BC-1 Top of Dakota(?) Sandstone

Barren

BC-2 5.6 feet above Dakota(?)

Barren

BC-3 9.8 feet above Dakota(?)

Barren

BC-4 15.4 feet above Dakota(?) P:B 1/25

Cytherelloidea ozanana Sexton (RV, Male)	1
Hedbergella delrioensis (Carsey)	2
Dentalina gracilis D'Orbigny	5
Frondicularia imbricata Young	7
Lenticulina cf. L. gaultina (Berthelin)	5
Reophax recta (Beissel)	5
Reophax inordinatus Young	3
Haplophragmoides cf. H. gilberti Eicher	8
Trochammina wickendeni Loeblich	17
Saccammina alexanderi (Loeblich and Tappan)	4
Miscellaneous--coprolites, bone fragments, glauconite	

BC-5 21.0 feet above Dakota(?) P:B 1/4

Hedbergella delrioensis (Carsey), weathered	17
Reophax cf. R. minuta Tappan	48
Coscinophragma? codyensis (Fox)	10
Haplophragmoides cf. H. hendersonense (Stelck Wall)	1
Trochammina wickendeni Loeblich	20
Saccammina alexanderi (Leoblich and Tappan)	1
Miscellaneous--bone fragments	

BC-6 28.6 feet above Dakota(?)

Barren

BC-7 39.8 feet above Dakota(?) P:B --

Cythereis eaglefordensis Alexander	5
Cytheropteron castorense Butler and Jones	3
Paracypris sp.	2
Dentalina gracilis D'Orbigny	14
Gavelinella dakotensis (Fox)	5

BC-7--Continued

Haplophragmoides collyra Nauss	49
Ammobaculites impexus Eicher	13
Trochammina wickendeni Loeblich	4
Miscellaneous--bone fragments	

BC-8 51.0 feet above Dakota(?) P:B --

Gavelinella dakotensis (Fox)	4

BC-9 62.2 feet above Dakota(?) P:B 3/2

Hedbergella delrioensis (Carsey)	39
Heterohelix globulosa (Ehrenberg)	9
Guembelitria harrisi Tappan	2
Citharina kochii (Roemer)	1
Dentalina gracilis D'Orbigny	8
Gavelinella dakotensis (Fox)	19
Neobulimina albertensis (Stelck and Wall)	1
Reophax inordinatus Young	5
Ammomarginulina carlilensis Lamb	5
Haplophragmium arenatum Lamb	6
Trochammina wickendeni Loeblich	4

BC-10 73.4 feet above Dakota(?) P:B 1/2

Hedbergella delrioensis (Carsey)	26
Heterohelix globulosa (Ehrenberg)	7
Citharina kochii (Roemer)	6
Dentalina gracilis D'Orbigny	11
Gavelinella dakotensis (Fox)	34
Neobulimina albertensis (Stelck and Wall)	4
Reophax cf. *R. minuta* Tappan	16
Reophax inordinatus Young	2
Trochammina wickendeni Loeblich	3

BC-11 84.6 feet above Dakota(?) P:B 1/15

Hedbergella delrioensis (Carsey)	4
Heterohelix globulosa (Ehrenberg)	4
Dentalina gracilis D'Orbigny	8
Gavelinella dakotensis (Fox)	44
Neobulimina albertensis (Stelck and Wall)	4
Haplophragmoides collyra Nauss	1
Reophax recta (Beissel)	10
Reophax minuta Tappan	4
Reophax inordinatus Young	7
Trochammina wickendeni Loeblich	11

BC-12 90.2 feet above Dakota(?)

Barren

BC-13 95.8 feet above Dakota(?) P:B 1/90

Hedbergella delrioensis (Carsey)	1
Citharina kochii (Roemer)	1
Frondicularia imbricata Young	1
Dentalina gracilis D'Orbigny	4
Gavelinella dakotensis (Fox)	52
Reophax recta (Beissel)	10
Reophax minuta Tappan	2
Reophax inordinatus Young	1
Trochammina wickendeni Loeblich	19

BC-14 107.0 feet above Dakota(?) P:B 2/1

Hedbergella delrioensis (Carsey)	45
Clavihedbergella simplex (Morrow)	1
Heterohelix globulosa (Ehrenberg)	11
Dentalina gracilis D'Orbigny	1
Frondicularia imbricata Young	3
Gavelinella dakotensis (Fox)	41
Coryphostoma plaita (Carsey)	2
Neobulimina albertensis (Stelck and Wall)	1
Haplophragmoides collyra Nauss	1
Reophax recta (Beissel)	1
Haplophragmium arenatum Lamb	3
Trochammina wickendeni Loeblich	3
Saccammina alexanderi (Loeblich and Tappan)	1

BC-15 118.2 feet above Dakota(?) P:B 7/2

Hedbergella delrioensis (Carsey)	36
Hedbergella portsdownensis (Williams-Mitchell)	6
Clavihedbergella simplex (Morrow)	7
Clavihedbergella subdigitata (Carman)	5
Heterohelix globulosa (Ehrenberg)	9
Heterohelix pulchra (Brotzen)	4
Citharina kochii (Roemer)	2
Dentalina gracilis D')rbigny	4
Frondicularia imbricata Young	1
Gavelinella dakotensis (Fox)	5
Coryphostoma plaita (Carsey)	4
Neobulimina albertensis (Stelck and Wall)	1
Haplophragmoides collyra Nauss	1
Reophax recta (Beissel)	10
Reophax inordinatus Young	2
Haplophragmium arenatum Lamb	6
Trochammina wickendeni Loeblich	7
Saccammina alexanderi (Loeblich and Tappan)	5

BC-16 129.4 feet above Dakota(?) P:B 2/1

Hedbergella delrioensis (Carsey)	32
Heterohelix globulosa (Ehrenberg)	3
Gavelinella dakotensis (Fox)	12
Haplophragmium arenatum Lamb	1
Saccammina alexanderi (Loeblich and Tappan)	4

BC-17 140.6 feet above Dakota(?) P:B 3/2

Hedbergella delrioensis (Carsey)	17
Heterohelix globulosa (Ehrenberg)	10
Dentalina gracilis D'Orbigny	2
Frondicularia imbricata Young	2
Gavelinella dakotensis (Fox)	10
Haplophragmoides cf. H. howardense Stelck and Wall	2
Coscinophragma? cf. C. codyensis (Fox)	18
Haplophragmium arenatum Lamb	1
Trochammina wickendeni Loeblich	1
Saccammina alexanderi (Loeblich and Tappan)	6
Miscellaneous--bone fragments, fish(?) scale	

BC-18 151.8 feet above Dakota(?) P:B 24/1

Hedbergella delrioensis (Carsey)	49
Hedbergella portsdownensis (Williams-Mitchell)	8
Clavihedbergella simplex (Morrow)	1
Heterohelix globulosa (Ehrenberg)	24
Heterohelix pulchra (Brotzen)	1
Gavelinella dakotensis (Fox)	10
Coryphostoma plaita (Carsey)	3
Neobulimina albertensis (Stelck and Wall)	1
Saccammina alexanderi (Loeblich and Tappan)	1

BC-19 163.0 feet above Dakota(?) P:B 32/1

Hedbergella delrioensis (Carsey)	34
Hedbergella portsdownensis (Williams-Mitchell)	7
Heterohelix globulosa (Ehrenberg)	4
Dentalina gracilis D'Orbigny	11
Gavelinella dakotensis (Fox)	10
Coscinophragma? cf. C. codyensis (Fox)	3
Trochammina wickendeni Loeblich	2
Saccammina alexanderi (Loeblich and Tappan)	3

BC-20 174.2 feet above Dakota(?) P:B 100/1

Hedbergella delrioensis (Carsey)	39
Hedbergella portsdownensis (Williams-Mitchell)	4
Heterohelix globulosa (Ehrenberg)	7
Heterohelix pulchra (Brotzen)	1
Dentalina gracilis D'Orbigny	2

BC-20--Continued

Gavelinella dakotensis (Fox)	4
Marginulinopsis amplaspira Young	2
Reophax recta (Beissel)	1
Trochammina wickendeni Loeblich	3
Saccammina alexanderi (Loeblich and Tappan)	4

BC-21 185.4 feet above Dakota(?) P:B 50/1

Hedbergella delrioensis (Carsey)	40
Hedbergella portsdownensis (Williams-Mitchell)	8
Clavihedbergella simplex (Morrow)	2
Clavihedbergella subdigitata (Carman)	1
Heterohelix globulosa (Ehrenberg)	21
Heterohelix pulchra (Brotzen)	2
Dentalina gracilis D'Orbigny	3
Frondicularia imbricata Young	1
Gavelinella dakotensis (Fox)	5
Neobulimina albertensis (Stelck and Wall)	3
Marginulinopsis amplaspira Young	4
Reophax inordinatus Young	1
Ammobaculites cf. A. impexus Eicher	1
Trochammina wickendeni Loeblich	3

BC-22 196.6 feet above Dakota(?) P:B 50/1

Hedbergella delrioensis (Carsey)	56
Hedbergella portsdownensis (Williams-Mitchell)	5
Clavihedbergella simplex (Morrow)	2
Heterohelix globulosa (Ehrenberg)	5
Heterohelix pulchra (Brotzen)	5
Gavelinella dakotensis (Fox)	12

BC-23 207.8 feet above Dakota(?) P:B over 100

Hedbergella delrioensis (Carsey)	36
Hedbergella portsdownensis (Williams-Mitchell)	5
Heterohelix globulosa (Ehrenberg)	20
Gavelinella dakotensis (Fox)	5
Trochammina wickendeni Loeblich	1

BC-24 219.0 feet above Dakota (?) P:B 12/1

Hedbergella delrioensis (Carsey)	32
Hedbergella portsdownensis (Williams-Mitchell)	6
Heterohelix globulosa (Ehrenberg)	3
Lenticulina cf. L. gaultina (Berthelin)	1
Gavelinella dakotensis (Fox)	7
Marginulinopsis amplaspira Young	3
Ammomarginulina cf. A. paterella Eicher	2

BC-24--Continued

	Reophax cf. *R. recta* (Beissel)		1
	Trochammina wickendeni Loeblich		12
BC-25	230.2 feet above Dakota(?)	P:B 100/1	
	Hedbergella delrioensis (Carsey)		40
	Hedbergella portsdownensis (Williams-Mitchell)		7
	Heterohelix globulosa (Ehrenberg)		4
	Gavelinella dakotensis (Fox)		8
	Neobulimina albertensis (Stelck and Wall)		1
	Reophax cf. *R. recta* (Beissel)		1
BC-26	241.4 feet above Dakota(?)	P:B 100/1	
	Hedbergella delrioensis (Carsey)		43
	Hedbergella portsdownensis (Williams-Mitchell)		13
	Heterohelix globulosa (Ehrenberg)		5
	Gavelinella dakotensis (Fox)		13
	Marginulinopsis amplaspira Young		2
BC-27	253.6 feet above Dakota(?)	P:B 5/1	
	Hedbergella delrioensis (Carsey)		31
	Hedbergella portsdownensis (Williams-Mitchell)		7
	Gavelinella dakotensis (Fox)		13
	Marginulinopsis amplaspira Young		1
	Reophax cf. *R. recta* (Beissel)		24
	Trochammina wickendeni Loeblich		16
	Miscellaneous--bone fragments		
BC-28	264.8 feet above Dakota(?)	P:B 50/1	
	Hedbergella delrioensis (Carsey)		28
	Hedbergella portsdownensis (Williams-Mitchell)		3
	Clavihedbergella simplex (Morrow)		1
	Clavihedbergella subdigitata (Carman)		1
	Heterohelix globulosa (Ehrenberg)		6
	Heterohelix pulchra (Brotzen)		1
	Gavelinella dakotensis (Fox)		3
	Coryphostoma plaita (Carsey)		4
	Neobulimina albertensis (Stelck and Wall)		3
BC-29	276.0 feet above Dakota(?)	P:B --	
	Saccammina alexanderi (Loeblich and Tappan)		2

BC-30	287.2 feet above Dakota(?) P:B 1/20	
	Hedbergella delrioensis (Carsey), weathered	10
	Gavelinella dakotensis (Fox)	14
	Haplophragmoides collyra Nauss	2
	Haplophragmoides cf. H. gilberti Eicher	4
	Reophax recta (Beissel)	10
	Trochammina wickendeni Loeblich	69
BC-31	294.8 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), weathered	19
	Hedbergella portsdownensis (Williams-Mitchell), weathered	2
	Heterohelix globulosa (Ehrenberg), weathered	2
	Gavelinella dakotensis (Fox)	2
	Haplophragmoides cf. H. gilberti Eicher	1
	Reophax recta (Beissel)	1
	Trochammina wickendeni Loeblich	7
BC-32	298.4 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), weathered	39
	Hedbergella portsdownensis (Williams-Mitchell), weathered	10
	Heterohelix globulosa (Ehrenberg), weathered	4
	Gavelinella dakotensis (Fox)	6
	Trochammina wickendeni Loeblich	8
BC-33	309.6 feet above Dakota(?)	
	Gavelinella dakotensis (Fox)	5
	Trochammina wickendeni Loeblich	19
	Saccammina alexanderi (Loeblich and Tappan)	1
BC-34	320.8 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), broken and weathered	12
	Heteroehelix globulosa (Ehrenberg), weathered	1
BC-35	332.0 feet above Dakota(?)	
	Barren	
BC-36	343.2 feet above Dakota(?)	
	Barren	
BC-37	354.4 feet above Dakota(?)	
	Barren	

BC-38	365.6 feet above Dakota(?)	
	Hedbergella sp., probably H. delrioensis (Carsey), broken and corroded	6
	Heterohelix globulosa (Ehrenberg), weathered	1
BC-39	376.8 feet above Dakota(?)	
	Barren	
BC-40	388.0 feet above Dakota(?)	
	Hedbergella sp., probably H. delrioensis (Carsey), broken and corroded	2
	Megaspores, species A	24
BC-41	399.2 feet above Dakota(?)	
	Megaspores, species A	11
BC-42	410.4 feet above Dakota(?)	
	Barren	
BC-43	421.6 feet above Dakota(?)	
	Megaspores, species A	12
	Megaspores, species B	3
BC-44	432.8 feet above Dakota(?)	
	Megaspores, species A	20
	Megaspores, species B	4
	Miscellaneous--broken internal casts of small gastropods	
BC-45	444.0 feet above Dakota(?)	
	Megaspores, species A	9
	Megaspores, species B	5
BC-46	455.2 feet above Dakota(?)	
	Megaspores, species A	9
	Megaspores, species B	8
BC-47	466.4 feet above Dakota(?)	
	Barren	

BC-48 477.6 feet above Dakota(?)

Barren

BC-49 488.8 feet above Dakota(?)

Barren

BC-50 500.0 feet above Dakota(?)

Trochammina cf. *T*. *wickendeni* Loeblich, crushed 8
Miscellaneous--bone fragments

BC-51 511.2 feet above Dakota(?)

Barren

BC-52 522.4 feet above Dakota(?)

Trochammina wickendeni Loeblich, crushed 14

BC-53 533.6 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered 1
Trochammina wickendeni Loeblich, crushed 8

BC-54 544.8 feet above Dakota(?)

Haplophragmoides cf. *H*. *gilberti* Eicher 8
Trachammina wickendeni Loeblich, crushed 19
Saccammina alexanderi (Loeblich and Tappan) 1

BC-55 556.0 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered 1
Valvulineria loetterlei (Tappan) 4
Reophax cf. *R*. *inordinatus* Young, broken 2
Trochammina wickendeni Loeblich, crushed 25
Miscellaneous--bone fragments

BC-56 567.2 feet above Dakota(?)

Valvulineria loetterlei (Tappan) 1
Ammomarginulina cf. *A*. *paterella* Eicher 3
Haplophragmoides cf. *H*. *gilberti* Eicher 19

BC-57 578.4 feet above Dakota(?)

Praeglobotruncana difformis (Gandolfi)
(=*P*. *marginata* (Reuss)), weathered 1
Gaudryina bentonensis (Carman) 5
Ammomarginulina cf. *A*. *paterella* Eicher 6

	Haplophragmoides cf. H. gilberti Eicher	26
	Trochammina wickendeni Loeblich	2
BC-58	589.6 feet above Dakota(?)	
	Haplophragmoides cf. H. gilberti Eicher	30
	Ammomarginulina cf. A. paterella Eicher	13
	Ammobaculites junceus Cushman and Applin	2
	Reophax cf. R. recta (Beissel)	1
BC-59	600.8 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	9
	Haplophragmoides cf. H. gilberti Eicher	18
	Ammomarginulina cf. A. paterella Eicher	5
	Trochammina wickendeni Loeblich	20
BC-60	612.0 feet above Dakota(?)	
	Haplophragmoides cf. H. gilberti Eicher	25
	Ammomarginulina cf. A. paterella Eicher	7
	Ammobaculites junceus Cushman and Applin	2
	Reophax cf. R. recta (Beissel)	6
	Trochammina wickendeni Loeblich	35
BC-61	623.2 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	35
	Haplophragmoides cf. H. gilberti Eicher	21
	Reophax cf. R. recta (Beissel)	3
	Trochammina wickendeni Loeblich	16
	Saccammina alexanderi (Loeblich and Tappan)	1
BC-62	634.4 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	26
	Haplophragmoides cf. H. gilberti Eicher	24
	Reophax recta (Beissel)	3
	Miscellaneous--simple tooth	
BC-63	645.6 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	42
	Haplophragmoides cf. H. gilberti Eicher	14
	Trochammina wickendeni Loeblich	16
BC-64	656.8 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	33
	Haplophragmoides cf. H. gilberti Eicher	12
	Trochammina wickendeni Loeblich	13

BC-65 668.0 feet above Dakota(?)

Barren

BC-66 676.9 feet above Dakota(?). Base of Toreva Sandstone.

Barren

Longhouse Valley

LHV-1	Top of Dakota(?) Sandstone		
	Barren		
LHV-2	4.9 feet above Dakota(?)		
	Gaudryina spiritensis Stelck and Wall		7
	Trochammina rutherfordi Stelck and Wall		17
LHV-3	9.8 feet above Dakota(?)		
	Miscellaneous--internal molds of small gastropods		5
LHV-4	14.7 feet above Dakota(?)		
	Barren		
LHV-5	19.6 feet above Dakota(?)		
	Cythereis eaglefordensis Alexander		1
	Gavelinella dakotensis (Fox)		8
	Saccammina alexanderi (Loeblich and Tappan)		1
	Miscellaneous--glauconite		
LHV-6	29.4 feet above Dakota(?)	P:B 1/4	
	Cythereis eaglefordensis Alexander		20
	Hedbergella delrioensis (Carsey)		5
	Citharina kochii (Roemer)		1
	Dentalina gracilis D'Orbigny		2
	Nodosaria bighornensis Young		3
	Gavelinella dakotensis (Fox)		6
	Quinquiloculina moremani Cushman		5
	Lingulogavelinella asterigerioides (Plummer)		3
LHV-7	39.2 feet above Dakota(?)	P:B 1/4	
	Cytheropteron cf. *C. castorense* Butler and Jones (l.v.)		1
	Heterohelix globulosa (Ehrenberg)		9
	Dentalina gracilis D'Orbigny		6
	Gavelinella dakotensis (Fox)		25
	Trochammina wickendeni Loeblich		3
LHV-8	49.0 feet above Dakota(?)	P:B 2/1	
	Hedbergella delrioensis (Carsey)		26
	Hedbergella portsdownensis (Williams-Mitchell)		2
	Heterohelix globulosa (Ehrenberg)		5
	Citharina kochii (Roemer)		4

LHV-8--Continued

	Gavelinella dakotensis (Fox)	22
	Neobulimina albertensis (Stelck and Wall)	2
	Haplophragmoides cf. H. howardense Stelck and Wall, coated	11
	Haplophragmium arenatum Lamb	1
	Saccammina alexanderi (Loeblich and Tappan)	1
LHV-9	58.8 feet above Dakota(?) P:B 2/1	
	Hedbergella delrioensis (Carsey)	28
	Hedbergella portsdownensis (Williams-Mitchell)	3
	Heterohelix globulosa (Ehrenberg)	11
	Guembelitria harrisi Tappan	6
	Citharina kochii (Roemer)	7
	Dentalina gracilis D'Orbigny	8
	Gavelinella dakotensis (Fox)	21
	Coryphostoma plaita (Carsey)	3
	Neobulimina albertensis (Stelck and Wall)	5
	Ammobaculites cf. A. impexus Eicher	1
	Haplophragmoides cf. H. hendersonense Stelck and Wall, coated	2
	Haplophragmium arenatum Lamb	4
LHV-10	68.6 feet above Dakota(?) P:B 2/1	
	Hedbergella delrioensis (Carsey)	38
	Hedbergella portsdownensis (Williams-Mitchell)	4
	Clavihedbergella simplex (Morrow)	1
	Heterohelix globulosa (Ehrenberg)	8
	Guembelitria harrisi Tappan	1
	Citharina kochii (Roemer)	3
	Dentalina gracilis D'Orbigny	2
	Gavelinella dakotensis (Fox)	21
	Coryphostoma plaita (Carsey)	3
	Neobulimina albertensis (Stelck and Wall)	1
	Trochammina wickendeni Loeblich	7
	Saccammina alexanderi (Loeblich and Tappan)	1
LHV-11	78.4 feet above Dakota(?) P:B 2/1	
	Hedbergella delrioensis (Carsey)	32
	Hedbergella portsdownensis (Williams-Mitchell)	2
	Clavihedbergella simplex (Morrow)	4
	Clavihedbergella subdigitata (Carman)	1
	Heterohelix globulosa (Ehrenberg)	11
	Heterohelix pulchra (Brotzen)	1
	Frondicularia imbricata Young	1
	Gavelinella dakotensis (Fox)	18
	Coryphostoma plaita (Carsey)	6
	Neobulimina albertensis (Stelck and Wall)	5

LHV-11--Continued

	Haplophragmoides collyra Nauss	1
	Trochammina wickendeni Loeblich	3
	Saccammina alexanderi (Loeblich and Tappan)	2
LHV-12	88.2 feet above Dakota(?) P:B 5/1	
	Hedbergella delrioensis (Carsey)	21
	Clavihedbergella simplex (Morrow)	5
	Heterohelix globulosa (Ehrenberg)	6
	Heterohelix pulchra (Brotzen)	1
	Guembelitria harrisi Tappan	3
	Frondicularia imbricata Young	6
	Nodosaria bighornensis Young	1
	Gavelinella dakotensis (Fox)	17
	Coryphostoma plaita (Carsey)	2
	Neobulimina albertensis (Stelck and Wall)	7
	Trochammina wickendeni Loeblich	3
LHV-13	98.0 feet above Dakota(?) P:B 1/1	
	Hedbergella delrioensis (Carsey)	22
	Hedbergella portsdownensis (Williams-Mitchell)	2
	Clavihedbergella simplex (Morrow)	5
	Clavihedbergella subdigitata (Carman)	1
	Heterohelix globulosa (Ehrenberg)	7
	Heterohelix pulchra (Brotzen)	2
	Dentalina gracilis D'Orbigny	2
	Gavelinella dakotensis (Fox)	6
	Haplophragmium arenatum Lamb	1
	Trochammina wickendeni Loeblich	11
	Saccammina alexanderi (Loeblich and Tappan)	1
LHV-14	107.8 feet above Dakota(?) P:B 10/1	
	Hedbergella delrioensis (Carsey)	27
	Hedbergella portsdownensis (Williams-Mitchell)	2
	Clavihedbergella simplex (Morrow)	1
	Clavihedbergella subdigitata (Carman)	4
	Heterohelix globulosa (Ehrenberg)	21
	Heterohelix pulchra (Brotzen)	4
	Gavelinella dakotensis (Fox)	8
	Neobulimina albertensis (Stelck and Wall)	2
	Trochammina wickendeni Loeblich	5
LHV-15	117.6 feet above Dakota(?) P:B 2/1	
	Hedbergella delrioensis (Carsey)	29
	Hedbergella portsdownensis (Williams-Mitchell)	6
	Clavihedbergella simplex (Morrow)	4
	Clavihedbergella subdigitata (Carman)	2

LHV-15--Continued

	Clavihedbergella moremani (Cushman)	1
	Heterohelix globulosa (Ehrenberg)	16
	Heterohelix pulchra (Brotzen)	3
	Planoglobulina cf. P. glabrata (Cushman)	1
	Frondicularia imbricata Young	4
	Gavelinella dakotensis (Fox)	32
	Coryphostoma plaita (Carsey)	2
	Neobulimina albertensis (Stelck and Wall)	5
	Ammobaculites cf. A. impexus Eicher, coated	1
	Haplophragmium arenatum Lamb	4
	Saccammina alexanderi (Loeblich and Tappan)	3
LHV-16	127.4 feet above Dakota(?) P:B 14/1	
	Hedbergella delrioensis (Carsey)	41
	Hedbergella portsdownensis (Williams-Mitchell)	7
	Clavihedbergella simplex (Morrow)	4
	Heterohelix globulosa (Ehrenberg)	9
	Heterohelix pulchra (Brotzen)	4
	Gavelinella dakotensis (Fox)	5
	Coryphostoma plaita (Carsey)	4
	Neobulimina albertensis (Stelck and Wall)	6
	Trochammina wickendeni Loeblich	1
	Saccammina alexanderi (Loeblich and Tappan)	1
LHV-17	137.2 feet above Dakota(?) P:B 20/1	
	Hedbergella delrioensis (Carsey)	56
	Hedbergella portsdownensis (Williams-Mitchell)	3
	Clavihedbergella simplex (Morrow)	3
	Clavihedbergella subdigitata (Carman)	2
	Heterohelix globulosa (Ehrenberg)	11
	Heterohelix pulchra (Brotzen)	4
	Dentalina gracilis D'Orbigny	2
	Frondicularia imbricata Young	1
	Gavelinella dakotensis (Fox)	10
	Neobulimina albertensis (Stelck and Wall)	2
	Reophax cf. R. recta (Beissel), crushed	2
	Saccammina alexanderi (Loeblich and Tappan)	1
LHV-18	147.0 feet above Dakota(?) P:B 50/1	
	Hedbergella delrioensis (Carsey)	42
	Hedbergella portsdownensis (Williams-Mitchell)	8
	Clavihedbergella simplex (Morrow)	3
	Clavihedbergella subdigitata (Carman)	2
	Heterohelix globulosa (Ehrenberg)	9
	Heterohelix pulchra (Brotzen)	2
	Gavelinella dakotensis (Fox)	6
	Saccammina alexanderi (Loeblich and Tappan)	1

LHV-19	156.8 feet above Dakota(?)	P:B 4/1	
	Hedbergella delrioensis (Carsey)		48
	Hedbergella portsdownensis (Williams-Mitchell)		5
	Clavihedbergella simplex (Morrow)		1
	Heterohelix globulosa (Ehrenberg)		2
	Heterohelix pulchra (Brotzen)		1
	Frondicularia imbricata Young		1
	Gavelinella dakotensis (Fox)		11
	Coryphostoma plaita (Carsey)		1
	Haplophragmoides collyra Nauss		1
	Haplophragmium arenatum Lamb		5
	Trochammina wickendeni Loeblich		2
	Saccammina alexanderi (Loeblich and Tappan)		1
LHV-20	166.6 feet above Dakota(?)	P:B over 100	
	Hedbergella delrioensis (Carsey)		42
	Hedbergella portsdownensis (Williams-Mitchell)		8
	Clavihedbergella simplex (Morrow)		3
	Clavihedbergella subdigitata (Carman)		1
	Heterohelix globulosa (Ehrenberg)		7
	Heterohelix pulchra (Brotzen)		2
	Gavelinella dakotensis (Fox)		3
	Coryphostoma plaita (Carsey)		2
LHV-21	176.4 feet above Dakota (!)	P:B 100/1	
	Hedbergella delrioensis (Carsey)		46
	Hedbergella portsdownensis (Williams-Mitchell)		8
	Clavihedbergella simplex (Morrow)		1
	Clavihedbergella subdigitata (Carman)		1
	Heterohelix globulosa (Ehrenberg)		16
	Heterohelix pulchra (Brotzen)		3
	Gavelinella dakotensis (Fox)		7
	Saccammina alexanderi (Loeblich and Tappan)		1
LHV-22	186.2 feet above Dakota(?)	P:B over 100	
	Hedbergella delrioensis (Carsey)		61
	Hedbergella portsdownensis (Williams-Mitchell)		4
	Clavihedbergella simplex (Morrow)		4
	Clavihedbergella subdigitata (Carman)		2
	Heterohelix globulosa (Ehrenberg)		1
	Heterohelix pulchra (Brotzen)		1
	Dentalina gracilis D'Orbigny		3
	Frondicularia imbricata Young		1
	Gavelinella dakotensis (Fox)		4
	Marginulinopsis amplaspira Young		1
	Saccammina alexanderi (Loeblich and Tappan)		1

LHV-23	196.0 feet above Dakota(?)	P:B 100/1	
	Hedbergella delrioensis (Carsey)		49
	Hedbergella portsdownensis (Williams-Mitchell)		9
	Clavihedbergella simplex (Morrow)		3
	Heterohelix globulosa (Ehrenberg)		12
	Heterohelix pulchra (Brotzen)		3
	Dentalina gracilis D'Orbigny		4
	Nodosaria bighornensis Young		1
	Neobulimina albertensis (Stelck and Wall)		1
	Marginulinopsis amplaspira Young		1
	Gavelinella dakotensis (Fox)		4
	Trochammina wickendeni Loeblich		2
	Saccammina alexanderi (Loeblich and Tappan)		2
LHV-24	205 feet above Dakota(?)	P:B 100/1	
	Hedbergella delrioensis (Carsey)		42
	Hedbergella portsdownensis (Williams-Mitchell)		5
	Clavihedbergella simplex (Morrow)		3
	Clavihedbergella subdigitata (Carman)		1
	Dentalina sp., broken, probably D. gracilis		1
	Marginulinopsis amplaspira Young		1
	Trochammina wickendeni Loeblich		2
LHV-25	215.6 feet above Dakota(?)	P:B 100/1	
	Hedbergella delrioensis (Carsey)		34
	Hedbergella portsdownensis (Williams-Mitchell)		10
	Heterohelix globulosa (Ehrenberg)		9
	Heterohelix pulchra (Brotzen)		1
	Gavelinella dakotensis (Fox)		3
	Trochammina wickendeni Loeblich		1
LHV-26	225.4 feet above Dakota(?)	P:B 32/1	
	Hedbergella delrioensis (Carsey)		40
	Hedbergella portsdownensis (Williams-Mitchell)		8
	Clavihedbergella simplex (Morrow)		8
	Heterohelix globulosa (Ehrenberg)		25
	Heterohelix pulchra (Brotzen)		3
	Dentalina gracilis D'Orbigny		1
	Gavelinella dakotensis (Fox)		11
	Reophax cf. R. recta (Beissel)		1
	Trochammina wickendeni Loeblich		4
	Saccammina alexanderi (Loeblich and Tappan)		1
LHV-27	235.2 feet above Dakota(?)	P:B over 100	
	Hedbergella delrioensis (Carsey)		40
	Hedbergella portsdownensis (Williams-Mitchell)		8
	Clavihedbergella simplex (Morrow)		1

LHV-27--Continued

	Heterohelix globulosa (Ehrenberg)	8
	Heterohelix pulchra (Brotzen)	5
	Dentalina gracilis D'Orbigny	4
	Nodosaria bighornensis Young	2
	Gavelinella dakotensis (Fox)	5
	Marginulinopsis amplaspira Young	3
	Reophax inordinatus Young	1
	Trochammina wickendeni Loeblich	9
	Saccammina alexanderi (Loeblich and Tappan)	2
	Miscellaneous--shark scale	
LHV-28	245.0 feet above Dakota(?) P:B 50/1	
	Hedbergella delrioensis (Carsey)	45
	Hedbergella portsdownensis (Williams-Mitchell)	9
	Clavihedbergella simplex (Morrow)	4
	Clavihedbergella subdigitata (Carman)	4
	Heterohelix globulosa (Ehrenberg)	7
	Heterohelix pulchra (Brotzen)	4
	Nodosaria bighornensis (Young)	1
	Gavelinella dakotensis (Fox)	15
	Neobulimina albertensis (Stelck and Wall)	1
	Marginulinopsis amplaspira Young	1
	Haplophragmoides collyra Nauss	2
	Trochammina wickendeni Loeblich	1
LHV-29	254.8 feet above Dakota(?) P:B 50/1	
	Hedbergella delrioensis (Carsey)	35
	Hedbergella portsdownensis (Williams-Mitchell)	11
	Clavihedbergella simplex (Morrow)	2
	Clavihedbergella subdigitata (Carman)	1
	Heterohelix globulosa (Ehrenberg)	8
	Heterohelix pulchra (Brotzen)	6
	Gavelinella dakotensis (Fox)	10
	Marginulinopsis amplaspira Young	1
	Haplophragmoides collyra Nauss	1
	Trochammina wickendeni Loeblich	2
	Saccammina alexanderi (Loeblich and Tappan)	6
LHV-30	264.6 feet above Dakota(?) P:B 100/1	
	Hedbergella delrioensis (Carsey)	35
	Hedbergella portsdownensis (Williams-Mitchell)	13
	Clavihedbergella subdigitata (Carman)	1
	Heterohelix globulosa (Ehrenberg)	8
	Heterohelix pulchra (Brotzen)	1
	Gavelinella dakotensis (Fox)	9

LHV-31	274.4 feet above Dakota(?)	P:B 16/1

Hedbergella delrioensis (Carsey)	27
Hedbergella portsdownensis (Williams-Mitchell)	10
Heterohelix globulosa (Ehrenberg)	3
Heterohelix pulchra (Brotzen)	1
Dentalina gracilis D'Orbigny	2
Gavelinella dakotensis (Fox)	3
Reophax sp. (*R. pepperensis* Loeblich ?), poor preservation	2
Trochammina wickendeni Loeblich	15

LHV-32	284.2 feet above Dakota(?)	P:B 13/1

Hedbergella delrioensis (Carsey)	27
Hedbergella portsdownensis (Williams-Mitchell)	11
Heterohelix globulosa (Ehrenberg)	1
Nodosaria bighornensis Young	1
Gavelinella dakotensis (Fox)	11
Marginulinopsis amplaspira Young	5
Reophax pepperensis Loeblich	3
Trochammina wickendeni Loeblich	20

LHV-33	294.0 feet above Dakota(?)	P:B 50/1

Hedbergella delrioensis (Carsey)	35
Hedbergella portsdownensis (Williams-Mitchell)	17
Clavihedbergella simplex (Morrow)	1
Heterohelix globulosa (Ehrenberg)	4
Frondicularia imbricata Young	2
Gavelinella dakotensis (Fox)	17
Marginulinopsis amplaspira Young	4
Trochammina wickendeni Loeblich	2

LHV-34	303.8 feet above Dakota(?)	P:B 32/1

Hedbergella delrioensis (Carsey)	27
Hedbergella portsdownensis (Williams-Mitchell)	14
Heterohelix globulosa (Ehrenberg)	2
Gavelinella dakotensis (Fox)	7
Reophax cf. *R. pepperensis* Loeblich	7
Trochammina wickendeni Loeblich	16

LHV-35	313.6 feet above Dakota(?)	P:B 1/1

Hedbergella delrioensis (Carsey), weathered	23
Hedbergella portsdownensis (Williams-Mitchell)	7
Nodosaria bighornensis Young, broken	1
Gavelinella dakotensis (Fox)	3
Haplophragmoides cf. *H. collyra* Nauss	5
Reophax recta (Beissel)	28
Trochammina wickendeni Loeblich	14
Saccammina alexanderi (Loeblich and Tappan)	3

LHV-36	323.4 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), corroded	1
	Gavelinella dakotensis (Fox)	10
	Reophax pepperensis Loeblich	6
	Reophax recta (Beissel)	23
	Trochammina wickendeni Loeblich	25
	Saccammina alexanderi (Loeblich and Tappan)	5
LHV-37	333.6 feet above Dakota(?)	
	Gavelinella dakotensis (Fox)	10
	Haplophragmoides howardense Stelck and Wall	2
	Reophax pepperensis Loeblich	5
	Reophax recta (Beissel)	19
	Trochammina wickendeni Loeblich	14
LHV-38	343.8 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), corroded	2
	Gavelinella dakotensis (Fox), weathered	4
	Reophax pepperensis Loeblich	4
	Reophax recta (Beissel)	9
	Trochammina wickendeni Loeblich	5
LHV-39	354.0 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), weathered and corroded	18
	Hedbergella portsdownensis (Williams-Mitchell), weathered and corroded	4
	Heterohelix globulosa (Ehrenberg), weathered	4
	Megaspores, species A	6
LHV-40	364.2 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), weathered and corroded	8
	Hedbergella portsdownensis (Williams-Mitchell), weathered and corroded	2
	Heterohelix globulosa (Ehrenberg), corroded	2
	Trochammina wickendeni Loeblich	56
	Megaspores, species A	7
LHV-41	374.4 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey, weathered and corroded	15
	Hedbergella portsdownensis (Williams-Mitchell), weathered and corroded	1

LHV-41--Continued

	Heterohelix globulosa (Ehrenberg), corroded	3
	Trochammina wickendeni Loeblich	1
	Megaspores, species A	2
LHV-42	399.9 feet above Dakota(?)	
	Hedbergella sp., weathered and broken chambers	3
	Trochammina wickendeni Loeblich	1
	Megaspores, species A	2
	Miscellaneous--bone fragments, shell hash	
LHV-43	410.1 feet above Dakota(?)	
	Hedbergella sp., weathered, broken chambers	3
	Megaspores, species A	5
	Miscellaneous--bone fragments	
LHV-44	420.3 feet above Dakota(?)	
	Megaspores, species A	10
	Miscellaneous--bone fragments	
LHV-45	430.5 feet above Dakota(?)	
	Megaspores, species A	5
LHV-46	445.8 feet above Dakota(?)	
	Trochammina wickendeni Loeblich	3
	Megaspores, species A	7
LHV-47	456.0 feet above Dakota(?)	
	Megaspores, species A	19
	Miscellaneous--iron oxide (?) concretions	
LHV-48	466.2 feet above Dakota(?)	
	Megaspores, species A	31
	Megaspores, species B	1
LHV-49	476.4 feet above Dakota(?)	
	Megaspores, species A	36
	Megaspores, species B	6
LHV-50	486.6 feet above Dakota(?)	
	Megaspores, species A	12
	Megaspores, species B	6

LHV-51	496.8 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), weathered and corroded	6
	Hedbergella portsdownensis (Williams-Mitchell), weathered and corroded	1
	Trochammina wickendeni Loeblich	6
	Megaspores, species A	4
	Megaspores, species B	3
	Miscellaneous--bone fragments, iron oxide (?) concretions	
LHV-52	507.0 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), weathered	1
	Hedbergella portsdownensis (Williams-Mitchell), weathered	1
	Megaspores, species A	3
	Megaspores, species B	1
LHV-53	517.2 feet above Dakota(?)	
	Megaspores, species A	14
	Megaspores, species B	8
LHV-54	527.4 feet above Dakota(?)	
	Trochammina wickendeni	21
	Megaspores, species A	1
	Megaspores, species B	1
	Miscellaneous--tooth(?)	
LHV-55	537.6 feet above Dakota(?)	
	Barren	
LHV-56	547.8 feet above Dakota(?)	
	Barren	
LHV-57	558.0 feet above Dakota(?)	
	Trochammina wickendeni Loeblich	17
LHV-58	568.2 feet above Dakota(?)	
	Trochammina wickendeni Loeblich	3
	Miscellaneous--bone fragments	
LHV-59	578.4 feet above Dakota(?)	
	Ammomarginulina perimpexus Eicher	19
	Trochammina wickendeni Loeblich	16

LHV-60	588.6 feet above Dakota(?)		
		Gaudryina bentonensis (Carman)	15
		Trochammina wickendeni Loeblich	2
		Miscellaneous--bone fragments, iron oxide (?) concretions	
LHV-61	598.8 feet above Dakota(?)		
		Gaudryina bentonensis (Carman)	24
		Trochammina wickendeni Loeblich	2
LHV-62	609.0 feet above Dakota(?)		
		Gaudryina bentonensis (Carman)	9
		Trochammina wickendeni Loeblich	12
		Miscellaneous--bone fragments	
LHV-63	619.2 feet above Dakota(?)		
		Gaudryina bentonensis (Carman)	12
		Trochammina wickendeni Loeblich	11
		Miscellaneous--bone fragments	
LHV-64	629.4 feet above Dakota(?)		
		Gaudryina bentonensis (Carman)	5
		Trochammina wickendeni Loeblich	8

58.8 feet (corrected) of Mancos Shale above LHV-64 covered by slide from overlying Toreva Sandstone, unsampled

Kayenta

K-1 Top of Dakota(?) Sandstone

Barren

K-2 16.8 feet above Dakota(?) P:B 2/1

Cythereis eaglefordensis Alexander	8
Cytheropteron cf. C. castorense Butler and Jones	4
Paracypris sp., broken	2
Hedbergella delrioensis (Carsey)	39
Hedbergella portsdownensis (Williams-Mitchell)	3
Clavihedbergella simplex (Morrow)	1
Heterohelix globulosa (Ehrenberg)	13
Guembelitria harrisi Tappan	1
Citharina kochii (Roemer)	3
Dentalina gracilis D'Orbigny	21
Gavelinella dakotensis (Fox)	15
Coryphostomas plaita (Carsey)	2
Haplophragmoides collyra Nauss	22
Haplophragmium arenatum Lamb	3
Trochammina sp., crushed	4
Saccammina alexanderi (Loeblich and Tappan)	1
Miscellaneous--shark scale, fish(?) scale	

K-3 22.4 feet above Dakota(?) P:B 9/10

Cytheropteron cf. C. castorense Butler and Jones	2
Hedbergella delrioensis (Carsey)	34
Heterohelix globulosa (Ehrenberg)	1
Dentalina gracilis D'Orbigny	4
Gavelinella dakotensis (Fox)	31
Haplophragmoides howardense Stelck and Wall	3
Ammomarginulina carlilensis Lamb	12
Haplophragmium arenatum Lamb	7
Reophax pepperensis Loeblich	1
Reophax inordinatus Young	3
Trochammina wickendeni Loeblich	22
Miscellaneous--simple teeth, bone fragments	

K-4 28.0 feet above Dakota(?) P:B 4

Bythocypris cf. B. windhami Butler and Jones	2
Hedbergella delrioensis (Carsey)	42
Hedbergella portsdownensis (Williams-Mitchell)	8
Heterohelix globulosa (Ehrenberg)	9
Citharina kochii (Roemer)	10
Dentalina gracilis D'Orbigny	7
Coryphostoma plaita (Carsey)	5
Gavelinella dakotensis (Fox)	14

K-4--Continued

	Neobulimina albertensis (Stelck and Wall)	3
	Ammomarginulina carlilensis Lamb	2
	Haplophragmium arenatum Lamb	12
	Ammobaculites cf. A. subcretaceous Cushman and Applin	1
	Trochammina wickendeni Loeblich	3
	Saccammina alexanderi (Loeblich and Tappan)	4
K-5	39.2 feet above Dakota(?) P:B 1/1	
	Hedbergella delrioensis (Carsey)	34
	Hedbergella portsdownensis (Williams-Mitchell)	4
	Heterohelix globulosa (Ehrenberg)	9
	Clavihedbergella simplex (Morrow)	4
	Guembelitria harrisi Tappan	1
	Citharina kochii (Roemer)	2
	Dentalina gracilis D'Orbigny	12
	Frondicularia imbricata Young	3
	Gavelinella dakotensis (Fox)	15
	Coryphostoma plaita (Carsey)	3
	Neobulimina albertensis (Stelck and Wall)	3
	Haplophragmoides collyra Nauss	7
	Reophax cf. R. recta (Beissel)	1
	Reophax inordinatus young	16
	Trochammina cf. T. wetteri Stelck and Wall	1
	Trochammina wickendeni Loeblich	14
	Saccammina alexanderi (Loeblich and Tappan)	5
	Miscellaneous--simple teeth, scales	
K-6	50.4 feet above Dakota(?) P:B 3/1	
	Hedbergella delrioensis (Carsey)	25
	Hedbergella portsdownensis (Williams-Mitchell)	4
	Clavihedbergella simplex (Morrow)	8
	Heterohelix globulosa (Ehrenberg)	11
	Guembelitria harrisi Tappan	2
	Planoglobulina cf. P. glabrata (Cushman)	2
	Heterohelix pulchra (Brotzen)	3
	Citharina kochii (Roemer)	1
	Frondicularia imbricata Young	3
	Gavelinella dakotensis (Fox)	19
	Coryphostoma plaita (Carsey)	11
	Neobulimina albertensis (Stelck and Wall)	9
	Haplophragmoides cf. H. collyra Nauss	1
	Reophax recta (Beissel)	3
	Trochammina wickendeni Loeblich	12
	Saccammina alexanderi (Loeblich and Tappan)	5

K-7 61.6 feet above Dakota(?) P:B 8/1

Hedbergella delrioensis (Carsey)	31
Hedbergella portsdownensis (Williams-Mitchell)	1
Clavihedbergella simplex (Morrow)	4
Clavihedbergella subdigitata (Carman)	7
Heterohelix globulosa (Ehrenberg)	15
Heterohelix pulchra (Brotzen)	2
Planoglobulina cf. P. glabrata (Cushman)	2
Gavelinella dakotensis (Fox)	20
Coryphostoma plaita (Carsey)	3
Neobulimina albertensis (Stelck and Wall)	7
Ammobaculites cf. A. junceus Cushman and Applin	1
Trochammina wickendeni Loeblich	5
Saccammina alexanderi (Loeblich and Tappan)	6

K-8 72.8 feet above Dakota(?) P:B 4/1

Hedbergella delrioensis (Carsey)	28
Hedbergella portsdownensis (Williams-Mitchell)	6
Clavihedbergella simplex (Morrow)	1
Clavihedbergella subdigitata (Carman)	5
Heterohelix globulosa (Ehrenberg)	7
Heterohelix pulchra (Brotzen)	4
Dentalina gracilis D'Orbigny	5
Frondicularia imbricata Young	7
Gavelinella dakotensis (Fox)	13
Coryphostoma plaita (Carsey)	4
Neobulimina albertensis (Stelck and Wall)	4
Ammomarginulina carlilensis Lamb	3
Haplophragmium arenatum Lamb	6
Reophax recta (Beissel)	6
Reophax inordinatus Young	5
Trochammina wickendeni Loeblich	4
Saccammina alexanderi (Loeblich and Tappan)	7
Miscellaneous--simple tooth, shark scale	

K-9 84.0 feet above Dakota(?) P:B 4/1

Hedbergella delrioensis (Carsey)	20
Hedbergella portsdownensis (Williams-Mitchell)	7
Clavihedbergella simplex (Morrow)	7
Clavihedbergella subdigitata (Carman)	1
Heterohelix globulosa (Ehrenberg)	7
Heterohelix pulchra (Brotzen)	5
Dentalina gracilis D'Orbigny	3
Citharina kochii (Roemer)	1
Frondicularia imbricata Young	8
Lenticulina gaultina (Berthelin)	1
Gavelinella dakotensis (Fox)	12
Coryphostoma plaita (Carsey)	6
Neobulimina albertneis (Stelck and Wall)	5

K-9--Continued

	Praebulimina ovulum (Reuss)		4
	Coscinophragma ? cf. C. codyensis (Fox)		15
	Haplophragmium arenatum Lamb		5
K-10	95.2 feet above Dakota(?)	P:B 100/1	
	Hedbergella delrioensis (Carsey)		31
	Hedbergella portsdownensis (Williams-Mitchell)		8
	Clavihedbergella simplex (Morrow)		2
	Clavihedbergella subdigitata (Carman)		1
	Heterohelix globulosa (Ehrenberg)		12
	Heterohelix pulchra (Brotzen)		3
	Gavelinella dakotensis (Fox)		2
	Coryphostoma plaita (Carsey)		3
	Ammobaculites cf. A. impexus Eicher		2
	Coscinophragma ? cf. C. codyensis (Fox)		2
	Reophax inordinatus Young		5
	Saccammina alexanderi (Loeblich and Tappan)		1
K-11	106.4 feet above Dakota(?)	P:B 100/1	
	Hedbergella delrioensis (Carsey)		34
	Hedbergella portsdownensis (Williams-Mitchell)		4
	Clavihedbergella subdigitata (Carman)		1
	Heterohelix globulosa (Ehrenberg)		17
	Dentalina gracilis D'Orbigny		1
	Gavelinella dakotensis (Fox)		10
	Reophax inordinatus Young		1
	Trochammina wickendeni Loeblich		3
	Saccammina alexanderi (Loeblich and Tappan)		3
	Miscellaneous--simple teeth, bone fragments		
K-12	117.6 feet above Dakota(?)	P:B 100/1	
	Hedbergella delrioensis (Carsey)		36
	Hedbergella portsdownensis (Williams-Mitchell)		2
	Clavihedbergella simplex (Morrow)		4
	Clavihedbergella subdigitata (Carman)		1
	Heterohelix globulosa (Ehrenberg)		23
	Gavelinella dakotensis (Fox)		1
K-13	128.8 feet above Dakota(?)	P:B 100/1	
	Hedbergella delrioensis (Carsey)		42
	Hedbergella portsdownensis (Williams-Mitchell)		7
	Clavihedbergella simplex (Morrow)		2
	Clavihedbergella subdigitata (Carman)		4
	Heterohelix globulosa (Ehrenberg)		9
	Heterohelix pulchra (Brotzen)		3
	Planoglobulina cf. P. glabrata (Cushman)		1

K-13--Continued

	Dentalina gracilis D'Orbigny	3
	Frondicularia imbricata Young	4
	Nodosaria bighornensis Young	3
	Gavelinella dakotensis (Fox)	9
	Coryphostoma plaita (Carsey)	1
	Marginulinopsis amplaspira Young	14
	Trochammina wickendeni Loeblich	1
	Saccammina alexanderi (Loeblich and Tappan)	2
K-14	140.0 feet above Dakota(?) P:B 100/1	
	Hedbergella delrioensis (Carsey)	40
	Hedbergella portsdownensis (Williams-Mitchell)	4
	Heterohelix globulosa (Ehrenberg)	11
	Dentalina gracilis D'Orbigny	1
	Gavelinella dakotensis (Fox)	1
	Miscellaneous--shark scale, bone fragments	
K-15	151.2 feet above Dakota(?) P:B 100/1	
	Hedbergella delrioensis (Carsey)	46
	Hedbergella portsdownensis (Williams-Mitchell)	4
	Clavihedbergella subdigitata (Carman)	2
	Heterohelix globulosa (Ehrenberg)	11
	Heterohelix pulchra (Brotzen)	3
	Planoglobulina cf. P. glabrata (Cushman)	1
	Gavelinella dakotensis (Fox)	2
K-16	162.4 feet above Dakota(?) P:B 100/1	
	Hedbergella delrioensis (Carsey)	43
	Hedbergella portsdownensis (Williams-Mitchell)	5
	Clavihedbergella simplex (Morrow)	3
	Clavihedbergella subdigitata (Carman)	1
	Heterohelix globulosa (Ehrenberg)	13
	Heterohelix pulchra (Brotzen)	2
	Dentalina gracilis D'Orbigny	4
	Marginulinopsis amplaspira Young	8
	Ammobaculites cf. A. junceus Cushman and Applin	7
	Trochammina wickendeni Loeblich	1
	Saccammina alexanderi (Loeblich and Tappan)	1
K-17	173.6 feet above Dakota(?) P:B 13/1	
	Hedbergella delrioensis (Carsey)	34
	Hedbergella portsdownensis (Williams-Mitchell)	5
	Heterohelix globulosa (Ehrenberg)	6
	Heterohelix pulchra (Brotzen)	4
	Dentalina gracilis D'Orbigny	2
	Frondicularia imbricata Young	1

K-17--Continued

Gavelinella dakotensis (Fox)	13
Marginulinopsis amplaspira Young	3
Reophax inordinatus Young	1
Trochamminoides apricarius Eicher	1
Trochammina wickendeni Loeblich	18
Saccammina alexanderi (Loeblich and Tappan)	2

K-18 184.8 feet above Dakota(?) P:B 100/1

Hedbergella delrioensis (Carsey)	33
Hedbergella portsdownensis (Williams-Mitchell)	4
Heterohelix globulosa (Ehrenberg)	18
Heterohelix pulchra (Brotzen)	4
Gavelinella dakotensis (Fox)	4

K-19 196.0 feet above Dakota(?) P:B 100/1

Hedbergella delrioensis (Carsey)	34
Hedbergella portsdownensis (Williams-Mitchell)	6
Heterohelix globulosa (Ehrenberg)	10
Heterohelix pulchra (Brotzen)	2
Gavelinella dakotensis (Fox)	4
Coryphostoma plaita (Carsey)	1
Trochammina wickendeni Loeblich	3

K-20 207.2 feet above Dakota(?) P:B 19/1

Hedbergella delrioensis (Carsey)	30
Hedbergella portsdownensis (Williams-Mitchell)	6
Clavihedbergella simplex (Morrow)	9
Praeglobotruncana difformis (Gandolfi) (=P. marginata (Reuss))	3
Heterohelix globulosa (Ehrenberg)	12
Heterohelix pulchra (Brotzen)	3
Frondicularia imbricata Young	4
Gavelinella dakotensis (Fox)	17
Coryphostoma plaita (Carsey)	1
Neobulimina albertensis (Stelck and Wall)	6
Marginulinopsis amplaspira Young	4
Trochammina wickendeni Loeblich	2

K-21 224.0 feet above Dakota(?) P:B 13/1

Hedbergella delrioensis (Carsey)	35
Hedbergella portsdownensis (Williams-Mitchell)	5
Clavihedbergella simplex (Morrow)	2
Clavihedbergella subdigitata (Carman)	1
Heterohelix globulosa (Ehrenberg)	2
Dentalina gracilis D'Orbigny	1
Gavelinella dakotensis (Fox)	13

K-21--Continued

	Reophax recta (Beissel)		14
	Trochammina wickendeni Loeblich		23
	Saccammina alexanderi (Loeblich and Tappan)		4
K-22	235.2 feet above Dakota(?)	P:B 1/6	
	Hedbergella delrioensis (Carsey)		13
	Gavelinella dakotensis (Fox)		8
	Reophax recta (Beissel)		22
	Gaudryina spritensis Stelck and Wall		2
	Trochammina alexanderi Loeblich		35
	Saccammina alexanderi (Loeblich and Tappan)		13
	Miscellaneous--bone fragments, simple teeth, spines		
K-23	246.4 feet above Dakota(?)	P:B over 100	
	Hedbergella delrioensis (Carsey), weathered		33
	Hedbergella portsdownensis (Williams-Mitchell)		3
	Clavihedbergella simplex (Morrow), weathered		1
	Heterohelix globulosa (Ehrenberg), weathered		27
	Heterohelix pulchra (Brotzen), weathered		3
	Reophax recta (Beissel)		1
K-24	257.6 feet above Dakota(?)		
	Hedbergella delrioensis (Carsey), weathered		24
	Hedbergella portsdownensis (Williams-Mitchell)		4
	Heterohelix globulosa (Ehrenberg), weathered		16
	Heterohelix pulchra (Brotzen), weathered		1
	Megaspores, species A		3
	Miscellaneous--iron oxide (?) concretions, simple teeth, bone fragments		
K-25	268.8 feet above Dakota(?)		
	Megaspores, species A		4
	Miscellaneous--bone fragments, spines		
K-26	280.0 feet above Dakota(?)		
	Hedbergella delrioensis (Carsey), corroded		9
	Reophax recta (Beissel)		10
	Trochammina wickendeni Loeblich		23
	Megaspores, species A		2
	Miscellaneous--simple teeth, bone, spines		

K-27	291.2 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), corroded	12
	Heterohelix pulchra (Brotzen), corroded	1
	Megaspores, species A	3
	Miscellaneous--iron oxide (?) concretions, bone fragments, simple teeth, spines	
K-28	302.4 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), corroded	14
	Heterohelix globulosa (Ehrenberg), corroded	5
	Megaspores, species A	5
	Miscellaneous--bone fragments	
K-29	313.6 feet above Dakota(?)	
	Trochammina wickendeni Loeblich	4
	Megaspores, species A	9
	Miscellaneous--iron oxide (?) concretions, bone fragments, simple teeth	
K-30	324.8 feet above Dakota(?)	
	Megaspores, species A	32
	Miscellaneous--bone fragments, simple teeth	
K-31	336.0 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), corroded	1
	Hedbergella portsdownensis (Williams-Mitchell)	1
	Heterohelix globulosa (Ehrenberg)	1
	Megaspores, species A	21
	Megaspores, species B	1
	Miscellaneous--iron oxide (?) concretions, simple teeth, bone fragments	
K-32	347.2 feet above Dakota(?)	
	Haplocytheridea (cf. *H*. *nanifaba* Crane) L.V.	1
	Cythereis (cf. *C*. *rugosissima* Alexander) L.V.	1
	Hedbergella delrioensis (Carsey), weathered	1
	Quinquiloculina sp., corroded	1
	Megaspores, species A	36
	Miscellaneous--broken and corroded scaphopod, iron oxide (?) concretions, small corroded gastropods, bone, scale	
	Oligostegina (*Pithonella*)	1

K-33 358.4 feet above Dakota(?)

Hedbergella delrioensis (Carsey), corroded	1
Trochammina cf. *T. wickendeni* Loeblich	90
Haplophragmoides sp.	1
Saccammina alexanderi (Loeblich and Tappan)	2
Oligostegina (*Pithonella*)	5
Megaspores, species A	1
Miscellaneous--bone fragments, simple teeth, shark scale	

K-34 369.6 feet above Dakota(?)

Trochammina cf. *T. wickendeni* Loeblich	2
Megaspores, species A	77
Megaspores, species B	17
Miscellaneous--bone fragments, simple teeth, scale	

K-35 380.8 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered	2
Trochammina wickendeni Loeblich	3
Megaspores, species A	70
Megaspores, species B	10
Oligostegina (*Pithonella*)	1
Miscellaneous--iron oxide (?) concretions, bone fragments, simple teeth, scale	

K-36 392.0 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered	1
Trochammina wickendeni Loeblich	12
Megaspores, species A	34
Megaspores, species B	5
Miscellaneous--bone fragments	

K-37 403.2 feet above Dakota(?)

Trochammina wickendeni Loeblich	5
Megaspores, species A	24
Megaspores, species B	9
Miscellaneous--bone fragments	

K-38 414.4 feet above Dakota(?)

Gavelinella dakotensis (Fox), weathered	1
Trochammina wickendeni Loeblich	27
Megaspores, species A	17
Megaspores, species B	13
Miscellaneous--bone fragments, three shark scales	

K-39	425.6 feet above Dakota(?)	
	<u>Hedbergella</u> <u>delrioensis</u> (Carsey), weathered	1
	<u>Haplophragmoides</u> cf. <u>H</u>. <u>gilberti</u> Eicher	1
	<u>Trochammina</u> <u>wickendeni</u> Loeblich	3
	Megaspores, species A	16
	Megaspores, species B	9
	Miscellaneous--bone fragments	
K-40	436.8 feet above Dakota(?)	
	<u>Gaudryina</u> <u>bentonensis</u> (Carman)	1
	<u>Trochammina</u> <u>wickendeni</u> Loeblich	5
	Megaspores, species A	24
	Megaspores, species B	9
	Miscellaneous--bone fragments	
K-41	448.0 feet above Dakota(?)	
	<u>Trochammina</u> <u>wickendeni</u> Loeblich	76
	Megaspores, species A	2
	Megaspores, species B	1
	Miscellaneous--gastropod, corroded and etched; bone fragments	
K-42	459.2 feet above Dakota(?)	
	<u>Trochammina</u> <u>wickendeni</u> Loeblich	98
	Megaspores, species A	2
	Megaspores, species B	3
	Miscellaneous--weathered and corroded gastropod; worm tube (?)	
K-43	470.4 feet above Dakota(?)	
	<u>Trochammina</u> <u>wickendeni</u> Loeblich	30
K-44	481.6 feet above Dakota(?)	
	<u>Trochammina</u> <u>wickendeni</u> Loeblich	26
K-45	492.8 feet above Dakota(?)	
	<u>Gaudryina</u> <u>bentonensis</u> (Carman)	27
	<u>Haplophragmoides</u> cf. <u>H</u>. <u>gilberti</u> Eicher	19
	<u>Trochammina</u> <u>wickendeni</u> Loeblich	5
	Miscellaneous--bone fragments, simple teeth, spines, shark scale	

K-46 504.0 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered	2
Dentalina gracilis D'Orbigny, weathered	1
Gaudryina bentonensis (Carman)	5
Trochammina wickendeni Loeblich	15
Miscellaneous--bone fragments, simple teeth, scale	

K-47 515.2 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered	1
Marginulinopsis amplaspira Young, weathered	1
Gaudryina bentonensis (Carman)	5
Trochammina wickendeni Loeblich	31
Miscellaneous--bone fragments, simple teeth, shark scale	

K-48 526.4 feet above Dakota(?)

Gaudryina bentonensis (Carman)	13
Haplophragmoides cf. H. gilberti Eicher	2
Trochammina wickendeni Loeblich	56
Trochammina wetteri Stelck and Wall	12
Miscellaneous--bone fragments, simple teeth, spines	

K-49 537.6 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered	1
Gaudryina bentonensis (Carman)	17
Trochammina wickendeni Loeblich	20
Trochammina wetteri Stelck and Wall	3
Miscellaneous--bone fragments, simple teeth, spines	

K-50 548.8 feet above Dakota(?)

Gaudryina bentonensis (Carman)	28
Trochammina wickendeni Loeblich	1
Trochammina wetteri Stelck and Wall	1
Spiroplectammina cf. S. acostai Tappan	1
Miscellaneous--bone fragments, spines, several "pavement" type scales	

K-51 627.2 feet above Dakota(?)

Gaudryina bentonensis (Carman)	27
Haplophragmoides cf. H. gilberti Eicher	13
Ammobaculites junceus Cushman and Applin	2
Reophax inordinatus Young	8
Trochammina wickendeni Loeblich	5

K-51--Continued

	Saccammina alexanderi (Loeblich and Tappan)	6
	Megaspores, species B	2
	Miscellaneous--bone fragments, weathered and corroded gastropods	
K-52	638.4 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	3
	Haplophragmoides cf. H. gilberti Eicher	38
	Haplophragmoides howardense Stelck and Wall	8
	Ammobaculites junceus Cushman and Applin	8
	Ammobaculites cf. A. impexus Eicher	3
	Reophax inordinatus Young	2
	Reophax pepperensis Loeblich	1
	Saccammina alexanderi (Loeblich and Tappan)	9
	Spiroplectammina acostai Tappan	20
	Miscellaneous--bone fragments	
K-53	649.6 feet above Dakota(?)	
	Gaudryina bentonensis (Carman)	33
	Haplophragmoides cf. H. gilberti Eicher	31
	Haplophragmoides howardense Stelck and Wall	2
	Ammobaculites junceus Cushman and Applin	7
	Reophax inordinatus Young	11
	Reophax pepperensis Loeblich	3
	Saccammina alexanderi (Loeblich and Tappan)	18
	Spiroplectammina acostai Tappan	2
	Miscellaneous--bone fragments, spines	
K-54	655.2 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), weathered	2
	Gaudryina bentonensis (Carman)	26
	Haplophragmoides cf. H. gilberti Eicher	8
	Haplophragmoides howardense Stelck and Wall	4
	Ammobaculites junceus Cushman and Applin	7
	Ammobaculites cf. A. impexus Eicher	7
	Reophax recta (Beissel)	1
	Reophax inordinatus Young	15
	Reophax pepperensis Loeblich	3
	Saccammina alexanderi (Loeblich and Tappan)	21
	Spiroplectammina acostai Tappan	10
	Miscellaneous--bone fragments, scales	

Lohali Point

LP-1	Immediately on top of Dakota(?) Sandstone P:B 32/1	
	Cythereis eaglefordensis Alexander	5
	Cytheropteron cf. *C. castorense* Butler and Jones	1
	Hedbergella delrioensis (Carsey)	27
	Hedbergella portsdownensis (Williams-Mitchell)	8
	Heterohelix globulosa (Ehrenberg)	5
	Dentalina gracilis D'Orbigny	2
	Gavelinella dakotensis (Fox)	5
	Haplophragmoides collyra Nauss	1
LP-2	5.7 feet above Dakota(?) P:B 50/1	
	Hedbergella delrioensis (Carsey)	36
	Heterohelix globulosa (Ehrenberg)	1
	Guembelitria harrisi Tappan	1
	Gavelinella dakotensis (Fox)	2
	Haplophragmoides collyra Nauss	1
	Saccammina alexanderi (Loeblich and Tappan)	1
LP-3	11.3 feet above Dakota(?) P:B 6/10	
	Cythereis eaglefordensis Alexander	1
	Hedbergella delrioensis (Carsey)	19
	Heterohelix globulosa (Ehrenberg)	3
	Dentalina gracilis D'Orbigny	1
	Lenticulina cf. *L. gaultina* (Berthelin)	2
	Gavelinella dakotensis (Fox)	2
	Reophax minuta Tappan	9
	Haplophragmoides collyra Nauss	6
	Trochammina wickendeni Loeblich	1
	Saccammina alexanderi (Loeblich and Tappan)	17
LP-4	17.0 feet above Dakota(?) P:B 7/1	
	Cythereis eaglefordensis Alexander	6
	Cytheropteron cf. *C. castorense* Butler and Jones	2
	Hedbergella delrioensis (Carsey)	19
	Hedbergella portsdownensis (Williams-Mitchell)	6
	Clavihedbergella simplex (Morrow)	3
	Guembelitria harrisi Tappan	3
	Globigerinelloides bentonensis	3
	Rotalipora greenhornensis (Morrow)	2
	Praeglobotruncana stephani (Gandolfi)	1
	Heterohelix globulosa (Ehrenberg)	4
	Citharina kochii (Roemer)	1
	Frondicularia imbricata Young	4
	Dentalina gracilis D'Orbigny	5
	Lenticulina cf. *L. gaultina* (Berthelin)	2

LP-4--Continued

	Gavelinella dakotensis (Fox)	6
	Neobulimina albertense (Stelck and Wall)	1
	Quinquiloculina moremani Cushman	5
	Trochammina wickendeni Loeblich	7
	Saccammina alexanderi (Loeblich and Tappan)	7
LP-5	22.7 feet above Dakota(?) P:B 5/1	
	Cythereis eaglefordensis Alexander	5
	Hedbergella delrioensis (Carsey)	12
	Hedbergella portsdownensis (Williams-Mitchell)	4
	Clavihedbergella simplex (Morrow)	3
	Guembelitria harrisi Tappan	6
	Globigerinelloides bentonensis (Morrow)	7
	Rotalipora greenhornensis (Morrow)	1
	Praeglobotruncana stephani (Gandolfi)	3
	Heterohelix globulosa (Ehrenberg)	4
	Dentalina gracilis D'Orbigny	3
	Lenticulina cf. L. gaultina (Berthelin)	1
	Gavelinella dakotensis (Fox)	3
	Quinquiloculina moremani Cushman	1
	Haplophragmoides collyra Nauss	3
	Reophax minuta Tappan	4
	Ammobaculites cf. A. impexus Eicher	7
	Saccammina alexanderi (Loeblich and Tappan)	3
	Miscellaneous--shark scales (2)	
LP-6	28.4 feet above Dakota(?) P:B 1/1	
	Cythereis eaglefordensis Alexander	5
	Cytheropteron cf. C. castorense Butler and Jones	1
	Hedbergella delrioensis (Carsey)	45
	Hedbergella portsdownensis (Williams-Mitchell)	2
	Citharina kochii (Roemer)	5
	Frondicularia imbricata Young	1
	Gavelinella dakotensis (Fox)	2
	Quinquiloculina moremani Cushman	38
	Haplophragmoides collyra Nauss	2
	Trochammina wickendeni Loeblich	2
LP-7	34.0 feet above Dakota(?) P:B 1/3	
	Cythereis eaglefordensis Alexander	2
	Hedbergella delrioensis (Carsey)	6
	Quinquiloculina moremani Cushman	20

LP-8 39.7 feet above Dakota(?) P:B 1/7

Cytheropteron cf. C. castorense Butler and Jones	6
Hedbergella delrioensis (Carsey)	9
Heterohelix globulosa (Ehrenberg)	9
Guembelitria harrisi Tappan	8
Citharina kochii (Roemer)	5
Dentalina gracilis D'Orbigny	2
Nodosaria bighornensis Young	1
Gavelinella dakotensis (Fox)	20
Coryphostoma plaita (Carsey)	2
Haplophragmoides collyra Nauss	19
Haplophragmoides cf. H. hendersonense Stelck and Wall	2
Haplophragmoides cf. H. gilberti Eicher	4
Trochammina wickendeni Loeblich	5

LP-9 51.0 feet above Dakota(.) P:B 4/1

Hedbergella delrioensis (Carsey)	25
Hedbergella portsdownensis (Williams-Mitchell)	5
Guembelitria harrisi Tappan	4
Globigerinelloides bentonensis (Morrow)	1
Heterohelix globulosa (Ehrenberg)	8
Citharina kochii (Roemer)	3
Dentalina gracilis D'Orbigny	12
Gavelinella dakotensis (Fox)	18
Neobulimina albertensis (Stelck and Wall)	6
Quinquiloculina moremani Cushman	1
Haplophragmoides collyra Nauss	2

LP-10 62.4 feet above Dakota(?) P:B 4/1

Hedbergella delrioensis (Carsey)	20
Hedbergella portsdownensis (Williams-Mitchell)	8
Clavihedbergella simplex (Morrow)	3
Clavihedbergella subdigitata (Carman)	4
Guembelitria harrisi Tappan	4
Heterohelix globulosa (Ehrenberg)	9
Heterohelix pulchra (Brotzen)	4
Dentalina gracilis D'Orbigny	9
Gavelinella dakotensis (Fox)	17
Coryphostoma plaita (Carsey)	2
Neobulimina albertensis (Stelck and Wall)	6
Reophax inordinatus Young	1
Trochammina wickendeni Loeblich	6
Saccammina alexanderi (Loeblich and Tappan)	1

LP-11 73.7 feet above Dakota(?) P:B 4/1

Hedbergella delrioensis (Carsey)	20
Hedbergella portsdownensis (Williams-Mitchell)	4
Clavihedbergella simplex (Morrow)	7
Clavihedbergella subdigitata (Carman)	4
Guembelitria harrisi Tappan	4
Heterohelix globulosa (Ehrenberg)	8
Heterohelix pulchra (Brotzen)	4
Citharina kochii (Roemer)	3
Dentalina gracilis D'Orbigny	2
Nodosaria bighornensis Young	3
Gavelinella dakotensis (Fox)	16
Coryphostoma plaita (Carsey)	3
Neobulimina albertense (Stelck and Wall)	7
Haplophragmoides collyra Nauss	1

LP-12 85.1 feet above Dakota(?) P:B 3/2

Hedbergella delrioensis (Carsey)	20
Hedbergella portsdownensis (Williams-Mitchell)	5
Clavihedbergella simplex (Morrow)	9
Clavihedbergella subdigitata (Carman)	5
Heterohelix globulosa (Ehrenberg)	7
Heterohelix pulchra (Brotzen)	4
Citharina kochii (Roemer)	1
Frondicularia imbricata Young	6
Dentalina gracilis D'Orbigny	1
Gavelinella dakotensis (Fox)	18
Coryphostoma plaita (Carsey)	6
Neobulimina albertense (Stelck and Wall)	7
Haplophragmoides collyra Nauss	2
Trochammina wickendeni Loeblich	2
Saccammina alexanderi (Loeblich and Tappan)	6

LP-13 96.4 feet above Dakota(?) P:B 4/1

Hedbergella delrioensis (Carsey)	20
Hedbergella portsdownensis (Williams-Mitchell)	5
Clavihedbergella simplex (Morrow)	1
Heterohelix globulosa (Ehrenberg)	6
Heterohelix pulchra (Brotzen)	6
Citharina kochii (Roemer)	1
Frondicularia imbricata Young	1
Gavelinella dakotensis (Fox)	9
Coryphostoma plaita (Carsey)	7
Neobulimina albertense (Stelck and Wall)	6

LP-14 107.7 feet above Dakota(?) P:B 100/1

Hedbergella delrioensis (Carsey)	20
Hedbergella portsdownensis (Williams-Mitchell)	10
Clavihedbergella simplex (Morrow)	3
Clavihedbergella subdigitata (Carman)	4
Heterohelix globulosa (Ehrenberg)	11
Heterohelix pulchra (Brotzen)	7
Lunatriella spinifera Eicher and Worstell	1
Planoglobulina cf. P. glabrata (Cushman)	2
Dentalina gracilis D'Orbigny	1
Gavelinella dakotensis (Fox)	7
Coryphostoma plaita (Carsey)	5
Neobulimina albertense (Stelck and Wall)	4
Saccammina alexanderi (Loeblich and Tappan)	3

LP-15 119.1 feet above Dakota(?) P:B 100/1

Hedbergella delrioensis (Carsey)	21
Hedbergella portsdownensis (Williams-Mitchell)	6
Clavihedbergella simplex (Morrow)	9
Clavihedbergella subdigitata (Carman)	3
Heterohelix globulosa (Ehrenberg)	10
Heterohelix pulchra (Brotzen)	7
Lunatriella spinifera Eicher and Worstell	7
Gavelinella dakotensis (Fox)	2
Coryphostoma plaita (Carsey)	1
Neobulimina albertense (Stelck and Wall)	1

LP-16 130.4 feet above Dakota(?) P:B 24/1

Hedbergella delrioensis (Carsey)	21
Hedbergella portsdownensis (Williams-Mitchell)	12
Clavihedbergella simplex (Morrow)	8
Clavihedbergella subdigitata (Carman)	6
Heterohelix globulosa (Ehrenberg)	7
Heterohelix pulchra (Brotzen)	5
Dentalina gracilis D'Orbigny	1
Gavelinella dakotensis (Fox)	9
Coryphostoma plaita (Carsey)	2
Neobulimina albertense (Stelck and Wall)	1
Saccammina alexanderi (Loeblich and Tappan)	7

LP-17 141.8 feet above Dakota(?) P:B 100/1

Hedbergella delrioensis (Carsey)	25
Hedbergella portsdownensis (Williams-Mitchell)	12
Clavihedbergella simplex (Morrow)	4
Heterohelix globulosa (Ehrenberg)	8
Heterohelix pulchra (Brotzen)	6

LP-17--Continued

	Dentalina gracilis D'Orbigny	1
	Gavelinella dakotensis (Fox)	3
	Saccammina alexanderi (Loeblich and Tappan)	9

LP-18 153.1 feet above Dakota(?) P:B 32/1

Hedbergella delrioensis (Carsey)	20
Hedbergella portsdownensis (Williams-Mitchell)	8
Clavihedbergella simplex (Morrow)	6
Clavihedbergella subdigitata (Carman)	5
Clavihedbergella moremani (Cushman)	1
Heterohelix globulosa (Ehrenberg)	9
Heterohelix pulchra (Brotzen)	7
Lunatriella spinifera Eicher and Worstell	3
Dentalina gracilis D'Orbigny	1
Frondicularia imbricata Young	1
Gavelinella dakotensis (Fox)	8
Coryphostoma plaita (Carsey)	2
Neobulimina albertense (Stelck and Wall)	4
Nodosaria bighornensis Young	3
Marginulinopsis amplaspira Young	4
Haplophragmoides collyra Nauss	3
Trochammina wickendeni Loeblich	1
Saccammina alexanderi (Loeblich and Tappan)	2

LP-19 164.4 feet above Dakota(?) P:B 100/1

Hedbergella delrioensis (Carsey)	20
Hedbergella portsdownensis (Williams-Mitchell)	7
Clavihedbergella simplex (Morrow)	8
Clavihedbergella subdigitata (Carman)	7
Heterohelix globulosa (Ehrenberg)	10
Heterohelix pulchra (Brotzen)	7
Gavelinella dakotensis (Fox)	5
Coryphostoma plaita (Carsey)	2
Marginulinopsis amplaspira Young	1
Trochammina wickendeni Loeblich	1

LP-20 175.8 feet above Dakota(?) P:B 100/1

Hedbergella delrioensis (Carsey)	24
Hedbergella portsdownensis (Williams-Mitchell)	13
Clavihedbergella simplex (Morrow)	5
Clavihedbergella subdigitata (Carman)	5
Heterohelix globulosa (Ehrenberg)	11
Heterohelix pulchra (Brotzen)	6
Nodosaria bighornensis Young	1
Gavelinella dakotensis (Fox)	7
Neobulimina albertensis (Stelck and Wall)	2
Trochammina wickendeni Loeblich	1

LP-21 187.1 feet above Dakota(?) P:B 24/1

Hedbergella delrioensis (Carsey)	22
Hedbergella portsdownensis (Williams-Mitchell)	6
Heterohelix globulosa (Ehrenberg)	6
Gavelinella dakotensis (Fox)	14
Marginulinopsis amplaspira Young	6

LP-22 198.5 feet above Dakota(?) P:B 24/1

Hedbergella delrioensis (Carsey)	21
Hedbergella portsdownensis (Williams-Mitchell)	13
Clavihedbergella simplex (Morrow)	7
Clavihedbergella subdigitata (Carman)	5
Clavihedbergella moremani (Cushman)	5
Heterohelix globulosa (Ehrenberg)	9
Heterohelix pulchra (Brotzen)	7
Planoglobulina cf. *P. glabrata* (Cushman)	2
Gavelinella dakotensis (Fox)	10
Coryphostoma plaita (Carsey)	2
Neobulimina albertense (Stelck and Wall)	4
Reophax inordinatus Young	2
Haplophragmoides collyra Nauss	3
Trochammina wickendeni Loeblich	8
Spiroplectammina cf. *S. acostai* Tappan	1

LP-23 209.8 feet above Dakota(?) P:B 100/1

Hedbergella delrioensis (Carsey)	25
Hedbergella portsdownensis (Williams-Mitchell)	12
Clavihedbergella simplex (Morrow)	2
Heterohelix globulosa (Ehrenberg)	11
Heterohelix pulchra (Brotzen)	4
Gavelinella dakotensis (Fox)	9
Trochammina wickendeni Loeblich	1

LP-24 221.1 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered	21
Hedbergella portsdownensis (Williams-Mitchell)	11
Heterohelix globulosa (Ehrenberg), weathered	10
Heterohelix pulchra (Brotzen), weathered	3

LP-25 232.5 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered	23
Hedbergella portsdownensis (Williams-Mitchell)	2
Heterohelix globulosa (Ehrenberg), weathered	7
Heterohelix pulchra (Brotzen), weathered	3

LP-26 243.8 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered	3
Trochammina wickendeni Loeblich	15
Megaspores, species A	1

LP-27 255.2 feet above Dakota(?)

Barren

LP-28 266.5 feet above Dakota(?)

Barren

LP-29 277.8 feet above Dakota(?)

Barren

LP-30 289.2 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered	3
Megaspores, species A	15

LP-31 300.5 feet above Dakota(?)

Hedbergella delrioensis (Carsey), weathered	1
Megaspores, species A	9

LP-32 311.9 feet above Dakota(?)

Hedbergella delrioensis (Carsey, weathered	4
Trochammina wickendeni Loeblich	22
Megaspores, species A	8

LP-33 323.2 feet above Dakota(?)

Megaspores, species A	31
Megaspores, species B	2

LP-34 334.5 feet above Dakota(?)

Megaspores, species A	34
Megaspores, species B	5

LP-35 345.9 feet above Dakota(?)

Megaspores, species A	36
Megaspores, species B	2

LP-36	357.2 feet above Dakota(?)	
	Megaspores, species A	29
	Megaspores, species B	5
LP-37	368.6 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), weathered	1
	Megaspores, species A	10
	Megaspores, species B	7
LP-38	379.9 feet above Dakota(?)	
	Megaspores, species A	26
	Megaspores, species B	5
LP-39	391.2 feet above Dakota(?)	
	Megaspores, species A	18
	Megaspores, species B	5
LP-40	402.6 feet above Dakota(?)	
	Trochammina wickendeni Loeblich	4
LP-41	413.9 feet above Dakota(?)	
	Trochammina wickendeni Loeblich	34
	Megaspores, species A	2
LP-42	425.3 feet above Dakota(?)	
	Trochammina wickendeni Loeblich	20
LP-43	427.6 feet above Dakota(?)	
	Hedbergella delrioensis (Carsey), weathered	3
	Gaudryina bentonensis (Carman)	1
	Trochammina wickendeni Loeblich	10
	Oligostegina (Pithonella)	1

APPENDIX II

LOCATION AND DESCRIPTION OF MEASURED AND SAMPLED OUTCROP SECTIONS OF MANCOS SHALE, BLACK MESA, ARIZONA

The locations of the five outcrop sections described in this section are shown on Figure 2 (in pocket).

Colors are designated according to the Munsell system of color classification (National Research Council Rock Color Chart, Goddard, 1948).

Howell Mesa Section

Section of Mancos Shale on eastern side of Howell Mesa, 10 miles northwest of Hotevilla, Coconino County, Arizona; line of section N. 85° W., dips 2° W.

(Measured by G. C. Hazenbush, July 15, 16, 1969)

	Thickness (feet)
Top of section; not top of exposure	
Toreva Sandstone (unmeasured):	
14. Sandstone, dark yellowish orange (10YR 6/6), weathering lighter orange, medium- to fine-grained, fair to poor sorting; composed of angular to subround quartz, dominantly subangular, weathered feldspar and bleached biotite; forms thin flat-lying horizontal beds from 1/4 inch to about 4 inches thick; forms top of northeast portion of Howell Mesa	
Mancos Shale:	
13. Silty shale and shale, 50%/50%; silty shale, grayish-orange (10YR 7/4); shale, pale-brown (5YR 5/2), interbedded in 1/8-inch to 1/2-inch beds; fissile to blocky, medium soft, appears horizontally laminated; weathers to form recess under overlying Toreva	1.6
12. Silty shale, moderate-brown (5YR 3/4 and 5YR 4/4), weathers lighter brown; clay and silt, fair to poor sorting; thin horizontal laminations; poor to fair cement, hard to medium soft; fissile to blocky; contains bleached biotite flakes and gypsum in fractures; forms steep slope.	56.0
11. Shale, dark yellowish brown (10YR 4/2), weathers lighter brown; clay and some silt, fair sorting, thin horizontal laminations, soft, poorly cemented, fissile, platy, gypsum in fractures; forms irregular slope; contains 8-inch bed of fine-grained sandstone 6 feet above base; sandstone is hard, blocky, quartzose	56.0
10. Covered interval, forms slope base	33.6

		Feet
9.	Shale, moderate yellowish brown (10YR 5/4) and dark yellowish brown (10YR 4/2), weathers lighter brown; thin horizontal laminations; clay and some silt; soft, poorly cemente; contains several thin (to 1/2-inch thick) fine-grained sandstone and sandy siltstone beds that contain ammonite (Collignoniceras) imprints; forms gentle, nearly flat slope.	39.2
8.	Shale, dusky-yellow (5Y 6/4), weathers grayish-orange (10YR 7/4); silty, soft; thin horizontal laminations, fissile; forms vertical cliff. Top 2 inches of unit are a fine-grained sandstone, quartzose, massive; forms top of cliff. . .	5.6
7.	Shale, light olive gray (5Y 5/2) and light olive brown (5Y 5/6), weathers moderate yellowish brown (10YR 5/4), silty, medium soft; thin horizontal laminations; blocky; contains numerous very thin (to 1-inch thick) ripple-marked fine quartzose sandstones. Ripple marks resemble current ripples on a beach; forms vertical cliff.	22.4
6.	Shale, brownish-gray (5YR 4/1), weathers gray, well-sorted, clay; thin horizontal laminations; fissile to massive and blocky when broken; when blocky, commonly shows subconchoidal to nearly conchoidal fracture; imprints of pelecypods; hard to medium soft; contains several thin (to 1/2-inch) orange bentonite beds; forms steep slope.	61.6
5	Shale, dark greenish gray (5G 4/1), weathers medium-gray (N 5); thin horizontal laminations; hard to medium soft; fissile to blocky; contains a 1/2-inch orange bentonite bed 15 feet above base; forms steep slope.	39.2
4.	Covered interval, slide debris.	28.0
3.	Shale, dark greenish gray (5GY 4/1), weathers medium-gray (N 5); clay; thin horizontal laminations; medium soft; fissile; forms gentle slope.	39.2
2.	Covered interval.	72.8

		Feet
1.	Shale, grayish-olive (10YR 4/2), weathers light olive gray (5Y 5/2); soft; thin horizontal laminations; fissile, thin chips; contains *Gryphaea newberryi*; forms gentle slope.	22.4
	Total of Mancos Shale	477.6

Dakota(?) Sandstone (unmeasured):

Sandstone, grayish-orange (10YR 7/4), fine- to medium-grained, poor sorting; dominantly quartz, angular to subround, dominantly subangular, decomposed feldspars and dark-brown limonite(?) cemented concretions. Petrified wood.

Base of section; not base of exposure.

Blue Canyon Section

Section of Mancos Shale at northwest fork of Blue Canyon, 14 miles south of Tonalea, Coconino County, Arizona; line of section N. 30° E., dips 2° NE.

(Measured by G. C. Hazenbush, R. F. Wilson, and J. W. Brown, July 30, 31, 1968)

	Feet
Top of section; not top of exposure	
Toreva Sandstone (unmeasured):	
13. Sandstone, light olive gray (5Y 5/2), weathering yellowish-gray (5Y 7/2), fine-grained, fair sorting; predominantly subangular quartz with weathered feldspar; 2-foot thick massive bed at base grading upward through thin (1/2- to 4-inch) silty shales into thick (5- to 20-foot) horizontally bedded medium-grained sandstone units with internal horizontal beds and low-angle cross beds; forms cliff.	
Mancos Shale:	
12. Siltstone and silty shale, light olive brown (5Y 5/6) and moderate olive brown (5Y 4/4), interbedded, weathering light olive gray (5Y 5/2), thinly laminated, hard, blocky, limonite staining, contains fine subangular quartz sand; some carbonaceous fragments; forms steep slope.	70.5
11. Shale, olive-gray (5Y 4/1) and grayish-olive (10Y 4/2), weathering molderate olive brown (5Y 4/4), clay and silt; thinly bedded, hard, blocky; limonite staining; forms steep slope. . .	22.4
10. Shale, dark greenish gray (5GY 4/1), weathering brownish gray (5YR 4/1), clay and silt; thinly bedded, hard, blocky to hackly; gypsum in fractures; weathers into chips; forms steep slope.	22.4

Feet

9. Silty shale, grayish-olive (10Y 4/2), weathering moderate olive brown (5Y 4/4), dirty, poor sorting, clay and silt; thinly laminated, medium hard, blocky to fissile; forms steep slope. 39.2

8. Shale, light-olive (10Y 5/4) and olive-gray (5Y 4/1) interbedded in thin beds, clay and some silt; thinly laminated; medium hard to medium soft; hackly fracture; ammonite (Collignoniceras) imprints; forms rolling slope. 28.0

7. Silty shale and siltstone, moderate yellowish brown (10YR 5/4) and dusky-yellow (5Y 6/4), interbedded in thin beds, clay and silt containing thin streaks of fine angular quartz sand with current ripples; thinly laminated; common ammonite (Collignoniceras) imprints, especially in the thin sand zones; forms gentle slope. 22.4

6. Shale, dominantly olive-gray (5Y 4/1) with beds of moderate yellowish brown (10YR 5/4), clay and some silt; thinly laminated, firm to hard, platy and fissile to blocky; contains ammonite imprints (Collignoniceras) and pelecypod imprints throughout; cone-in-cone structure toward top; local thin (to 2 inches) fine quartz sandstone beds containing ammonite imprints; forms rolling slope. 168.0

5. Silty shale and siltstone, moderate yellowish brown (10YR 7/4), interbedded in thin beds; clay and silt, containing thin streaks of fine angular quartz sandstone with current ripples with heights as large as 1/4 inch; soft, brittle; ammonite (Collignoniceras) imprints throughout; forms flat slope at top of cliff-forming unit below. 22.4

4. Shale, greenish-black (5G 2/1) and olive-gray (5Y 4/1) at bottom, grading upward into silty shale and siltstone, grayish-orange (10YR 7/4) and dark yellowish orange (10YR 6/6) at top. Gypsum in fractures throughout. Entire unit contains about 20 orange bentonite beds 1 inch to 4 inches thick, spaced 4 to 5 feet apart at bottom of unit and about 2 feet apart near top.

	Feet
Shale and silty shale are thinly laminated, hard, platy and fissile. Top 2 feet of unit is a bundle of thin(as much as 2 inches thick), fine-grained quartz sandstone beds with current ripple marks on upper surfaces, wavelength of ripples is 1 to 3 inches, height is 1/4 inch. Entire unit contains scattered pelecypod imprints and shell fragments; forms nearly vertical cliff.	73.8
3. Shale, greenish-black (5G 2/1 and 5GY 2/1) predominantly, with shale, dark greenish gray (5GY 4/1) interbedded, weathering light olive gray (5Y 6/1), clay and minor silt; thinly laminated, soft to medium hard, fissile to blocky; thin (as thick as 3 inches) yellow-orange bentonite beds erratically interbedded. Unit contains scarce ammonite imprints and locally plentiful small pelecypod imprints; forms rolling slope.	100.8
2. Shale, dark-gray (N 3) to medium-gray (N 5), weathering predominantly medium light gray (N 6); contains yellowish-orange bentonite beds as much as 4 inches thick sparsely interbedded. Shale is clay, thinly laminated, hard and blocky to fissile, with gypsum in fractures; many Gryphaea newberryi shells we weathered out on slope, and as local beds of close-packed shells as thick as 1.5 feet; imprints of other pelecypods and gastropods; forms rolling gentle slope.	86.0
1. Shale, black (N 1) to dusky-brown (5YR 2/2), clay with carbonaceous material; hard and platy, with gypsum and limonite or jarosite in fractures; contains small amounts of petrified wood near base; forms gentle slope.	21.0
Total of Mancos Shale	676.9

Dakota(?) Sandstone (unmeasured):

Sandstone, moderate yellowish brown (10YR 5/4), medium- to fine-grained, poor sorting; dominantly quartz, angular to subround, dominantly

Feet

subangular, contains weathered feldspars; forms cliff.

Base of section; not base of exposure.

Longhouse Valley Section

Section of Mancos Shale at Longhouse Valley, immediately east of State Highway 164, 25 miles northeast of Tonalea, Navajo County, Arizona; line of section N. 85° E., dips 28° NE.

(Measured by G. C. Hazenbush, August 23, 24, 1968)

		Feet
Top of section; not top of exposure		
Toreva Sandstone (unmeasured):		
15.	Sandstone, dusky-yellow (5Y 6/4), weathering yellowish gray (5Y 7/2), fine- to medium-grained, poor to fair sorting; predominantly quartz, angular to round, predominantly subangular, weathered feldspars and bleached biotite; forms flat-lying 2.5-foot beds with silty shale partings 2 to 6 inches thick, grading upward into 5- to 15-foot sand units with internal low-angle cross beds.	
Mancos Shale:		
14.	Covered interval, Mesa Verde debris.	58.8
13.	Shale, brownish-black (5YR 2/1) damp, brownish-gray (5YR 4/1) dry; clay with some silt, medium soft; thinly laminated, fissile to blocky, brittle, with limonite stains in fractures; forms steep slope.	81.6
12.	Shale, dusky yellowish brown (10YR 2/2) damp, dark yellowish brown (10YR 4/2) dry; clay with some silt, medium soft to hard; thinly laminated, fissile to blocky; forms steep slope.	56.1
11.	Shale, olive-black (5Y 2/1) damp, olive-gray (5Y 4/1) dry; clay with some silt, medium soft, thinly laminated, fissile; forms steep slope. . . .	51.0
10.	Covered interval, Mesa Verde debris.	10.2

		Feet
9.	Shale, olive-black (5Y 2/1) damp, olive-gray (5Y 4/1) dry; clay with some silt; medium soft to hard, thinly laminated, fissile to blocky; ammonite (Collignoniceras) imprint 10 feet above base of unit; forms steep slope. . .	35.7
8.	Covered interval, Mesa Verde debris.	15.3
7.	Shale, olive-gray (5Y 4/1) dry; clay; very thinly laminated, soft to medium hard, brittle, fissile; forms steep slope.	51.0
6.	Shale, dusky yellowish green (10GY 3/2), mottled lighter color; clay; very thinly laminated, soft and somewhat soapy, brittle, fissile; unit contains three thin (1/2- to 1-inch) yellow bentonite beds and two 1/2-inch fine-grained sandstone beds; forms base of steep slope. . . .	19.8
5.	Shale, dark greenish gray (5GY 4/1); clay; soft to medium hard, thinly laminated, fissile. Unit contains approximately thirty 1/2- to 3-inch orange-yellow bentonite beds; forms rolling slope.	68.6
4.	Shale, grayish-green (5G 5/2 and 10G 4/2) 90%, and grayish-olive (10Y 4/2) 10%, interbedded; clay; thinly laminated, hard to medium soft, fissile to blocky; contains approximately ten 1-inch to 4-inch bentonite beds and several thin (1/4-inch), fine-grained sandstone beds; foraminifera visible under hand lens; forms a rolling slope.	112.7
3.	Shale, grayish-olive (10Y 4/2) 80% and pale yellowish brown (10YR 6/2) 20%, interbedded; clay; thinly laminated, soft to medium hard, fissile to blocky; foraminifera visible under hand lens; forms rolling slope.	68.6
2.	Shale, pale yellowish brown (10YR 6/2) and moderate yellowish brown (10YR 5/4); bentonitic with some fine quartz sand; soapy, soft, fissile; Gryphaea newberryi weathering out on slope; forms rolling slope.	34.3
1.	Shale, black (N 1) and olive-black (5Y 2/1) in basal half, grading upward to brownish-gray (5YR 4/1) in top half; basal half is carbonaceous,	

Feet

with limonite or jarosite in fractures, hard, and semi-fissile; top half contains thin grayish-orange siltstone beds; entire unit contains Gryphaea newberryi fragments and discontinuous lenses of shells as thick as one foot; imprints of small pelecypods throughout; gypsiferous; forms steep slope. 24.5

Total of Mancos Shale 688.2

Dakota(?) Sandstone (unmeasured):

Sandstone, grayish-orange (10R 7/4), fine-grained, fair sorting; predominantly quartz, subangular to well-rounded and frosted, dominantly subround; decomposed feldspar; well cemented and hard, probably carbonate cement; contains Gryphaea fragments; forms cliff.

Base of section; not base of exposure.

Kayenta Section

Section of Mancos Shale, northern part of Black Mesa, 4 miles southeast of Kayenta, Navajo County, Arizona; line of section N. 10° E., dips 4° NE.

(Measured by G. C. Hazenbush and J. B. Holly, June 3, 4, 1969)

		Feet
Top of section; not top of exposure		
Toreva Sandstone (unmeasured):		
14.	Sandstone, moderate yellowish brown (10YR 5/4), weathering grayish orange (10YR 7/4), fine- to medium-grained; predominantly quartz, subangular to subround, dominantly subangular, weathered feldspar and bleached biotite; in flat-lying 1- to 2-foot sets with internal low-angle cross-bedding separated by 4- to 6-inch shale partings, grading upward to medium-grained sandstone units 5 to 20 feet thick.	
Mancos Shale:		
13.	Covered interval, Mesa Verde debris.	56.0
12.	Shale, olive-black (5Y 2/1) damp, olive-gray (5YR 4/1) dry; clay and silt, thinly laminated, soft to medium hard, fissile to blocky; forms steep slope.	33.6
11.	Covered interval, Mesa Verde debris.	72.8
10.	Shale, brownish-black (5YR 2/1) damp, brownish-gray (5YR 4/1) dry; clay; thinly laminated, soft, fissile; forms steep slope.	56.0
9.	Shale, brownish-gray (5YR 4/1) damp, light brownish gray (5YR 6/1) dry at base, grading upward to moderate brown (5YR 3/4) at top; thinly laminated and fissile to blocky, limonite-stained, cone-in-cone structure in several 2-inch to 3-inch beds; forms steep slope.	39.2

		Feet
8.	Shale, olive-black (5Y 2/1) damp, olive-gray (5Y 4/1) dry, weathering olive-gray (5Y 4/1); clay with some silt; thinly laminated, soft to medium hard, fissile. Unit contains scattered thin (as much as 1/2 inch) bentonite beds throughout, a few thin (as much as 3 inches) beds showing cone-in-cone structure, and several thin (1/4 to 1/2 inch) fine-grained sandstone beds with current ripples and containing ammonite (Collignoniceras) imprints near top; ammonite imprints also found sporadically through the shale; forms steep slope. . .	100.8
7.	Shale, dark greenish gray (5GY 4/1) and grayish-olive (10Y 4/2) interbedded, weathers grayish olive (10Y 4/2) dry; clay; thinly laminated, soft, broken, fissile; forms base of steep slope.	61.6
6.	Shale, brownish-black (5YR 2/1) damp, grayish-olive (10Y 4/2) dry; clay; thinly laminated; basal 4 feet hard and blocky, rest of unit soft, broken, fissile. Unit contains two thin (1/4- to 1/2-inch) bentonite beds, one near base and one near top; forms gently rolling slope.	89.6
5.	Shale, olive-black (5Y 2/1) damp, olive-gray (5Y 4/1) dry; clay; calcareous in part; thinly laminated, hard to medium soft; blocky to fissile. Unit contains one thinly bedded fine-grained sandstone bed 3 inches thick near base and one 3-inch orange bentonite bed 5 feet below top; forms steep slope.	50.4
4.	Shale, greenish-black (5GY 2/1) and olive-black (5Y 2/1) damp, predominantly dark greenish gray (5GY 4/1) dry; clay; in part calcareous; thinly laminated, hard and blocky to soft and fissile; two current-rippled fine-grained sand beds containing broken shell hash in lower 8 feet; Ptychodus teeth and one vertebra of Hybodont shark; forms rolling slope.	67.2
3.	Shale, olive-gray (5Y 4/1) damp, dark greenish gray (5G 4/1) dry; clay; thinly laminated, fissile; forms gently rolling slope.	33.6

		Feet
2.	Shale, olive-black (5Y 2/1) and brownish-gray (5YR 4/1) damp, predominantly light olive gray (5Y 6/1) dry; clay; thinly laminated, fissile, broken into small chips; contains Gryphaea newberryi in place and weathering out on slope; forms gently rolling slope.	39.2
1.	Covered interval, slope wash and mud; contains Gryphaea shells and fragments.	11.2
	Total of Mancos Shale	711.2

Dakota(?) Sandstone:

Sandstone, grayish-orange (10YR 7/4), fine-grained, fair sorting; predominantly quartz, subangular to well rounded and frosted, dominantly subround; decomposed feldspar; well-cemented and hard, probably carbonate cement; contains broken Gryphaea fragments and local well-rounded, gray, black, and brown chert pebbles as large as 1 inch in diameter; forms cliff. Carbonaceous shale and shale unit below sandstone contains abundant petrified logs.

Base of section; not base of exposure.

Lohali Point Section

Section of Mancos Shale on eastern side of Black Mesa, southwest side of Lohali Point, 16 miles west of Chinle, Apache County, Arizona; line of section N. 80° E., dips 2° NE.

(Measured by G. C. Hazenbush, June 23, 24, 1968)

Feet

Top of section; not top of exposure

Toreva Sandstone (unmeasured):

11. Sandstone, yellowish-gray (5Y 7/2), medium- to fine-grained, fair to poor sorting; composed predominantly of quartz, subangular to well-rounded and frosted, dominantly subangular, with weathered feldspar and bleached biotite; in a 4-foot thick, broken and cracked, nearly massive unit; poorly cemented and friable; contact with Mancos is abrupt, not gradational, on shale and silty shale, the top 3 feet of which has been rolled into balls as large as 2 feet in diameter, and mixed with sand from the overlying Toreva; contact appears to be a low-angle slide, with unknown amount of Mancos Shale missing from the top of the section; forms a vertical cliff.

Mancos Shale:

10. Shale, dark yellowish brown (10YR 4/2) 90%, and dusky yellowish brown (10YR 2/2) 10%, interbedded, clay and silt; thinly laminated, medium hard, blocky to fissile except top 3 or 4 feet which is soft and friable; gypsum in fractures. Unit contains numerous thin (1/8-inch to maximum of 2-inch) discrete, yellowish, fine-grained sandstone beds, many of which show current ripples; forms very steep slope. 115.7

9. Shale, moderate-brown (5YR 3/4) 80%, and dark yellowish brown (10R 4/2) 20%, interbedded; clay; thinly laminated, hard, fissile; forms bottom of very steep slope. 79.4

		Feet
8.	Shale, pale yellowish brown (10YR 6/2); clay; calcareous in part; thinly laminated, medium soft to hard, fissile, brittle; forms gentle slope. . . .	39.7
7.	Shale, light-brown (5YR 6/4) in basal half, and dark-gray (N 3) in top half, all weathering medium light gray (N 6); clay; thinly laminated, hard, fissile; forms gentle slope.	22.6
6.	Shale, olive-gray (5Y 3/2); clay; thinly laminated, medium soft, fissile; forms steep slope.	17.0
5.	Shale, pale yellowish brown (10YR 6/2) at base, grading upward to dark yellowish brown (10YR 4/2) at top, all weathering moderate yellowish brown (10YR 5/4); clay; thinly laminated, medium hard to medium soft; fissile; <u>Gryphaea newberryi</u> fragments weathering out of base of unit; forms steep slope.	45.4
4.	Shale, medium bluish gray (5B 5/1), weathering brownish gray (5YR 4/1); clay; thinly laminated, medium hard to medium soft, blocky to fissile; one 2-inch fine-grained sandstone bed in middle of unit shows ripple marks, wavelength about 1/2 to 1 inch, height is 1/4 inch; tooth of shark (<u>Isurus</u> cf. <u>I.</u> <u>desorii</u>) weathered out on slope near middle of unit; forms base of steep slope. . .	39.6
3.	Shale, light bluish gray (5B 7/1) 80%, with shale, moderate dark reddish brown (10R 3/4) 20%, interbedded in bottom 29 feet, top 5 feet shale, light olive gray (5Y 5/2); all weathering light brownish gray (5YR 6/1); clay; gypsum in fractures; thinly laminated, soft, fissile; forms gentle rolling slope; common <u>Gryphaea</u> fragments.	34.0
2.	Shale, olive-gray (5Y 3/2) 95% with shale, moderate dark reddish brown (10R 3/4) 5%, interbedded; all weathering light gray (N 7); clay with some gypsum in fractures; many <u>Gryphaea</u> shells and fragments; thinly laminated, soft, fissile; forms gentle slope.	28.6
1.	Siltstone and silty shale, variegated and interbedded, blackish-red (5R 2/2) and moderate reddish orange (10R 6/6), clay with considerable	

Feet

silt and fine sand; thinly laminated, hard, fissile; forms base of gentle slope above Dakota(?). 5.6

Total of Mancos Shale 427.6

Dakota(?) Sandstone (unmeasured):

Sandstone, moderate yellowish brown (10YR 5/4), coarse- to medium-grained, poor sorting; predominantly quartz, subangular to well-rounded, dominantly subangular, contains sparse, rounded chert pebbles as large as 1/4 inch and carbonaceous material; upper unit is 5 feet thick, internally crossbedded at low angles; overlies 2 feet of coaly shale; forms cliff.

Base of section; not base of exposure.

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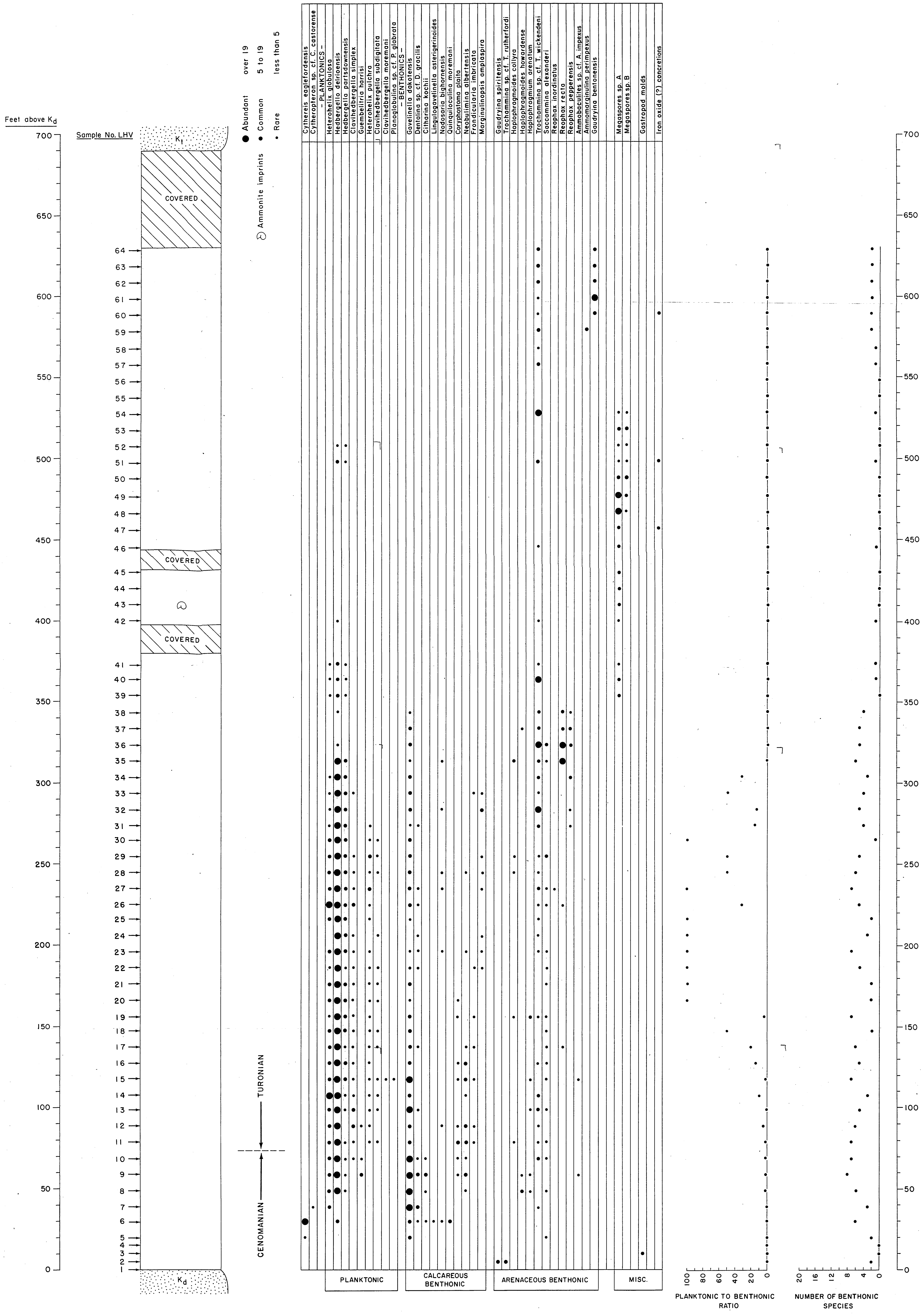

Figure 5. Distribution of microfossils at Longhouse Valley.

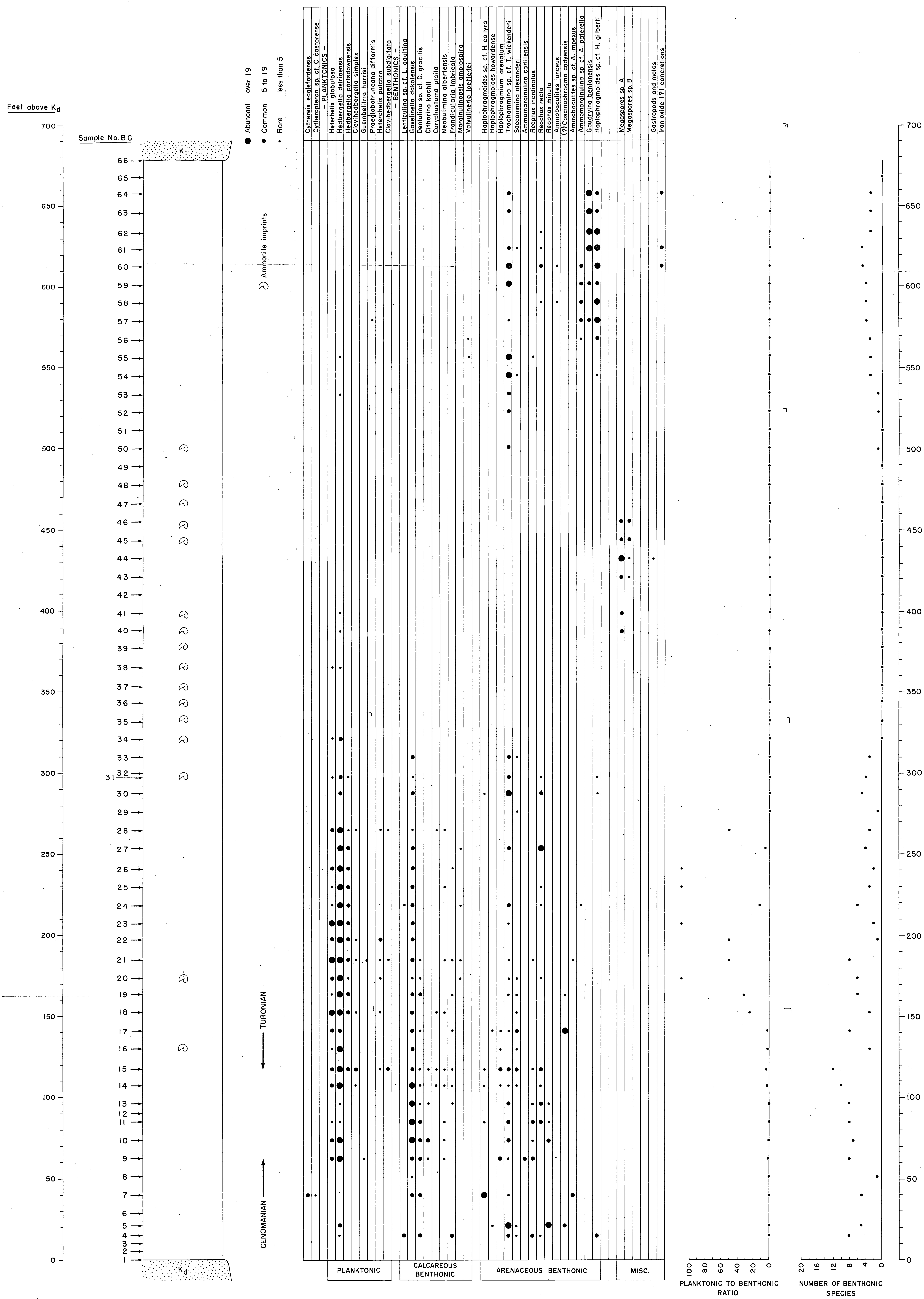

Figure 4. Distribution of microfossils at Blue Canyon.

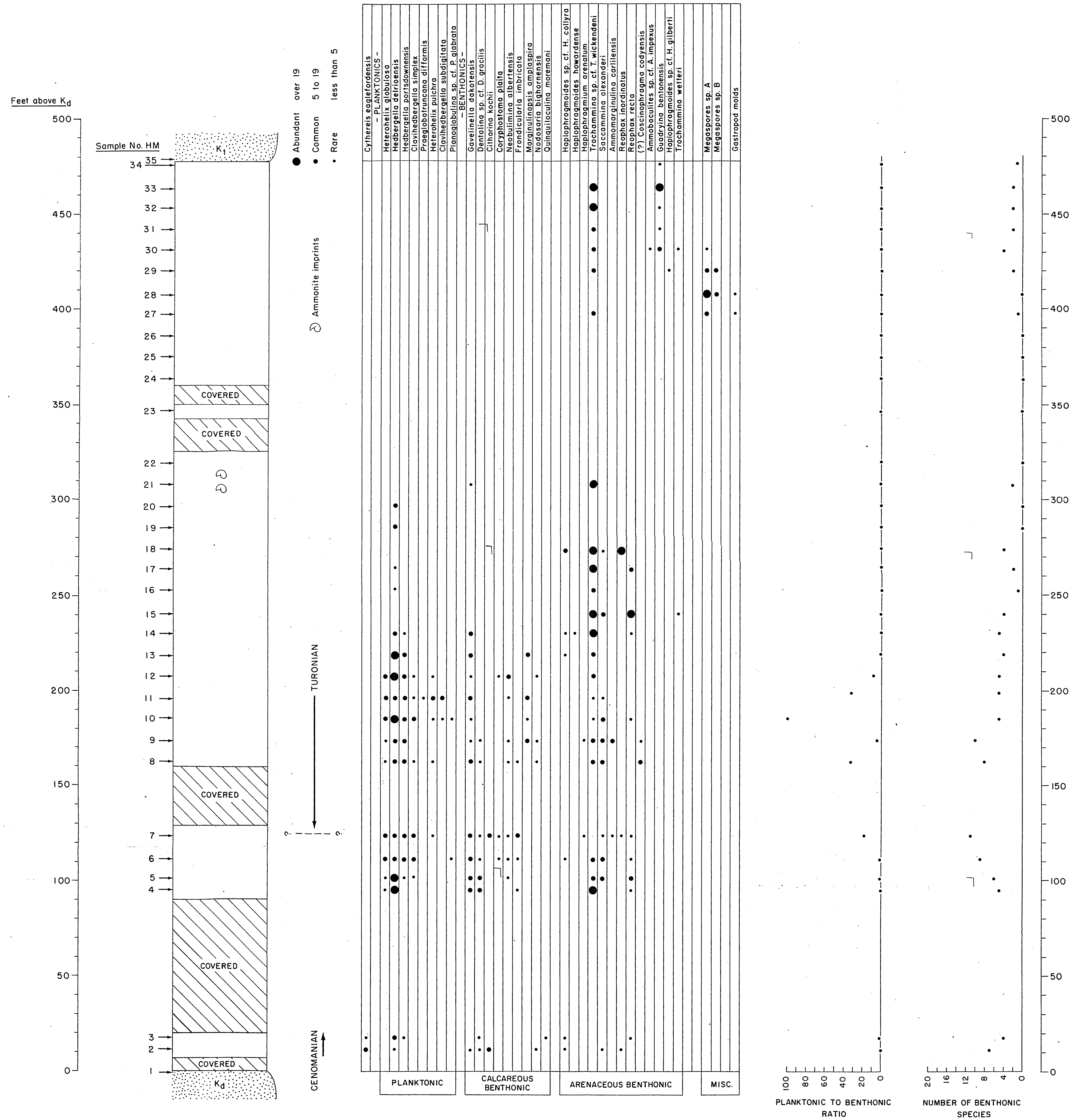

Figure 3. Distribution of microfossils at Howell Mesa.

Figure 6. Distribution of microfossils at Kayenta.

Figure 11. Fence diagram of the Mancos Shale, viewed from southeast.

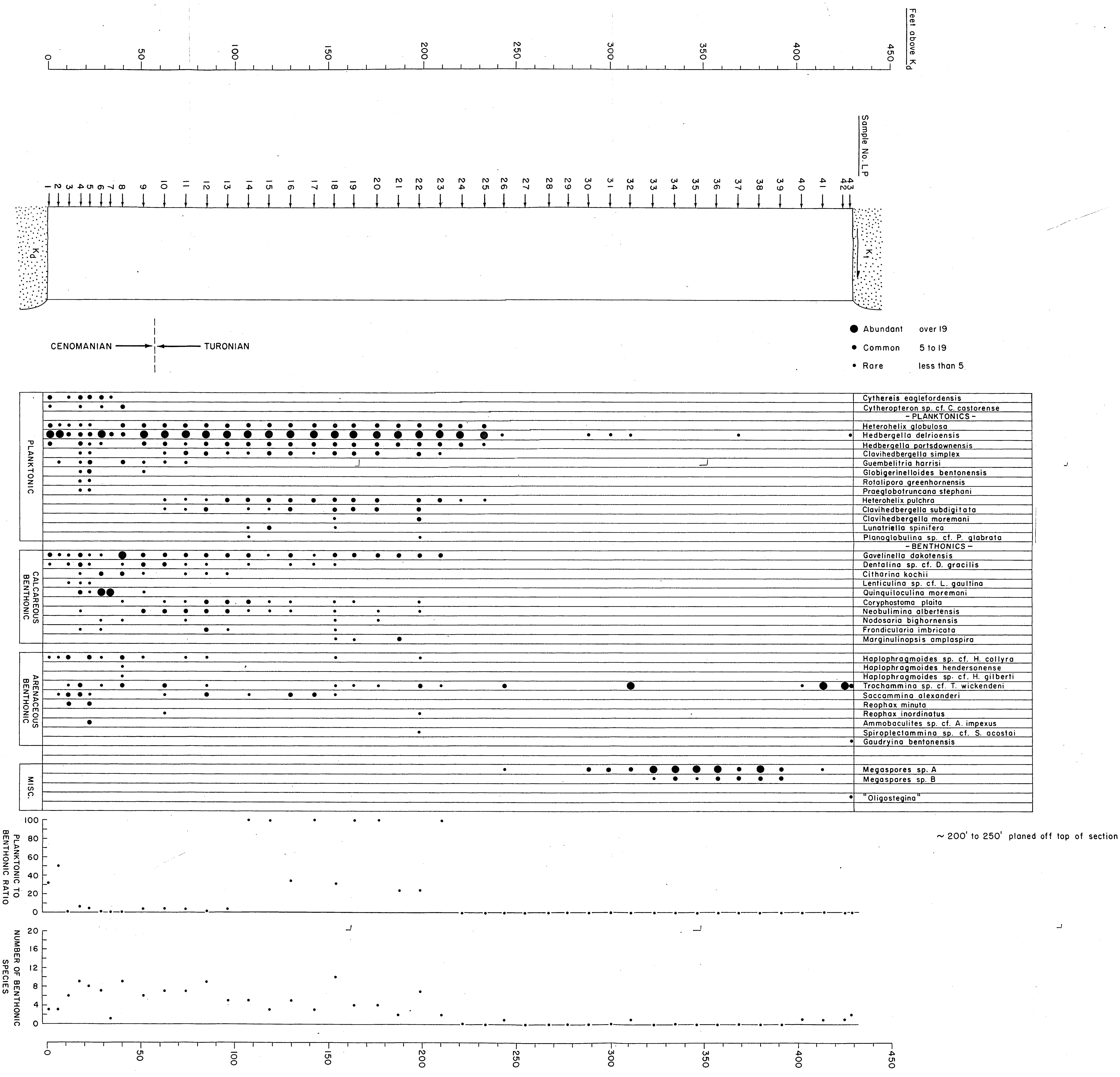

Figure 7. Distribution of microfossils at Lohali Point.

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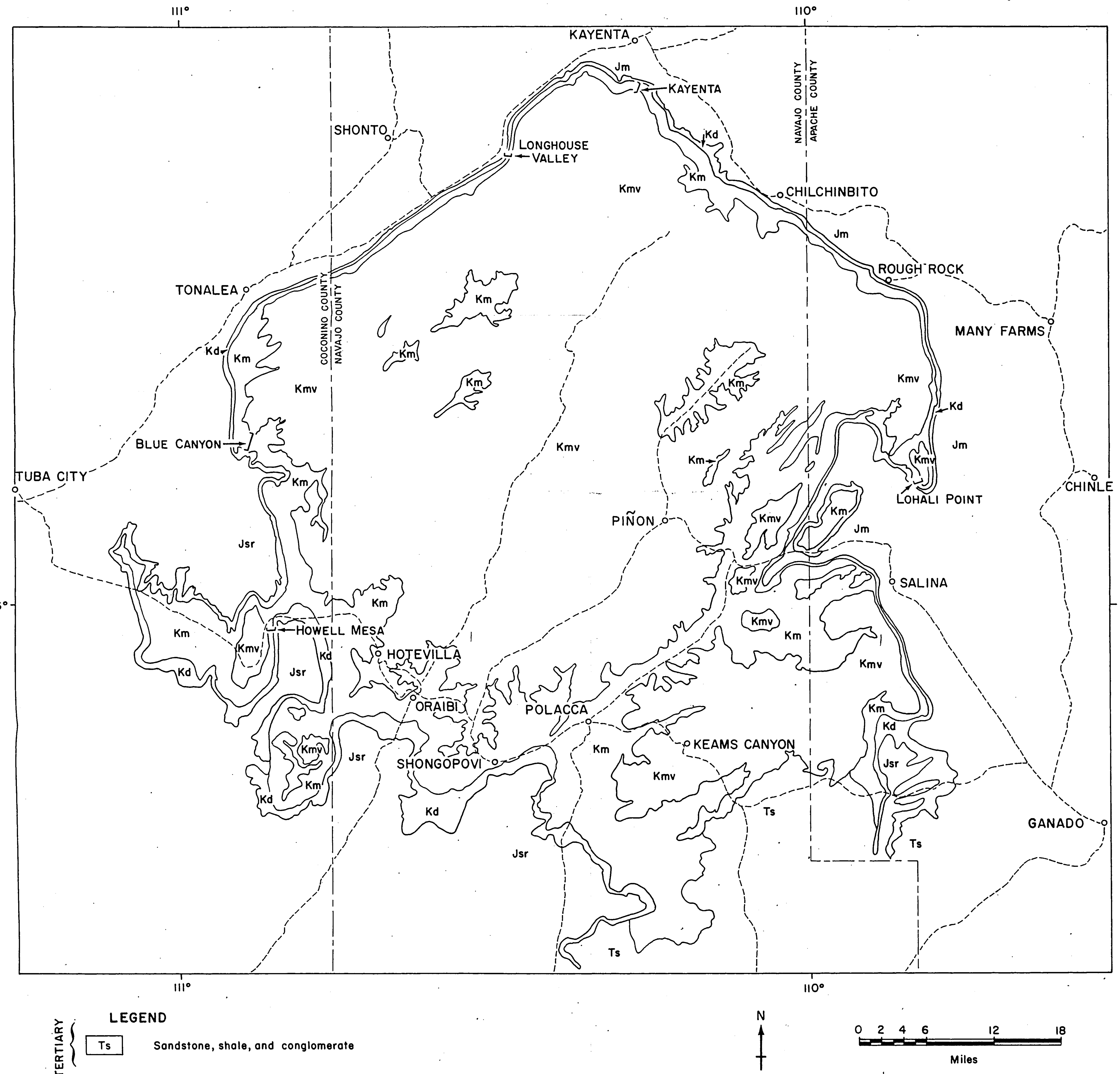

LEGEND

TERTIARY	Ts	Sandstone, shale, and conglomerate
CRETACEOUS	Kmv	Mesa Verde Group – includes Yale Point Sandstone, Wepo Formation, and Toreva Formation
	Km	Mancos Shale
	Kd	Dakota Sandstone
JURASSIC	Jm	Morrison Formation
	Jsr	San Rafael Group – includes Summerville Formation, Cow Springs Sandstone, Bluff Sandstone, Entrada Sandstone, and Carmel Formation

Figure 2. Generalized geologic map of Black Mesa Basin, Arizona, showing locations of sampled sections.

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Figure 10. Fence diagram of the Mancos Shale, viewed from southwest.

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