PALEOECOLOGY OF THE LATE CRETACEOUS UPPER FRONTIER AND HENEFER FORMATIONS (WANSHIP) NEAR COALVILLE, UTAH

A THESIS
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BY
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This, my first major professional work, is dedicated to the memory of the beautiful lady who so unselfishly and lovingly cared for the often naughty little boy and sometimes rude and thoughtless young man that I have been. Oriana Jane Decaster Goodner passed away during the preparation of this work. God bless you, Mother. You are missed.

Abstract

The late Cretaceous upper Frontier and Henefer Formations exposed near Coalville, Utah were deposited in a fluctuating set of freshwater, brackish, and marine environments. Sediment was derived from a western source area elevated during the Sevier and Laramide orogenies, pulsations of which are evidenced by unconformities within the Frontier and Henefer Formations in the Coalville area. A series of 6 marine transgressive-regressive sequences during deposition of the Upton Sandstone Member of the Frontier Formation is hypothesized based on a Simpson species diversity study within the benthonic community of ostracodes and foraminifers. The Simpson diversity index ranges from 1.7 to 9.2 for the beds of the Upton Sandstone Member of the Frontier Formation.

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Introduction

It is the intent of this report to present an interpretation of the paleoecology of the late Cretaceous upper Frontier and Henefer Formations of northeast Utah based on the evidence provided by foraminifers and ostracodes.

The title of this paper incorporates the formational term "Wanship," but due to the confusion arising from its ever-changing use over the past 20 years, the writer proposes that the term "Wanship" be abandoned by future workers in the Coalville area in favor of the stratigraphic nomenclature proposed by Trexler (1955) and modified by Hale (1962) (figure 1). The Term "Wanship Formation" has been used informally by various workers in the Coalville area since the early 1950's. Eardley (1952) described it as unconformably overlying the Frontier Formation and unconformably underlying the Almy (Echo Canyon) Conglomerate. Lankford (Peterson, Gauger, and Lankford, 1953) included members of the upper Frontier and Henefer Formations as "Wanship." Jones, Picard, and Wyeth (1954) described the "Wanship" as overlying the Henefer Formation. Williams (1955) described it as truncating the Frontier Formation and representing continuous deposition from the late Cretaceous (Montanan) through early Paleocene time. Williams and Madsen (1959) stated that the "Wanship Formation" unconformably overlies the Frontier Formation and underlies the Echo Canyon Conglomerate, and suggested that the upper members of the Frontier Formation be excluded from that formation and included in the "Wanship." Williams and Madsen also stated that a proposal to accept "Wanship" as a formal formation was forthcoming but no such proposal was located by this writer.

The writer has subdivided the upper Frontier and Henefer Formations into 6 units in ascending order, based on depositional environments, as evidenced by fossil assemblages (figure 1). Units 1, 2, and 3 comprise the middle portion of the Dry Hollow Member (Hale, 1962) of the Frontier Formation. Unit 4 includes the upper sandstone unit of the Dry Hollow Member in addition to the entire Grass Creek Member (Hale, 1962) of the Frontier Formation. Unit 5 is equivalent to the Upton Sandstone Member (Trexler, 1955) of the Frontier, and unit 6 is correlative with the Henefer Formation (Eardley, 1944) which grades upward into the Echo Canyon Conglomerate. The Judd Shale Member (Trexler, 1955) is absent in the area of these exposures.

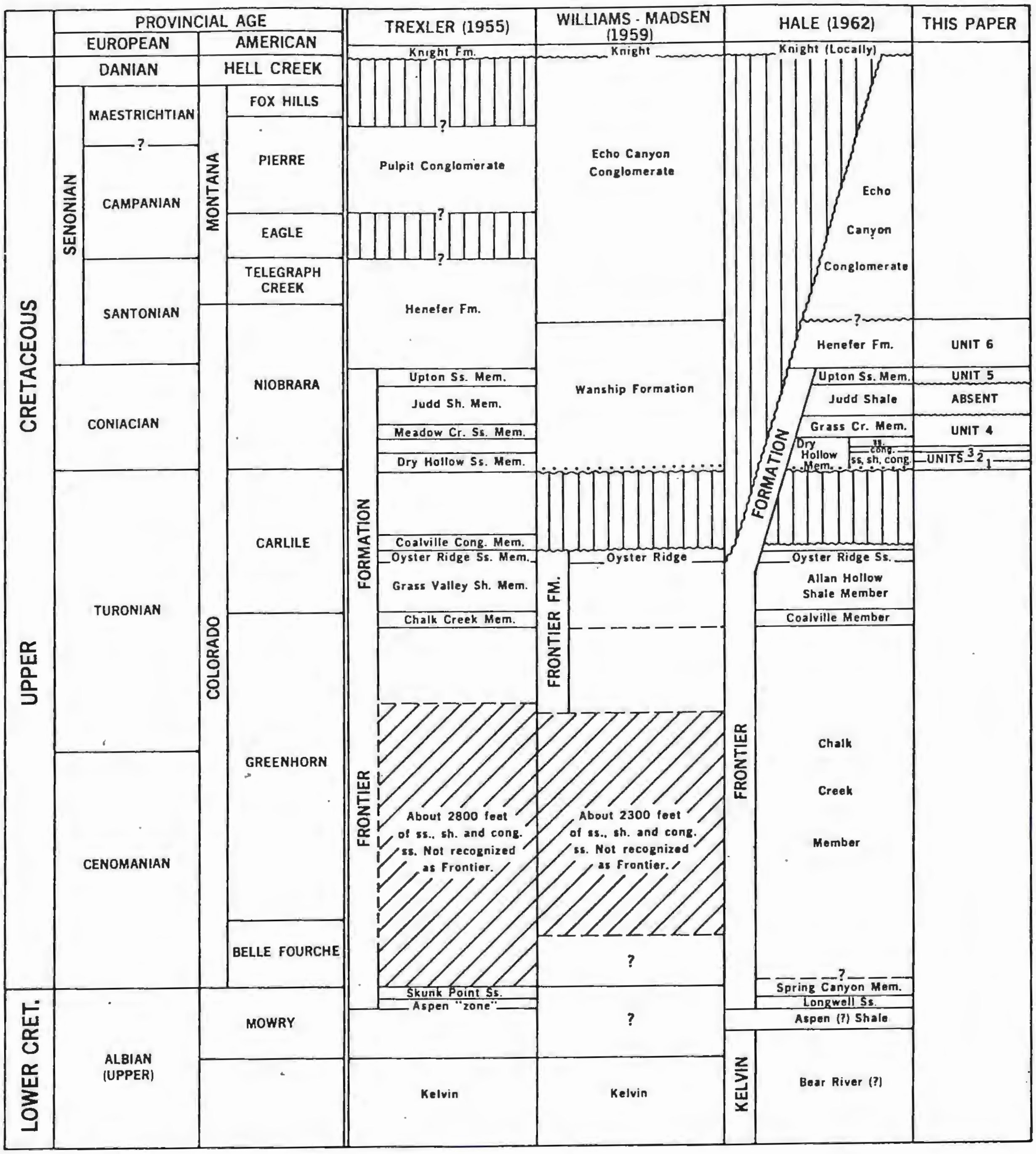

FIGURE 1. NOMENCLATURAL HISTORY OF THE CRETACEOUS SECTION OF THE COALVILLE AREA, UTAH. MODIFIED AFTER HALE, 1962, P. 212.

Acknowledgments

The writer would like to express his appreciation and gratitude to Dr. David G. Darby, advisor for this research, for his advice and assistance in all phases of the work. Also deserving of thanks and recognition are Dr. Richard W. Ojakangas and Dr. Blanchard O. Krogstad, members of the graduate committee, for their advice and assistance in various phases of this project.

Deserving of special acknowledgment and gratitude are my field assistant and brother, Roy L. Goodner, and my laboratory assistant and wife, Marlene S. Goodner, both of whom devoted a large amount of time and energy to this research, and both of whom gave me a tremendous amount of encouragement and understanding.

Previous Work

H. Englemann (1859) Identified the main divisions of the Tertiary and the unconformable Tertiary-Cretaceous contact in the Chalk Creek area east of Coalville.

F. V. Hayden (1869) Named the Wasatch Group of the Echo Canyon area.

F. B. Meek (1871) Identified the Coalville deposits as Cretaceous and published the first stratigraphic section of these deposits in 1872.

L. Lesquereaux (1873) Based on evidence from fossil flora, misinterpreted the Coalville deposits as being of Tertiary age.

C. King (1878) Described the Coalville stratigraphy from deposits along the Weber River and Chalk Creek.

C. A. White (1879) Based on paleontological evidence, assigned the Coalville deposits to the Late Cretaceous.

T. W. Stanton (1893) Detailed the stratigraphy of the Coalville area and described the fossil content of each unit.

A. C. Veatch (1907) Briefly described the Coalville section for a comparison with a report of the section of southwestern Wyoming.

C. H. Wegemann (1915) Described the Coalville section and published the first geologic map of the area. Emphasis was placed on coal deposits.

J. D. Forrester (1937) Reported the structure of the Uinta Mountains and recorded the existence of the Morrison, Frontier, and Mesaverde Formations of the Coalville area.

A. C. Eardley (1944) Included the Coalville area in a report of the northcentral Wasatch Mountains, named the Henefer Formation, and identified the angular unconformity between the Echo Canyon and Knight Conglomerates exposed in Echo Canyon.

W. A. Cobban and J. B. Reeside, Jr. (1952) Composed the first detailed stratigraphic section of the Frontier Formation of southwestern Wyoming.

R. H. Peterson, D. J. Gauger, and R. R. Lankford (1953) described the microfossils of the Frontier and "Wanship" Formations of the Coalville area and the Hilliard Shale of southwestern Wyoming.

D. W. Trexler (1955) Described the stratigraphy and structure of the Coalville area and established several new members of the Frontier Formation.

N. C. Williams and J. H. Madsen, Jr. (1959) Recognized evidence of a significant tectonic disturbance within the Frontier Formation and proposed establishing the upper Frontier contact at the level of this conglomerate bed within the lower portion of the Dry Hollow Member of the Frontier and the renaming of the overlying materials beneath the Echo Canyon Conglomerate. "Wanship" is the name suggested to incorporate what was previously classified as upper Frontier and Henefer sediments.

L. A. Hale (1962) Studied the Coalville stratigraphy and endorsed, with minor modifications, the nomenclature established by Trexler in 1955.

Geographic Location

The study area is located near the town of Coalville in Summit County, northeastern Utah. Coalville lies approximately 12 miles east of the northcentral Wasatch Mountains and 17 miles north of the western termination of the Uinta uplift.

The Frontier Formation and the overlying Late Cretaceous rocks are exposed in much of northeastern Utah and southwestern Wyoming and have been the subject of numerous investigations within the general Coalville area. The column studied by the present writer is found in a series of roadcuts exposed during the construction of Interstate 80 in the late 1960's. They extend from Coalville approximately 3 miles to the north along the western edge of Echo Reservoir. The exposures are in portions of T.2N.,R.5E., sections 5 and 8; and T.3N.,R.5E., sections 31 and 32, Salt Lake Meridian.

Field Procedure

Field work was conducted during the summer of 1973. Each of the 146 recognized beds of the upper Frontier and Henefer Formations was measured, described and sampled.

Being careful to remove the mantle of rock waste covering the surface of the exposures, I used an entrenching tool to obtain approximately 5 pounds of material from each bed. Generally, a bed was sampled only once, but those 30 feet or more in thickness were sampled in the lower, middle, and upper portions. Sample locations were recorded on a series of 12 photographs taken westward from the east side of Echo Reservoir with a telephoto lens.

Laboratory Procedure

The following procedures were used to extract the microfossils from the rock samples. A six hundred cc. dry sample from each bed was immersed in a 10% Calgon and water solution until disassociation of the grains occurred. This generally required less than 48 hours. If further treatment was necessary to disaggregate the clastic material so that microfossils could be removed, the sample was boiled for 30 minutes in a 20% (by volume) solution of "Quaternary-O" (a dispersant manufactured by Ciba-Geigy) and water.

Once the microfossils were freed from the sediment, the sample was washed over a sieve with openings of 62 microns, removing all silt and clay-sized materials. The sample was then oven-dried at 90°C and shaken through a series of 4 sieves with openings of 850, 250, 150, and 75 microns. Each sample size was then placed in a separate storage bag and labeled.

The material which passed through the 850 micron sieve and was retained by the 250 micron mesh, and the material which passed through the 250 micron sieve and was retained by the 150 micron mesh was found to contain all of the microfossils. Attention was therefore focused on material in these size ranges. The fossils were then extracted by hand picking from each sample and mounted on 3 inch by 1 inch cardboard depression slides.

Due to the poor preservation of many of the ostracodes, it was necessary to immerse specimens for 24 hours in a 20% (by volume) solution of hydrofluoric acid and water (Sohn, 1956). This caused the opaque calcite to convert to transparent or translucent fluorite. Muscle scar patterns and dentition were often made visible using this technique.

Regional Geologic History

During Cretaceous time, Utah was the scene of orogenic activity in a north-south trending belt and sediment deposition in an asymmetrically subsiding basin to the east of the mountains. The climate was warm and humid, probably similar to that of the present southern Atlantic Coast of the United States (Rocky Mountain Association of Geologists, 1972, p. 190). Inland areas between the infant mountains and the fluctuating coast supported pine forests, while coastal plains often included vast swamps harboring diverse populations of dinosaurs. Beaches were sandy and barrier bars commonly sheltered bays, estuaries, and lagoons from the open sea. The mountains grew by vertical uplift, large-scale low-angle thrusting toward the east, batholith and laccolith emplacement and volcanic activity.

Late Jurassic and early Cretaceous time was characterized tectonically by intense overthrust faulting and mountain building within the Cordilleran geosyncline. Eastward pulses of thrusting continued into the Tertiary along the hinge-line between the Paleozoic and early Mesozoic geosyncline and platform. This tectonism represents the Sevier orogeny (Rocky Mountain Association of Geologists, 1972, p. 190).

The seas which would cover much of central and eastern Utah later in the Cretaceous period did not advance northward of Mexico during the early Cretaceous. Sedimentary rocks of this age occurring in Utah are mainly fluvial conglomerate, sandstone, and shale.

During mid-Cretaceous time, mountain building was continuing to the west and the southern sea was advancing northward spasmodically. It eventually met a boreal sea advancing southward from Alberta, forming one vast inland sea extending the length of the North American continent from Utah eastward to the present Mississippi River. The lower members of the Frontier Formation were deposited along the western margin of this, the Turonian sea. Eicher (1969) estimated that the axis of the Turonian sea was located over eastern Colorado and western Nebraska, and that the maximum depth reached 2000 to 3000 feet at these localities. The seas became greatly reduced during the late Turonian and by the end of the age had almost completely withdrawn. This withdrawal of the seas at the close of the Turonian corresponds to the tectonic episode evidenced by the disconformity and conglomerate of the Frontier (reported by Williams and Madsen in 1959 in the Dry Hollow Member). It is plausible that this episode of marine withdrawal and renewed tectonic activity signals the first pulsations of the Laramide orogeny.

The following Coniacian and Santonian ages represent the time during which the rocks of the study area were being deposited (figure 1). Marine invasions were less extensive geographically and of shorter duration than they had been during Cenomanian-Turonian time. Berquist (1971) compared Niobrara foraminifers with the habitats of living related forms and, based on this evidence, estimated the depth of the Coniacian and Santonian seas over Colorado to have been approximately 200 meters. Deposition during this time occurred mainly east of Utah.

The Campanian sea was both shallow and short-lived. Hale (1962) believes this to be the age during which the bulk of the Echo Canyon Conglomerate was being deposited.

By mid-Maestrichtian time, withdrawal was complete. Berquist (1971) suggests that deposition of the

Pierre Shale and overlying Fox Hills Sandstone correspond with the final regression.

It is generally conceded that the Laramide orogeny commenced during the Late Cretaceous. Whether this is reflected by an unconformable horizon within the Frontier Formation as conjectured earlier, or by one higher in the Cretaceous section is immaterial. The tectonic pulsations of the Laramide orogeny began sometime during the Late Cretaceous and continued into the early Tertiary. The major structural features of the Coalville area date from this time.

The Wasatch Mountains to the west of Coalville represent the results of Laramide tectonism and are similar in origin to the ranges of the Basin and Range province farther west. They are comprised of an upthrown block of material associated with the Wasatch fault zone extending along the western flank of the range. Many of the thrust sheets in the Wasatch Range illustrate displacement in an easterly direction.

The Uinta Mountains to the south and southeast of Coalville represent a huge east-west trending anticline which originated as a taphrogenic uplift (an uplift bounded by steeply dipping normal faults) during the late stages of the Laramide orogeny and continued well into Tertiary time. The range has since been breached by erosion exposing its Precambrian igneous core and is now flanked by a series of hogback ridges.

The most conspicuous of the structural features in the Coalville area is a series of north-south to northeast-southwest trending folds. Eardley (1944) suggested that these are related to the easterly thrusting in the Wasatch Mountains. According to Eardley's hypothesis, the folding and the present orientation of the folds were both produced near the close of Cretaceous time. The Wasatch thrusts forced the rocks of the Coalville area eastward resulting in folding and overturning of such features as the Coalville anticline. The Uinta uplift in the east acted as a buttress, impeding displacements south of the Coalville area, and caused a general northeast-southwest orientation of the folds. Faults which displace only Cretaceous material were related to this episode of thrusting and folding. Those displacing Tertiary and Cretaceous deposits, however, were related to later uplifts in the Uintas.

The most prominent fold in the area is the Coalville anticline, an overturned northeast plunging anticline located east of Coalville. Flanking the Coalville anticline to the west is the Stevenson Canyon syncline, an asymmetric fold with dips of 75° on the northwest limb near Henefer and 25° on the southeast limb. The axis of this syncline is located approximately 2 miles west of Echo Reservoir and trends north-south to northeast-southwest. The upper Frontier and Henefer exposures of this study are located on the southeast limb of this structure. Strike directions within the exposures range from N.8°E. to N.20°E. and dips vary from 19° to 28° in a westerly direction.

Stratigraphic Section of the Study Area

The upper Frontier and Henefer Formations as exposed in the roadcuts of Interstate 80 north of Coalville consist of calcareous sandstone, siltstone, and shale. Also present are several beds of conglomerate in the upper portion of the section. The locations given in parentheses in the following stratigraphic description are approximations referring to the survey system employed by the Utah Department of Highways to establish the position of the centerlines of the east and west-bound lanes during the construction of this portion of Interstate 80 in the late 1960's. A series of topographic sheets containing the survey locations can be obtained from that agency. The survey locations are given in feet. For example, 1070 + 00 translates to 107,000 feet measured from the base point. In the following descriptions, the upper Frontier and Henefer Formations have been broken down into 6 units, in ascending order, on the basis of interpreted depositional environments. The 6 recognized units will be introduced in this section and their lithologies and fossil contents briefly described. The depositional environments will be described in greater detail in a later section of this report.

Unit	Lithology	Thickness in Feet
6	(1154+00-1210+00) Henefer Formation. Infrequent freshwater fossils. Red and green shale beds alternate with medium- to coarse-grained sandstone and conglomerate in the upper 1000 feet and with fine-grained sandstone in the lower 1500 feet. The conglomerate contains clasts averaging 6 inches in diameter. Bed thickness ranges from 1 to 20 feet.	2500
5	(1142+00-1154+00) Upton Sandstone Member, Frontier Formation. Abundant marine fossils. Siltstone alternating with fine- to medium-grained sandstone and shale. Bed thickness ranges from 1 to 40 feet.	200
4	(1104+00-1142+00) Upper sandstone unit of Dry Hollow Member and entire Grass Creek Member, Frontier Formation. Infrequent freshwater fossils. Beds of fine-grained sandstone alternating with shale. Bed thickness ranges from 1 to 25 feet.	1500
3	(1096+00-1104+00) Middle portion of Dry Hollow Member, Frontier Formation. Infrequent marine fossils. Black carbon rich and coaly shale beds alternating with fine-grained sandstone and siltstone. Bed thickness ranges from 0.5 to 20 feet.	200

Unit	Lithology	Thickness in Feet
2	(1086+00-1096+00) Middle portion of Dry Hollow Member, Frontier Formation. Infrequent marine fossils. Medium-grained sandstone alternating with siltstone and shale. Bed thickness ranges from 1 to 60 feet.	150
1	(1070+00-1086+00) Middle portion of Dry Hollow Member, Frontier Formation. Infrequent freshwater fossils. Fine- to medium-grained sandstone alternating with shale. Bed thickness ranges from 1 to 3 feet.	350
	Approximate total thickness in feet:	4900

Depositional Environments

The depositional history, based on lithologic and biologic evidence in the Upper Frontier and Henefer Formations is one common to many parts of the Rocky Mountain region during Late Cretaceous time. A mountainous source area within the geosynclinal belt to the west contributed sediments which were transported by rivers and wind across a broad alluvial coastal plain occupied occasionally by freshwater lakes or swamps. The sea to the east presented such depositional environments as salt marsh, tidal flats, barrier bars, and open sea.

Unit 1, exposed immediately north of Coalville, is partially covered by a large deposit of red Quaternary alluvium. This unit consists of fluvial deposits containing such freshwater fossils as the ostracode _Candona_, plant remains, worm tubes, pelecypods, and gastropods. The basal sandstone is quite immature and contains numerous fragments of feldspar and mica. Beds of sandstone alternate with shale and range from 1 to 3 feet in thickness.

Unit 2 consists of a marine fossil assemblage including worm tubes, the pelecypod _Inoceramus_, and such Foraminifera as _Quinqueloculina_, _Textularia_, _Epistomina_, and _Haplophragmoides_. Specimens of the unidentified species of _Inoceramus_ are large individuals occurring abundantly in zones within several beds of fine-grained sandstone. Bed thickness ranges from 1 to 60 feet and beds consist of fine- to medium-grained sandstone, siltstone, or shale. Pyrite occurs in association with _in situ_ coal deposits indicating reducing conditions caused by build-up of decaying vegetation. Scour and fill features are numerous and range from 100 to 300 feet in width and 5 to 60 feet in depth. Small-scale cross-bedding exists in several of the channel fills. The sediments of this unit are interpreted as having been deposited in a tidal flat environment.

Unit 3 contains the Foraminifera, *Haplophragmoides*, and *Epistomina*, and consists of layers of coal several inches thick alternating with coaly shale, carbon-rich shale, siltstone, and fine-grained sandstone. Bed thickness ranges from 0.5 to 20 feet. Sedimentary sulfides continue to be associated with the coal and thin veins of gypsum occur as well. Several shallow channel fills are present ranging up to 100 feet wide and 15 feet deep. Deposition is thought to have occurred in a salt marsh which was being occasionally encroached upon by tidal waters.

Unit 4 contains freshwater fossils, including insects, leaf, wood and plant fragments, charophytes, pelecypods, gastropods, and specimens of the ostracode, *Candona*. Beds of fine-grained sandstone alternate with shale; thickness ranges from 1 to 25 feet. Channel deposits are numerous and contain fining-upward sequences of sediments. Associated with and bordering several of these channels are coaly shales of probable flood-plain origin. Deposition was probably in a fluvial setting.

Unit 5 (figure 2) contains abundant marine fossils, including ostracodes, foraminifers and mollusks. Beds of siltstone alternate with fine- to medium-grained sandstone and shale; bed thickness ranges from 1 to 40 feet. Deposition occurred in a marine environment and the paucity of planktonic microfossils suggests the existence of barrier bars or barrier islands restricting the influx of such forms into the area. It is generally believed that the Cretaceous climate was warm and humid

Figure 2. The roadcuts in the center of the photo are comprised of the Upton Sandstone Member of the Frontier Formation, the present writer's unit 5. The dip-slope (right flank of the ridge) is the locally unconformable contact between the Frontier Formation and the overlying Henefer Formation.

but the abundance of arenaceous Foraminifera in this unit is suggestive of cool water. A species diversity study of the microfossils of this unit was conducted and will be discussed in a later phase of this report.

Unit 6 contains a freshwater assemblage of fossils, including insects, plant remains, resin, charophytes, pelecypods, gastropods, and specimens of the ostracode, Candona. Beds of shale alternating with fine-grained sandstone occur in the lower portion of this unit and conglomerate, medium- to coarse-grained sandstone, and shale occur in the upper portion. Bed thickness ranges from 1 to 20 feet. Numerous gravel-filled channels are present throughout (figures 4 and 5). Deposition occurred in a fluvial setting with the upper portion being deposited in closer proximity to the source area.

The Henefer Formation (unit 6) is gradationally overlain by the massive red Echo Canyon Conglomerate (figure 6). The age of the Echo Canyon Conglomerate has been the subject of much debate but the Rocky Mountain Association of Geologists (1972, pp. 194-195) has assigned it to the Late Cretaceous. Eardley (1944) showed that approximately two-thirds of the boulders present in the Echo Canyon Conglomerate are composed of Weber Quartzite (Pennsylvanian), and one-third is limestone from the Brayer (Mississippian), Park City (Permian and Pennsylvanian?), and Twin Creek (Jurassic) Formations. The source of these materials was the north-central Wasatch Mountains to the west and deposition was probably in a fluvial environment.

Figure 3. Channel cross-bedding present in the Upton Sandstone Member of the Frontier Formation. The trend of this channel is N.86°E.

Figures 4 (above) and 5. Channel features within the Henefer Formation (unit 6). Channel trend is N.79^{o}E., which is in general agreement with the trend of the cross-bedding of the underlying unit 5 (figure 3). The channels of figure 4 are approximately 3 feet in length.

Figure 6. The Echo Canyon Conglomerate overlies the Henefer Formation and is believed to represent continuous deposition from Late Cretaceous through early Tertiary time.

Species Diversity

The Simpson diversity index (Simpson, 1949) has gained popularity as a means of distinguishing between physically controlled (on-shore) communities and biologically controlled off-shore communities. The term "community" as used here refers to an association of recurring species that are numerically dominant and that may show some linkage to a physical environmental parameter (Bretsky, 1969). It must be kept in mind, however, that there is a significant difference between fossil and living communities. As Bandy (1964) points out, the fossil assemblage, as an accumulation, more closely approaches the total production of preservable individuals of the community than it does the standing crop which defines all members of the community living at a point in time regardless of their likelihood of being preserved as fossils.

Diversity is a difficult concept to work with when dealing with a fossil assemblage. It is dependent on total chemistry of the water, value of pH, salinity, temperature, quality of substrate, wave and current energy, kind and quantity of food supply, rate of sediment deposition, and interaction with other components of the biota. These factors may vary greatly in shallow marine environments, even within habitats comparable in depth and distance from shore, but Bretsky and Lorenz (1970) state that high diversity indices are uncommon near shore. Diversity increases as depth increases, and paleoecologists use diversity as an indicator of relative distance from shore.

The most rigorous of the marine environments occurs between the shoreline and a depth of 10 fathoms. Within this zone a wide range of erratically varying physical parameters restrict the biota. A relatively few species of organisms are able to withstand these harsh conditions and those that are able to survive in this region are therefore subjected to very little interspecific competition for resources and may become very abundant. Species density seemingly increases until limited by intraspecific competition.

The physical environmental parameters of the offshore region do not vary erratically and large numbers of species are able to thrive. These communities become biologically controlled. Interspecific competition for resources is high and niches become narrow. Species densities are maintained at a low level by the interaction of interspecific and intraspecific competition.

Simpson (1949) suggested using an index to represent the number of randomly selected pairs of individuals that must be drawn from a community in order to have an even chance of obtaining a pair with both individuals belonging to the same species. His formula was first proposed as $D = \frac{\Sigma n(n-1)}{N(N-1)}$ but has become widely used in reciprocal form, $D = \frac{N(N-1)}{\Sigma n(n-1)}$ where D = the diversity index, N = the total number of individuals present from all species, and n = the number of individuals belonging to a single species. D increases from a value of 1.0 for a community containing only one species to an infinite value for a community in which each individual is a member of a different species.

The 21 beds of unit 5 contain a recurring association of species of foraminifers and ostracodes that is therefore thought to represent a fossil community. The Simpson diversity index was applied to each bed (figure 7) in an attempt to recognize minor bathymetric fluctuations within the general marine depositional environment of unit 5. The results of this study were then compared to the lithologic character of the beds (figure 8). Low Simpson index values were found to correspond to coarser grain sizes of the clastic sediments and the higher index values correlate with sediments of finer grain size. Since, by inspection, there does seem to be a correlation between these two lines of evidence, it is thought that the Simpson diversity index values may indeed be recording bathymetric trends. If this is the case, 6 minor transgressive-regressive sequences occurred during deposition of this, the Upton Sandstone Member of the Frontier Formation, the present writer's unit 5.

NUMBER OF INDIVIDUALS

BEDS																					FOSSILS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	(OSTRACODA)
309	67	109	165	11	76		182	75	55	128	481	19	106	248	146	11	79	4			BRACHYCYTHERE SPHENOIDES
95	13	13	28	5	16	2	18	11	33	8	70		7								BRACHYCYTHERE SP.
11	3	2	19	5			8	29	14	223	143	24	39	30	67	3	196	28		2	CYTHERIDEA BAIRDIOIDES
								1													CYTHERIDEA PERFORATA
2	1		24			1	4		1	109	3		5	29	11	29	152	69	19	31	CYTHERIDEA POSTEROVATA
				2		1					12					24		21	47		CYTHERIDEA SP.
39		87	50		38		107	60	15	141	538	31	19	10	114		52	4	1		CYTHERELLA OBESA
																2				1	CYTHERELLA SP.
58	26	12	50	25	28		100	65	26	133	299	23	38	68	99	4	112	14	1	2	CYTHEREIS COALVILLENSIS
2	5	1	6		4		3				4				3						CYTHEREIS THOMASI
						2															CYTHEREIS SP.
										2	5										ORTHONOTACYTHERE HANAI
																					(FORAMINIFERA)
		9	13		1		58	21	165	101	146	5	37	63	49	35	75	43		1	MARGINULINA AUSTINIANA
28	4	6	5	1	7	5	5	2	18	15	19	3	10	8	10	18	24	17	5	1	DENTALINA UTAHENSIS
171	89	13	52	1	41	4	25	11	12	41	67	1	7	3	8	2	13	1		2	DENTALINA SUMMITENSIS
56	24	20	18	3	57	3	44	14	47	65	118	5	14	20	47	9	32	11	2		DENTALINA FRONTIERENSIS
13	2		6	2	3	6			19	19	13		9	5	5	16	20	14	1		DENTALINA COALVILLENSIS
133	27	10	22			11	5	10	21	46	11		16	7	6	9	27	5			DENTALINA SP.
99		150	102	103	98		100	96	106	94	97	108	91	111	89			93		112	SPIROPLECTAMMINA LALICKERI
	6	2	1		4		4	1							1						HAPLOPHRAGMOIDES PLATUS
					8		7			3	4										HAPLOPHRAGMOIDES GLABER
	31	12	11		35		38	5		5	10			2	15						HAPLOPHRAGMOIDES ORIANA
	1		3		20		5	11			9				15				1		HAPLOPHRAGMOIDES EXCAVATUS
	8				16		22														HAPLOPHRAGMOIDES SP.
	22	45	7		9		13	9	8	19	51		2		24		1				AMMOBACULITES FRAGMENTARIUS
							2				4		2		8						AMMOBACULITES TEXANUS
	5															1					AMMOBACULITES SP.
3	1																				LENTICULINA ROTULATA
	4	15	1		3		8														GYROIDINA DEPRESSA
	7	85	8				124				587										EPISTOMINA SUPRACRETACEA
		1																			LAGENA ACUTICOSTA
	1	1																			MARSSONELLA CONICA
	5	4																			TROCHAMMINA DIAGONIS
						1															TEXTULARIA SP.
											5			1							DOROTHIA BULLETTA
													3								PROTEONINA DIFFLUGIFORMIS
6.1	7.7	6.8	7.3	2.2	8.7	6.9	8.8	7.2	6.2	9.2	7.0	3.4	7.0	4.3	8.3	7.8	6.7	6.1	2.3	1.7	DIVERSITY INDEX FOR BED

FIGURE 7 MICROFOSSIL CONTENT OF THE BEDS OF UNIT 5, THE UPTON SANDSTONE MEMBER OF THE FRONTIER FORMATION. THESE DATA USED IN SIMPSON'S FORMULA, $D = \frac{N(N-1)}{\Sigma n(n-1)}$, YIELD THE SPECIES DIVERSITY INDEX OF EACH BED. BEDS ARE NUMBERED IN ASCENDING ORDER.

Bed Number	Simpson Diversity Index Values Presented Here To Scale	General Lithology
21	1.7	sandstone
20	2.3	sandstone
19	6.1	siltstone
18	6.7	siltstone
17	7.8	sandstone
16	8.3	shale
15	4.3	siltstone
14	7.0	siltstone
13	3.4	sandstone
12	7.0	shale
11	9.2	shale
10	6.2	sandstone
9	7.2	siltstone
8	8.8	shale
7	6.9	sandstone
6	8.9	shale
5	2.2	sandstone
4	7.3	shale
3	6.8	shale
2	7.7	shale
1	6.1	sandstone

Figure 8. Represented here are the beds of unit 5, the Upton Sandstone Member of the Frontier Formation. Simpson diversity index values were found to increase as grain size decreases, with few exceptions. Rock-type identification is based on field observations. 6 minor transgressive-regressive sequences are hypothesized.

Conclusions

The upper Frontier and Henefer Formations were deposited under a rapidly fluctuating and diverse set of environmental conditions during or immediately prior to the early pulsations of the Laramide orogeny. These conclusions are based on fossil assemblages, lithology, and sedimentary structures. The Dry Hollow Member of the Frontier Formation was deposited under fluvial, tidal flat, and salt marsh conditions in ascending order. The Grass Creek Member of the Frontier Formation represents fluvial deposition. The Judd Shale Member is absent in the study area. The Upton Sandstone Member of the Frontier Formation was deposited under six transgressive-regressive sequences as indicated by species diversity within a benthonic foraminifer and ostracode community. The Henefer Formation represents withdrawal of the sea and deposition under fluvial conditions once again.

8 ostracode and 20 foraminifer species were identified by the writer. Simpson's species diversity index was found to range from 1.7 to 9.2 for the benthonic foraminifer and ostracode community contained within beds of the Upton Sandstone Member of the Frontier Formation.

Appendix A (Systematic Descriptions of Microfossils)

The classification scheme employed in this report is that used by the Geological Society of America in the Treatise on Invertebrate Paleontology.

Abbreviated citations have been used in the synonymy listings which follow. Series, volume, part, and pages are expressed in a commonly used convention as follows: [1] 2 (3) : 4 1 = series, 2 = volume, 3 = number or part, 4 = page.

Phylum PROTOZOA
Class SARCODINA Butschli, 1882
Order FORAMINIFERA D'Orbigny, 1826
Suborder TEXTULARIINA Delage and Hérouard, 1896
Superfamily Lituolacea de Blainville, 1825
Family Hormosinidae Haeckel, 1894
Subfamily Hormosininae Haeckel, 1894
Genus *Proteonina* Williamson, 1858

Proteonina difflugiformis (Brady)

Reophax difflugiformis Brady, 1879, The Quarterly Journal of Microscopical Science, 19:51, pl. 4, f. 3a-b.

Proteonina difflugiformis (Brady). Rhumbler, 1903, Archiv für Protistenkunde, 3:245, tf. 80a-b. Cushman, 1946, United States Geological Survey Professional Papers 206:15, pl. 1, f. 7-8 (synonymy).

Test a single elongate oval or pyriform chamber with a more or less distinct tubular neck, usually tapering gradually from the body of the chamber, undivided; wall fairly thick, of sand grains of variable size, firmly cemented; aperture circular, simple, terminal. Height 0.50 mm., diameter 0.40 mm.

Family Lituolidae de Blainville, 1825
Subfamily Haplophragmoidinae Maync, 1952
Genus Haplophragmoides Cushman, 1910

Haplophragmoides excavatus Cushman and Waters
Haplophragmoides excavata Cushman and Waters, 1927, Cushman Laboratory for Foraminiferal Research Contributions, 2(4):82, pl. 10, f. 3a-b. Cushman and Todd, 1943, ibid., 19(3):50 (check list). Cushman, 1946, United States Geological Survey, Professional Papers, 206:21, pl. 2, f. 13-15 (synonymy).

Test closely coiled, planispiral, compressed, periphery subacute; chambers distinct, 10 in the last-formed whorl of the adult, the borders of each chamber distinctly thickened, central portion depressed; sutures straight, radial, not usually distinct; wall finely arenaceous, with a relatively small amount of cement, smoothly finished. Diameter usually about 1.00 mm., thickness 0.20 to 0.40 mm.

Haplophragmoides glaber Cushman and Waters
Haplophragmoides glabra Cushman and Waters, 1927, Cushman Laboratory for Foraminiferal Research, Contributions, 2(4):83, pl. 10, f. 6a-b. Cushman and Todd, 1943, ibid., 19(3):50 (check list). Cushman, 1946, United States Geological Survey, Professional Papers, 206:20, pl. 2, f. 16-17 (synonymy).

Test closely coiled, planispiral, somewhat compressed, umbilicate, periphery rounded; chambers fairly distinct, 9 to 10 in last-formed whorl of the adult, rounded; sutures slightly depressed; wall finely arenaceous, smoothly finished. Diameter up to 0.55 mm., thickness 0.12 to 0.18 mm.

Haplophragmoides oriana (Gauger) new name

Haplophragmoides rugosa Gauger, 1953, Utah Geological and Mineralogical Survey Bulletin, 47:53, pl. 4, f. 6, (homonym; Cushman and Waters, 1927).

Test large, planispiral, tending to become evolute, slightly inflated, umbilicate; periphery very broadly rounded, lobulate; chambers triangular in outline, distinct, 8 to 10 in last whorl; sutures commonly indistinct, but marked by depressions between the slightly inflated chambers; wall arenaceous, neatly joined abundant grains 0.01 mm. in diameter embedded in a small amount of cement; aperture a low-arched slit at the base of the septal face of the last formed chamber. Greatest diameter 0.9 to 1.3 mm., least diameter 0.4 to 1.0 mm., thickness 0.4 to 0.5 mm.

Haplophragmoides platus Loeblich

Haplophragmoides platus Loeblich, 1946, Journal of Paleontology, 20(2):134-135, pl. 22, f. 5a-b.

Test free, compressed, planispiral, small, not completely involute; periphery sharp and lobulate; chambers numerous, rapidly increasing in size as added, 6 or 7 in last whorl, usually 1½ whorls being visible as the later chambers do not reach entirely to the center of the test, chambers slightly collapsed centrally, probably originally slightly inflated; sutures distinct, straight with a very slight backward swing at the periphery, slightly depressed; wall thin, finely arenaceous, smoothly finished; aperture a high arch at the base of the apertural face. Diameter 0.21 to 0.32 mm., thickness 0.03 mm.

Subfamily Lituolinae de Blainville, 1825

Genus Ammobaculites Cushman, 1910

Ammobaculites fragmentarius Cushman

Ammobaculites fragmentaria Cushman, 1927, Royal Society of Canadian Transactions, Ottawa, [3]21(4):130, pl. 1, f. 8.

A. fragmentarius Cushman, 1946, United States Geological Survey, Professional Papers, 206:23, pl. 3, f. 10-16 (synonymy; two species shown in figures).

(?) A. fragmentarius Cushman. Cushman and Applin, 1946, Cushman Laboratory for Foraminiferal Research, Contributions, 22(3):74.

Test large, compressed, early portion planispiral, later portion larger and uniserial, rectilinear, with the sides tapering; chambers distinct, gradually increasing in size as added, greatest width of the test made by last-formed chamber; sutures distinct, depressed; wall of coarse sand in flat flakes, rather neatly cemented; aperture elliptical, terminal. Length up to 1.50 mm.

Ammobaculites texanus Cushman

Ammobaculites texana Cushman, 1933, Cushman Laboratory for Foraminiferal Research, Contributions, 9(3): 50, pl. 5, f. 3.

A. texanus Cushman. Cushman and Todd, 1943, ibid., 19(3):50 (check list). Cushman, 1946, United States Geological Survey, Professional Paper, 206:23-24, pl. 3, f. 22-23.

Test large, compressed, umbilical region somewhat excavated and the test becoming somewhat evolute in the adult; periphery lobulate and rounded; chambers fairly distinct, especially in the adult, usually 5 or 6 in the whorl of the younger stages, slightly more in the adult before uncoiling takes place, slightly inflated, especially in the later development; sutures indistinct, very slightly depressed; wall very coarsely arenaceous, compressed, considerable proportion of cement, somewhat roughly finished in the younger stages, becoming smoother in the adult. Up to 2.0 mm. in diameter, thickness 0.60 mm. in the adult.

Family Textulariidae Ehrenberg, 1838
Subfamily Spiroplectammininae Cushman, 1927
Genus Spiroplectammina Cushman, 1927

Spiroplectammina lalickeri Albritton and Phleger

Spiroplectammina lalickeri Albritton and Phleger, 1937, Journal of Paleontology, 11:353 tf. 2-3. Cushman, 1946, United States Geological Survey, Professional Paper, 206:29, pl. 6, f. 28-29.

Test small, slender, elongate, slightly bent with sides converging toward and evenly rounded initial end; periphery narrowly rounded, initially smooth, lobulate in later portion of the test; chambers numerous, first few in a planispiral coil, succeeding ones biserial, increasing gradually in height as added; sutures fairly distinct, limbate, slightly raised in initial half of test, thereafter depressed; sutures oblique, forming an angle of 20° to 45° with the horizontal; wall arenaceous, smoothly finished, with a considerable amount of cement; aperture a low subrectangular opening at the flattened base of the last-formed chamber. Length 0.50-0.60 mm., width 0.22-0.25 mm., thickness 0.08 mm.

Family Trochamminidae Schwager, 1877
Subfamily Trochammininae Schwager, 1877
Genus Trochammina Parker and Jones, 1859

Trochammina diagonis (Carsey)

Haplophragmoides diagonis Carsey, 1926, University of Texas Bulletin, 2612:22, pl. 3, f. 1.

H. coronatus (H. B. Brady). Albritton and Phleger, 1936, Journal of Paleontology, 11:350 (not Trochammina coronata Brady).

Trochammina diagonis (Carsey). Cushman and Waters, 1927, Cushman Laboratory for Foraminiferal Research, Contributions, 2(4):84, pl. 10, f. 7. Cushman, 1946, United States Geological Survey, Professional Paper, 206:49-50, pl. 15, f. 1-3 (synonymy).

Test trochoid, somewhat compressed; periphery lobulated, chambers distinct, 6 or 7 in the last-formed whorl, increasing rather uniformly in size as added, the general shape being fairly constant; sutures distinct, depressed, on the dorsal side slightly curved, on the ventral side nearly radial; wall arenaceous, with much cement; aperture a narrow opening on the ventral side at the inner margin of the last-formed chamber. Diameter 0.65-0.80 mm.

Family Ataxophragmiidae Schwager, 1877

Subfamily Globotextulariinae Cushman, 1927

Genus Dorothia Plummer, 1931

Dorothia bulletta (Carsey)

Gaudryina bulletta Carsey, 1926, University of Texas Bulletin, 2612:28, pl. 4. f. 4.

Dorothia bulletta (Carsey). Plummer, 1931, University of Texas Bulletin, 3101:132, pl. 8, f. 13-17. Cushman, 1946, United States Geological Survey, Professional Paper, 206:46, pl. 12, f. 21-26 (synonymy).

Test generally cylindrical, the base somewhat tapering or rounded, sides nearly parallel for most of the length, transverse section rounded or slightly compressed, earliest whorl with 4 or 5 chambers, later triserial, and in the adult biserial; chambers distinct, very slightly inflated, increasing in size very little as added, somewhat overlapping; sutures distinct, slightly depressed in the adult portion; wall distinctly arenaceous, but with much cement and smoothly finished; aperture a low, broad opening at the inner margin of the last-formed chamber, often with a slight lip. Length up to 1.0 mm., diameter 0.35 mm.

Genus Marsonella Cushman, 1933

Marsonella conica Gauger

Marsonella conica Gauger, 1953, Utah Geological and Mineralogical Survey Bulletin, 47:62, pl. 6, f. 14a, 15, 16.

Test trochoid, in front view generally triangular with a flaring apertural end and a blunt initial end, roughly conical, somewhat circular in transverse section, test tilted with respect to plane of the final chamber; 2 or 3 chambers to a whorl, adult whorl contains 1 or 2 chambers, chambers numerous, may be indistinct; sutures are for the most part distinct, almost flush with the surface, in some specimens slightly depressed, meeting in a zig-zag pattern; wall arenaceous, much cement, smoothly finished except for last 2 whorls which are rather coarsely arenaceous; aperture large, semi-circular or horseshoe-shaped opening at the base of the inner margin of the last-formed chamber. Length up to 1.6 mm., diameter 1.5 mm.

Suborder ROTALIINA Delage and Herouard, 1896

Superfamily Nodosariacea Ehrenberg, 1838

Family Nodosariidae Ehrenberg, 1838

Subfamily Nodosariinae Ehrenberg, 1838

Genus <u>Dentalina</u> D'Orbigny, 1826

<u>Dentalina</u> <u>coalvillensis</u> Peterson

<u>Dentalina</u> <u>coalvillensis</u> Peterson, 1953, Utah Geological and Mineralogical Survey Bulletin, 47:38, pl. 2, f. 1, 2.

Test elongate, slightly tapering, slightly curved, initial end usually with a distinct spine; early chambers indistinct, not inflated, strongly overlapping, later chambers distinct, inflated, slightly longer than broad; sutures on later portion distinct, depressed, slightly oblique; wall smooth; aperture terminal, radiate. Length up to 1.25 mm., greatest diameter 0.18 mm.

<u>Dentalina</u> <u>frontierensis</u> Peterson

<u>Dentalina</u> <u>frontierensis</u> Peterson, 1953, Utah Geological and Mineralogical Survey Bulletin, 47:37, pl. 1, f. 25, 26.

Test elongate, slender, gently curved, initial end with a distinct spine, tapering with greatest width near apertural end; initial chambers quite distinct but not inflated, later chambers greatly inflated, usually as long as broad; sutures distinct, flush with surface in initial portion, depressed in later portion; surface ornamented by distinct longitudinal costae, 8-10 in number, continuous from 1 chamber to the next, present on all chambers except the last-formed one; aperture terminal, radiate. Length up to 1.64 mm., width up to 0.2 mm.

<u>Dentalina</u> <u>summitensis</u> Peterson

<u>Dentalina</u> <u>summitensis</u> Peterson, 1953 Utah Geological and

Mineralogical Survey Bulletin, 47:39, pl. 2, f. 5, 6.

Test elongate, slender, gently curved, initial end with distinct spine, tapering with greatest width near apertural end; initial chambers indistinct, later chambers distinct, slightly overlapping, as long as broad; sutures on initial portion indistinct, flush with surface, sutures on later portion distinct, depressed, slightly oblique; surface ornamented by numerous longitudinal costae, continuous from chamber to chamber, usually 16-18 in number, costae somewhat oblique; aperture terminal, radiate. Length up to 3.50 mm; diameter 0.45 mm.

Dentalina utahensis Peterson

Dentalina utahensis Peterson, 1953, Utah Geological and Mineralogical Survey Bulletin, 47:38-39, pl. 2, f. 3, 4.

Test elongate, slightly tapering, slightly curved, initial end often with distinct spine; early chambers indistinct, strongly overlapping, later chambers distinct, slightly overlapping, about as long as broad; sutures on initial portion indistinct, flush with surface, sutures on later portion distinct, depressed; surface smooth except for a light roughening in the early portions of some specimens, no distinct costae. Length up to 4.5 mm., greatest diameter 0.50 mm.

Genus Marginulina D'Orbigny, 1826

Marginulina austiniana Cushman, var. directa Cushman

Marginulina austiniana Cushman, var. directa Cushman (in part), 1937, Cushman Laboratory for Foraminiferal Research, Contributions, 13(4):93, pl. 13, f. 5-8. Cushman, 1946, United States Geological Survey

Professional Paper, 206:59, pl. 20, f. 11-14, 16 (not f. 15).

Test elongate, somewhat compressed, early portion closely coiled and umbonate, later portion uncoiled, dorsal side straight or slightly concave, ventral side slightly lobulate; chambers of the early coiled portion indistinct, later uncoiled chambers more distinct, somewhat inflated; sutures indistinct except in the later portion, where they are slightly curved, somewhat limbate, with a decided bosslike thickening toward the dorsal side of the middle; wall smooth except for the sutural enlargements; aperture radiate, at outer peripheral angle. Length up to 2.50 mm., width 0.7-0.8 mm.

Genus Lenticulina Lamarck, 1804

Lenticulina rotulata (Lamarck)

(?) Lenticulites rotulata Lamarck, 1804, Muséum National d'Histoire Naturelle, Annales, 5:188.

Cristellaria rotulata (Lamarck). Carsey, 1926, University of Texas Bulletin, 3101:142, pl. 11, f. 20. Cushman, 1941, Cushman Laboratory for Foraminiferal Research, Contributions, 17(3):67, pl. 16, f. 13. Cushman (in part), 1946, United States Geological Survey Professional Paper, 206:56-57, pl. 18, f. 19, pl. 19, f. 2-7 (not f. 1).

Test free, planispiral, involute, lenticular, biumbonate; periphery with a distinct keel; chambers increasing gradually in size as added, chambers of greater breadth than height; sutures radial, slightly curved and depressed. Diameter up to 1.75 mm., thickness at umbo 0.75 mm.

Genus Lagena Walker and Jacob, 1798

Lagena acuticosta Reuss

Lagena acuticosta Reuss, 1862, Kaiserlichen Akademie der Wissenschaften, Mathematisch-Naturwissanschaftliche Classe, Sitzungsberichte, 44(1):305, pl. 1, f. 4. Cushman, 1946, United States Geological Survey Professional Paper, 206:94, pl. 39, f. 14-15.

Test unilocular, broadest near the base, somewhat broadly pyriform; surface ornamented with few, high, plate-like costae; aperture on elongate neck, may have hyaline lip, not radiate. Size variable.

Superfamily Cassidulinacea d'Orbigny, 1839

Family Alabaminidae Hofker, 1951

Genus Gyroidina d'Orbigny, 1826

Gyroidina depressa (Alth)

Rotalia depressa Alth, 1850, Naturwissenschaftliche abhandlungen, 3:266, pl. 13, f. 21.

R. cretacea Carsey, 1926, University of Texas Bulletin, 2612:48, pl. 5, f. 1.

R. beccarii (Linné) var. ripleyensis Berry, 1929, in Berry and Kelley, United States National Museum, Proceedings, 76(19):15, pl. 3, f. 10-12.

Gyroidina depressa (Alth). Cushman and Church, 1929, California Academy of Sciences, Proceedings, 4 18: 515, pl. 41, f. 4-6. Cushman, 1946, United States Geological Survey Professional Paper, 206:139-140, pl. 58, f. 1-4 (f. 3c and 4c transposed; synonymy).

Valvulineria cretacea (Carsey). Cushman and Todd, 1943, Cushman Laboratory for Foraminiferal Research, Contributions, 19(3):67-68, pl. 12, f. 1. Cushman, 1946, United States Geological Survey Professional Paper, 206:138-139, pl. 57, f. 8.

Test much compressed, trochoid, biconvex, the dorsal side in many specimens nearly flat, periphery rounded, umbilicus in many specimens open; chambers numerous, 10-12 in the last-formed whorl, distinct; sutures distinct, on the dorsal side nearly flush with the surface, slightly limbate, curved, on the ventral side slightly curved, nearly radial, slightly depressed; wall smooth; aperture on the ventral side between the periphery and umbilicus, low. Diameter 0.25-0.55 mm., height 0.10-0.25 mm.

Superfamily Robertinacea Reuss, 1850
Family Ceratobuliminidae Cushman, 1927
Subfamily Epistomininae Wedekind, 1937
Genus *Epistomina* Terquem, 1883

Epistomina supracretacea ten Dam

Epistomina caracolla (Roemer). Franke, 1925, Greifswald, Universität, Geologisch-Palaeontologischen Institute, Abhandlungen, 6:88, pl. 8, f. 10. (In part) Cushman, 1946, United States Geological Survey Professional Paper, 206:142-143, pl. 59, f. 2 (not f. 1; synonymy in part only). (Not *Gyroidina caracolla* Roemer.)

E. elegans (d'Orbigny). Cushman, 1927, Journal of Paleontology, 1(2):166, pl. 26, f. 3-4 (not *Rotalia elegans* d'Orbigny).

E. partschiana (d'Orbigny). Franke, 1929, K. Preussischen Geologischen Landesanstalt, Abhandlungen, [NF] 111:185-186, pl. 17, f. 9 (not *Rotalina partschiana* d'Orbigny).

E. supracretacea ten Dam, 1948, Revue de l'Institut Francais du Pétrole et Annales des Combustibles liquides, 3(6):163-164, pl. 1, f. 8.

Test biconvex, dorsally showing the earlier whorls, ventrally involute; periphery acute and slightly keeled; chambers distinct, 6 to 8 in the last-formed whorl, not inflated, of uniform shape, very gradually increasing in size as added; sutures strongly limbate, flush with the surface or raised in worn specimens, dorsally gently curved, ventrally nearly radiate or slightly tangential; wall smooth, the sutures usually lighter than the remainder, and the areas of the chambers often with a pattern of light and dark that is due to thickenings; apertures on the ventral side just below the periphery and also along the ventral margin of the chamber. Diameter 0.40-0.65 mm., height 0.25-0.35 mm.

Phylum ARTHROPODA Siebold and Stannius, 1845
Subphylum MANDIBULATA Clairville, 1798
Class CRUSTACEA Pennant, 1777
Subclass OSTRACODA Latrielle, 1806
Order PODOCOPIDA Müller, 1894
Suborder PODOCOPINA Sars, 1866
Superfamily Cytheracea Baird, 1850
Family Brachycytheridae Puri, 1954
Genus Brachycythere Alexander, 1933

Brachycythere sphenoides (Reuss)

Cythere sphenoides Reuss, 1854, Beiträge zur Characteristik Der Kreideschichten In Den Ostalpen, Besonders In Fosauthale Und Am Wolfgangsee, p. 141, pl. 27, f. 2a-c.

Cytheropteron sphenoides Jones and Hinde, 1889, A Supplementary Monograph of the Cretaceous Entomostraca of England and Ireland. Paleontographical Soc. London, 43:33, pl. 1, f. 18-20.

Cytheropteron sp. B Israelsky, 1929, Arkansas Geological Survey Bulletin, 2:8, pl. 1A, f. 2a-c.

Cythere sphenoides Alexander, 1929, University of Texas Bulletin 2907:81, pl. 7, f. 9, 14.

Brachycythere sphenoides Alexander, 1933, Journal of Paleontology, 7:205, pl. 25, f. 3a-c; pl. 26, f. 7a-b; pl. 27, f. 19. Loetterle, 1937, Nebraska Geological Survey, 2nd Series, Bulletin, 12:53, pl. 9, f. 1a-b. Calahan, 1939, Shreveport Geological Society, Guidebook Fourteenth Annual Field Trip, p. 41, pl. 3, f. 5a-c. Alexander, 1939, ibid., p. 66. Swain, 1952, United States Geological Survey Professional Paper, 234B:80, pl. 8, f. 42, 43. Butler and Jones, 1957, Louisiana Geological Survey Bulletin, 32:27, pl. 3, f. 1.

Carapace ovate, highest in front of middle, dorsal margin arched, angled at terminal dentitions, anterior broadly obliquely rounded and denticulate, posterior compressed, subangular, and denticulate below; a longitudinal ridge marks the ventro-lateral edge of the valves and the shell is depressed just above the anterior end of this ridge; muscle scar pattern consists of a v-shaped frontal scar and a vertical row of 3 scars, the dorsal one v-shaped and the middle scar subdivided into 2 scars; a glassy eye-spot is present; hinge is hemiamphidont, the posterior elements crenulate; the marginal area is broad and contains numerous radial canals which tend to branch, and to widen bulbously near the outer margin. Length 0.90-1.00 mm., width 0.41 mm., height 0.52 mm.

Family Cytherideidae Sars, 1925

Subfamily Cytherideinae Sars, 1925

Genus Cytheridea Bosquet, 1852

Cytheridea bairdioides Alexander

Cytheridea bairdioides Alexander, 1929, University of Texas Bulletin, 2907:70, pl. 4, f. 18.

Carapace in side view ovate, highest at middle, height equal to about two-thirds length, carapace of moderate convexity, widest slightly posterior to middle, surface punctate, dorsal margin evenly arched, ventral margin convex downward; anterior end broadly and evenly rounded, posterior margin extended into a short, subacute beak at the middle; left valve overlaps right valve around the entire periphery, overlap strongest along middle of dorsal and ventral margins; muscle scar pattern consists of v-shaped frontal scar and vertical row of 4 ovate scars; hinge merodont; marginal area widest at ends. Length 0.75 mm., width 0.32 mm., height 0.48 mm.

Cytheridea perforata (Roemer)

Cytherina perforata Roemer, 1838, Neues Jahrbuch für Min., Geol., Pal., p. 516, pl. 6, f. 11.

Cytheridea perforata (Roemer). Jones, 1856, Monograph of the Tertiary Entomostraca of England, Paleontographical Society of London, p. 44, pl. 4, f. 14. Jones and Hinde, 1890, Supplementary Monograph of the Cretaceous Entomostraca of England and Ireland, Paleontographical Society of London, p. 29, pl. 1, f. 1-4.

Carapace in side view elongate-ovate, highest anterior to middle, in dorsal view carapace widest at middle, tapering uniformly to very sharply rounded ends; surface coarsely pitted, evenly distributed; anterior end broadly rounded, oblique dorsally, posterior end more sharply rounded than anterior; dorsal margin arched, ventral margin gently convex downward; left valve overlapping right nearly equally; muscle scar pattern consists of a v-shaped frontal scar and a vertical row of 4 ovate scars; hinge merodont. Length 0.42 mm., width 0.19 mm., height 0.20 mm.

Cytheridea posterovata Lankford

Cytheridea posterovata Lankford, 1953, Utah Geological and Mineralogical Survey Bulletin, 47:99, pl. 15, f. 3a-c.

Carapace in side view elongate-ovate, highest anterior to middle; surface ornamented with shallow punctations distributed centrally and lacking on the marginal areas of valves; anterior end broadly rounded, slightly oblique dorsally, posterior end sharply and evenly rounded; dorsal margin arched, ventral margin straight along posterior half, anterior half sinuate; left valve overlaps right valve, more strongly at dorsal and ventral margins than at ends; muscle scar pattern consists of v-shaped frontal scar and vertical row of 4 scars; hinge merodont. Length 0.69mm., width 0.31 mm., height 0.52 mm.

Family Cytheruridae Muller, 1894

Genus Orthonotacythere Alexander, 1933

Orthonotacythere hannai (Israelsky)

Cytheridea(?) hannai Israelsky, 1929, Arkansas Geological Survey Bulletin, 2:12, pl. 2A, f. 10a-b.

Cytheropteron hannai Alexander, 1929, University of Texas Bulletin, 2907:105, pl. 9, f. 16.

Orthonotacythere hannai Alexander, 1933, Journal of Paleontology, 7:200, pl. 25, f. 1a-c; pl. 26, f. 6a-b; pl. 27, f. 14a-b.

Carapace plump, in side view ovate, highest anteriorly, surface reticulate with a ventral row of tubercles, above which are other tubercles in front of and behind a median sulcus; anterior end obliquely rounded with 6-8 dentitions, posterior with a short blunt caudal process near dorsal margin; dorsal margin straight, ventral convex; eye spot distinct; adductor muscle scars in vertical row of 4; hinge of right valve with terminal crenulate cusps between which is a finely crenulate narrow furrow; marginal pore canals few, simple, straight. Length 0.65 mm.

Family Trachyleberididae Sylvester and Bradley, 1948

Genus Cythereis Jones, 1849

Cythereis coalvillensis Lankford

Cythereis coalvillensis Lankford, 1953, Utah Geological and Mineralogical Survey Bulletin, 47:97, pl. 16, f. 1a-c.

Carapace oblong, highest anteriorly, surface of valves with median, longitudinal, dissected ridge, highest at middle, beginning behind anterior marginal rim, extending obliquely, posteriorly, and upward and terminating at the point opposite the dorsoventral angle, low ridges connecting this ridge with the dorsal and ventral margins form a moderate reticulation; anterior end slightly rounded, rimmed, moderately denticulate, continuations of the anterior marginal rim extending as narrow ridges along dorsal and ventral margins, ventral ridges expanding laterally and terminating in pitted flanges; dorsal ridge with prominent node anterior to center and ending opposite ventral ridge, posterior end rimmed, denticulate, compressed, broadly angled at middle; dorsal margin straight, ventral margin straight to slightly convex downward, dorsal and ventral margins subparallel, converging posteriorly; muscle scar pattern consists of a v-shaped antennal scar anterior to 4 vertically arranged adductor scars; hinge paramphidont. Length 0.71 mm., width 0.33 mm., height 0.36 mm.

<u>Cythereis</u> <u>thomasi</u> (Israelsky)

<u>Cytheropteron</u> <u>ponderosa</u> Israelsky, 1929, Arkansas Geological Survey Bulletin, 2:9, pl. 2A, f. 1a-c, (not <u>Cythereis</u> <u>ponderosa</u> Israelsky, 1929, op. cit., p. 13, pl. 3A, f. 5-8).

<u>Cythereis</u> <u>thomasi</u> Alexander, 1933, Journal of Paleontology, 7(2):211, pl. 25, f. 16; pl. 27, f. 17.

Carapace in side view elongate, quadrate in outline, highest at anterior end, anterior portion of the carapace is compressed, the carapace widens gradually posteriorly, and attains its greatest width at the ventral margin, directly below the posterior end of the hinge line and just in front of the compressed posterior end, the ventral edge of each valve bears a strong compressed wing-like lateral expansion, in dorsal view the carapace is broadly sagittate in outline; anterior end broadly and slightly obliquely rounded with thickened rounded marginal rim, and bearing numerous long strong spine-like teeth along the lower two-thirds of the margin, posterior end is broadly rounded below and obliquely truncated above, curved lower border bears 5 or 6 teeth similar to those at the anterior end; dorsal margin straight except for slight downward slope just behind the high anterior end, ventral margin straight, dorsal and ventral margins subparallel, converging slightly posteriorly; muscle scars consist of a v-shaped antennal scar anterior to a vertical row of 4 adductor scars; hinge paramphidont. Length 0.95 mm., width 0.8 mm., height 0.5 mm.

Suborder PLATYCOPINA Sars, 1866
Family Cytherellidae Sars, 1866
Genus *Cytherella* Jones, 1849

Cytherella obesa Alexander

Cytherella obesa Alexander, 1929, University of Texas Bulletin, 2907:51, pl. 1, f. 3, 6.

Carapace in side view ovate, highest at middle, valves strongly convex with greatest width near posterior end; in dorsal view, anterior end subacute, posterior end blunt, rounded, surface smooth; dorsal margin gently and evenly arched, ventral margin gently and evenly convex downward; right valve overlapping left with overlap stronger along dorsal and ventral borders than along anterior margin; muscle scars consist of 2 slightly bent rows, each with 5-9 scars. Length 0.82 mm., width 0.4 mm., height 0.54 mm.

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