UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Foraminifers from the Upper Part of the Lewis Shale (Upper Cretaceous) near Durango, Colorado

By

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INTRODUCTION

This project examined the foraminifers in a relatively thick, continuous section of the upper part of the Lewis Shale. The locality selected for study is at Carbon Junction, just south of the city limits of Durango, Colorado on the east side of the Animas River (fig. 1). This locality was selected because of: 1) excellent exposure, 2) ease of access, and 3) absence of exposure of the Lewis Shale at the described type locality. The study involved the collection of 29 rock samples through a 300-ft-thick section of the upper part of the Lewis Shale. Foraminifers recovered from these samples were identified, and, on the basis of their paleoecology, were used as indicators of the environments of deposition for the upper part of the Lewis Shale in the northern San Juan basin.

LEWIS SHALE

Origin of Name

The Lewis Shale was named and described by Cross and others (1899). They described the Lewis as "the heavy shale formation succeeding the Mesaverde [that] is here named the Lewis shale from its occurrence at Fort Lewis, in the La Plata Valley a few miles south of the quadrangle line." They further wrote that "only a few hundred feet of the shale are now preserved within the La Plata quadrangle," (fig. 2) "and exposures of these beds are rare,"..."but the entire thickness is well exposed in the adjacent Durango quadrangle on either side of the Animas River. There the Lewis shale was found by Mr. Spencer to have a thickness of 2000 feet..."
Cross and others (1899) provided no detailed lithologic description and no thickness measurement of the Lewis Shale at the Fort Lewis locality. Their only description of the Lewis reads as follows: "The Lewis shale is a body of more or less sandy shales and clays with occasional thin layers of impure limestones, or of concretionary masses at several different horizons. As far as examined, it has even less tendency than the Mancos shale to becomesandy...The only fossil of identifiable character as yet obtained from the Lewis shale is *Baculites asper*..."

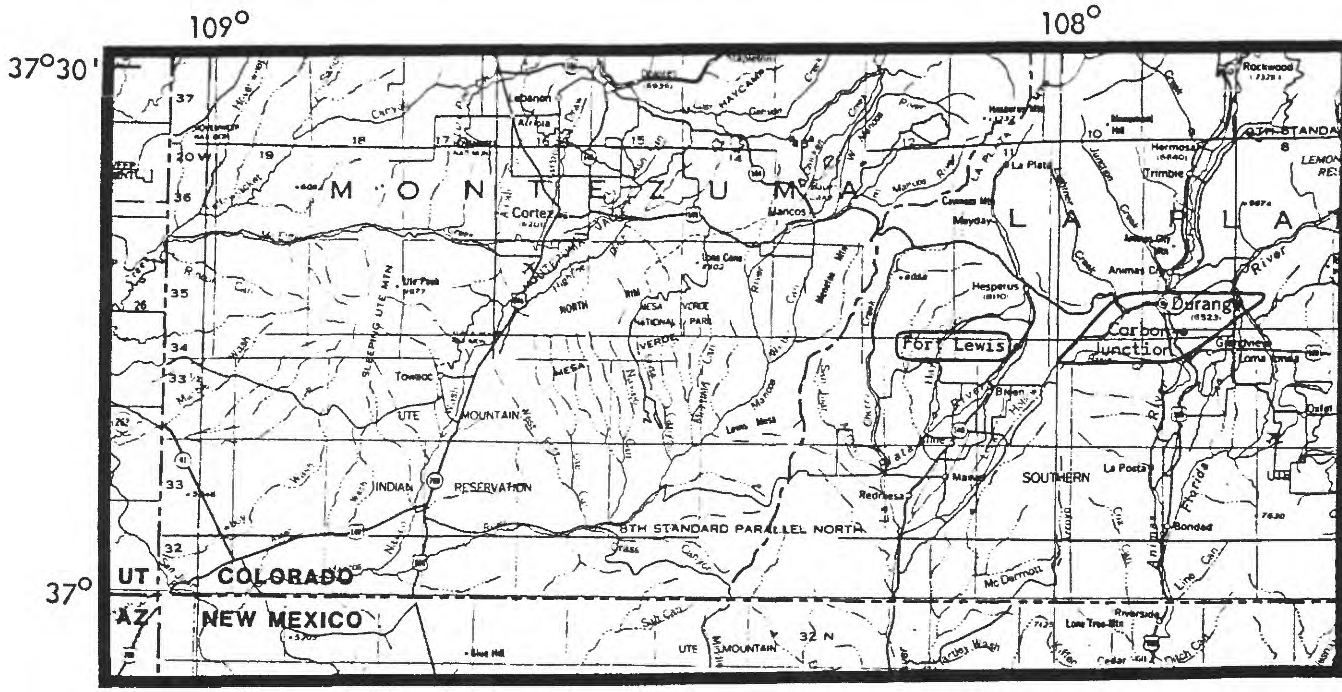


Figure 1. Index map of southwest Colorado showing the locations of Fort Lewis, Durango, and Carbon Junction. (Modified from unpublished U.S. Geological Survey base map)

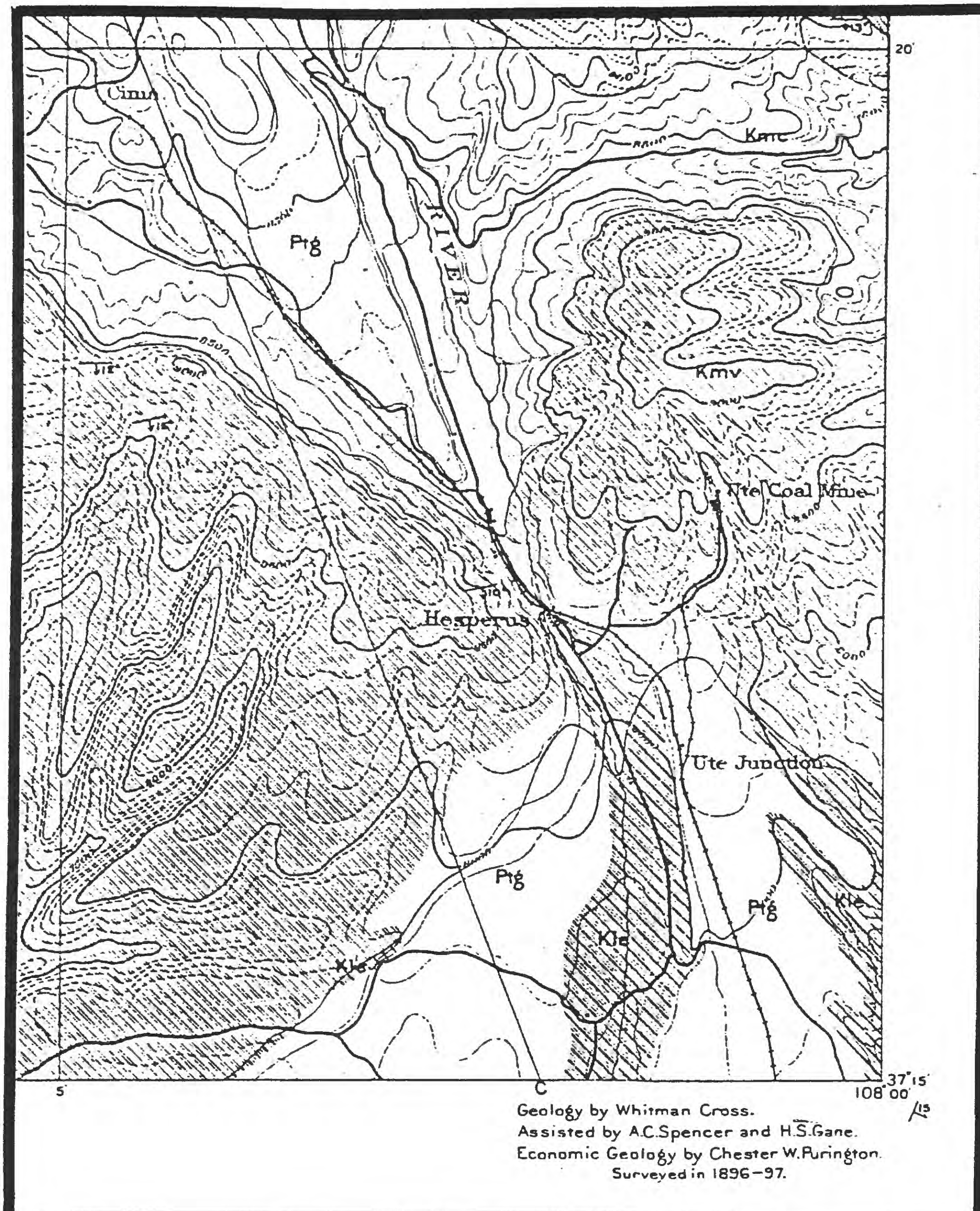


Figure 2. Southeast corner of 1899 geologic map of the La Plata quadrangle by Cross and others (1899), shows the outcrop of the Lewis Shale in a very dark shaded pattern (Kle). The type section, according to the original description, is south of the quadrangle line. Scale 1:62,500.

I conducted a field reconnaissance in sections 3 and 4 (fig. 3) of T. 34 N., R. 11 W. in the northeast area of the Kline, Colorado, quadrangle. These two sections have been designated the type locality of the Lewis Shale according to the original description by Cross and others (1899) (Wilmarth, 1957). Section 3 was almost entirely covered with agricultural crops and stock pens of the Colorado State University (CSU) agricultural experiment station, which is now located on the site. On the basis of the topographic relief present in section 3 (fig. 3), it is physically impossible for a few hundred feet of Lewis shale to be exposed there as indicated by Cross and others (1899).

In 1896-97 at the time of Cross's survey, Fort Lewis could have been a much larger town than the area in section 25, T. 35 N., R 11 W. on the Hesperus quadrangle. Cross's and others' use of the phrase, "from its [the Lewis shale] occurrence at Fort Lewis," may have meant something very different than what is exposed at Fort Lewis today. Perhaps the town of Fort Lewis extended southward down the La Plata Valley, thus encompassing a much larger area. Therefore, "it's occurrence at Fort Lewis," could be correct. The present study indicates that there is no Lewis Shale exposed at Fort Lewis today. Therefore, the location of the type locality of the Lewis shale as originally described by Cross and others in 1899 could not be found at Fort Lewis (fig. 3).

Use of Name Outside San Juan Basin

The name "Lewis Shale" has been used for rocks of northwest Colorado and parts of Wyoming (Wilmarth, 1957). Although the Lewis in those areas is also an offshore-marine rock unit, it is younger (Maastrichtian) than the Lewis Shale of the San Juan basin (Campanian). Apparently, the "Lewis" name was carried from the type area in southwest Colorado to northwest Colorado and Wyoming on the assumption that all of these rocks were the same age. Molenaar (1977) has indicated that the use of the name "Lewis" in northwest Colorado and Wyoming was based on a miscorrelation and that the name "Lewis" in those areas is now usually denoted by quotes.

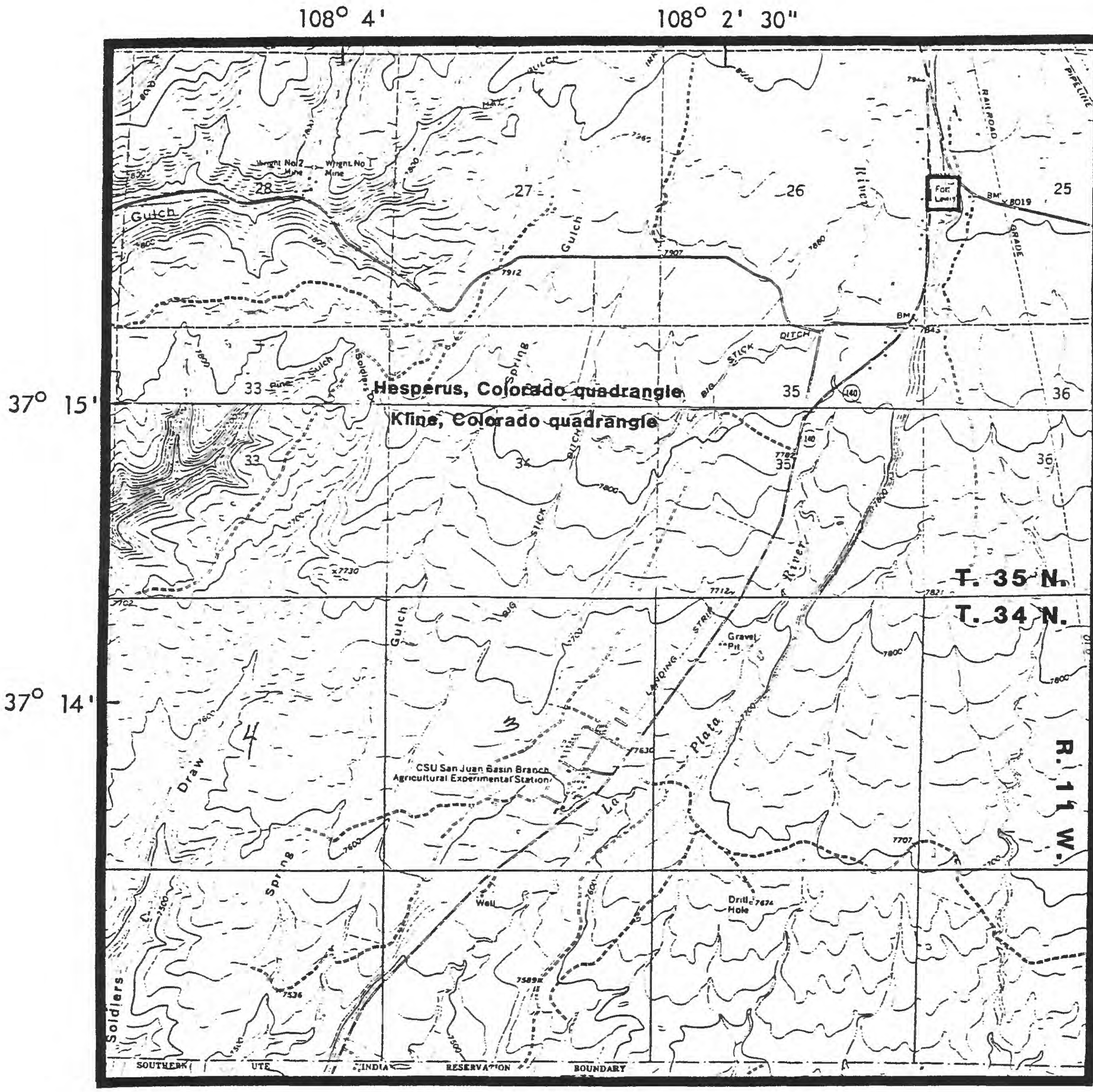


Figure 3. Southeast corner of the Hesperus, Colorado USGS 7.5' (Topo) quadrangle (upper part of figure), showing the location of Fort Lewis marked with a square. Durango is about 9.5 miles east of Fort Lewis. Northeast area of the Kline, Colorado USGS 7.5' (Topo) quadrangle (lower part of figure), showing sections 3 and 4 in T. 34 N., R. 11 W. Fort Lewis is about 2.5 miles north of the CSU compound.

Geometry and Origin

The Lewis Shale is a wedge-shaped stratigraphic unit as represented in cross section (fig. 4). The Lewis was deposited as an offshore-marine rock unit during the time the underlying Cliff House Sandstone transgressed southwestward and the overlying Pictured Cliffs Sandstone regressed northeastward across the basin. A cross section by Fassett (1977) shows the Lewis to be more than 2,200 ft thick in the northeast part of the San Juan basin, and it thins to 0 ft in the southwest part of the basin. Figure 5 shows the maximum western extent of deposition of the Lewis Shale in the Cretaceous seaway during middle Campanian time (transgression 3 of Weimer, (1960), line T3 on figure 5). The Lewis Shale at the study locality is about 2,000 feet thick.

Lithology

Fassett and Hinds (1971) described the Lewis Shale as a "light- to dark-gray and black shale that contains interbeds of light-brown sandstone, sandy to silty limestone, calcareous concretions, and bentonite." One of the bentonite beds in the Lewis was named the Huerfanito Bentonite Bed (Fassett and Hinds, 1971). This bed has been used as a datum for stratigraphic studies throughout the San Juan basin. The Huerfanito Bed is located approximately 800 feet below the base of the Pictured Cliffs Sandstone (top of the Lewis Shale) in the study area (J.E. Fassett, oral commun., 1989) and thus is well below the rocks sampled.

SAMPLING and SAMPLE PREPARATION

Rock samples from the uppermost 300 ft of the Lewis Shale were collected at 10-foot intervals in the study area near Carbon Junction, Colorado (figs. 6 and 7). Table 1 shows the stratigraphic positions of the 29 samples collected. Sample number 0 is a shale unit in the Pictured Cliffs Sandstone (PC Ss) and is represented as -10 ft in the table. Sample number 1 is the top of the Lewis Shale. The only break in the collection sequence is in a 40-ft-thick section near the top of the Lewis in the transition zone with the base of the PC Ss. This interval is between the

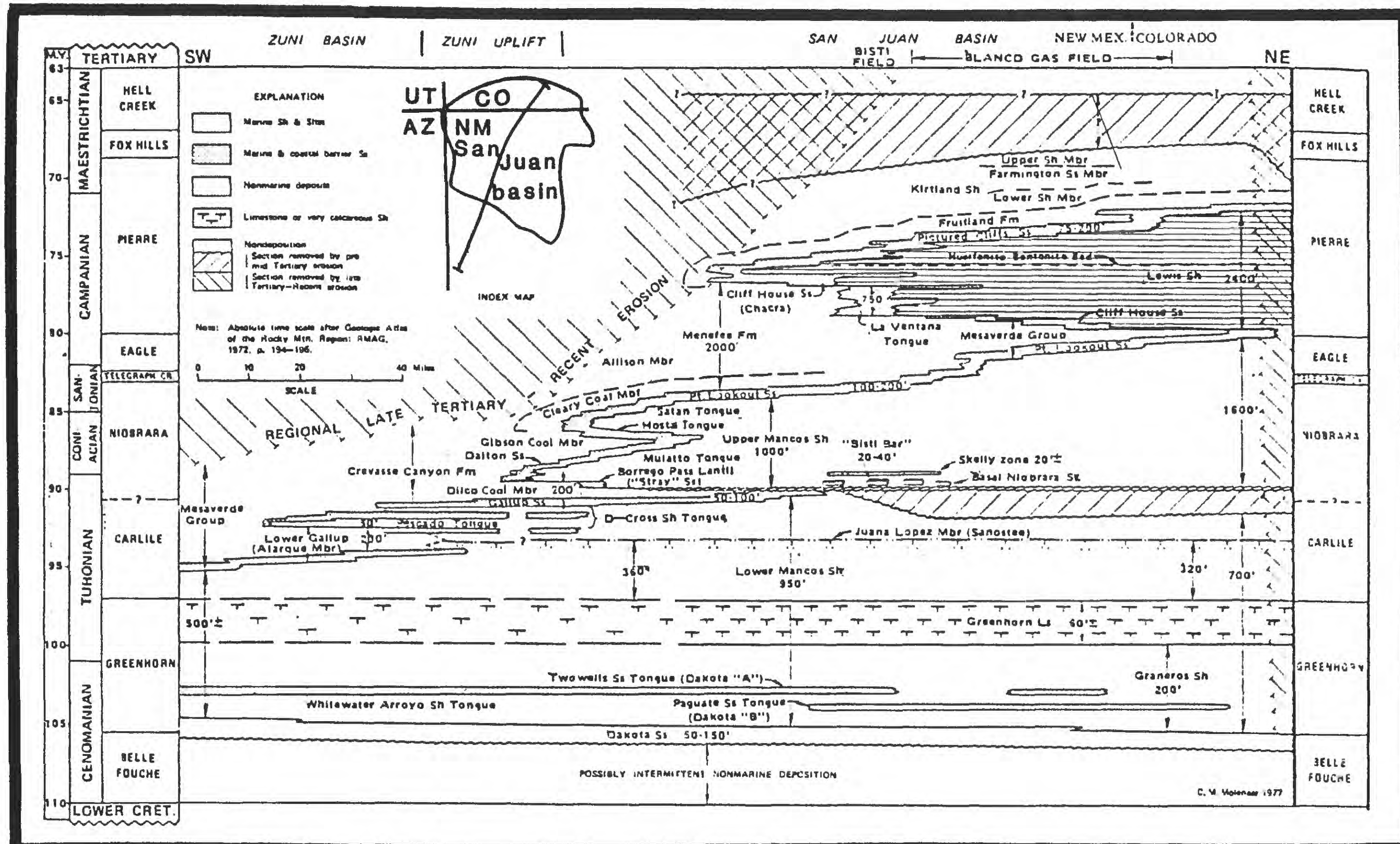


Figure 4. Upper Cretaceous time-stratigraphic section, Zuni basin-San Juan basin, northwestern New Mexico and southwestern Colorado. The Lewis Shale in the upper part of the diagram is underlain by the Cliff House Sandstone and overlain by the Pictured Cliffs Sandstone. (From Molenaar, 1977)

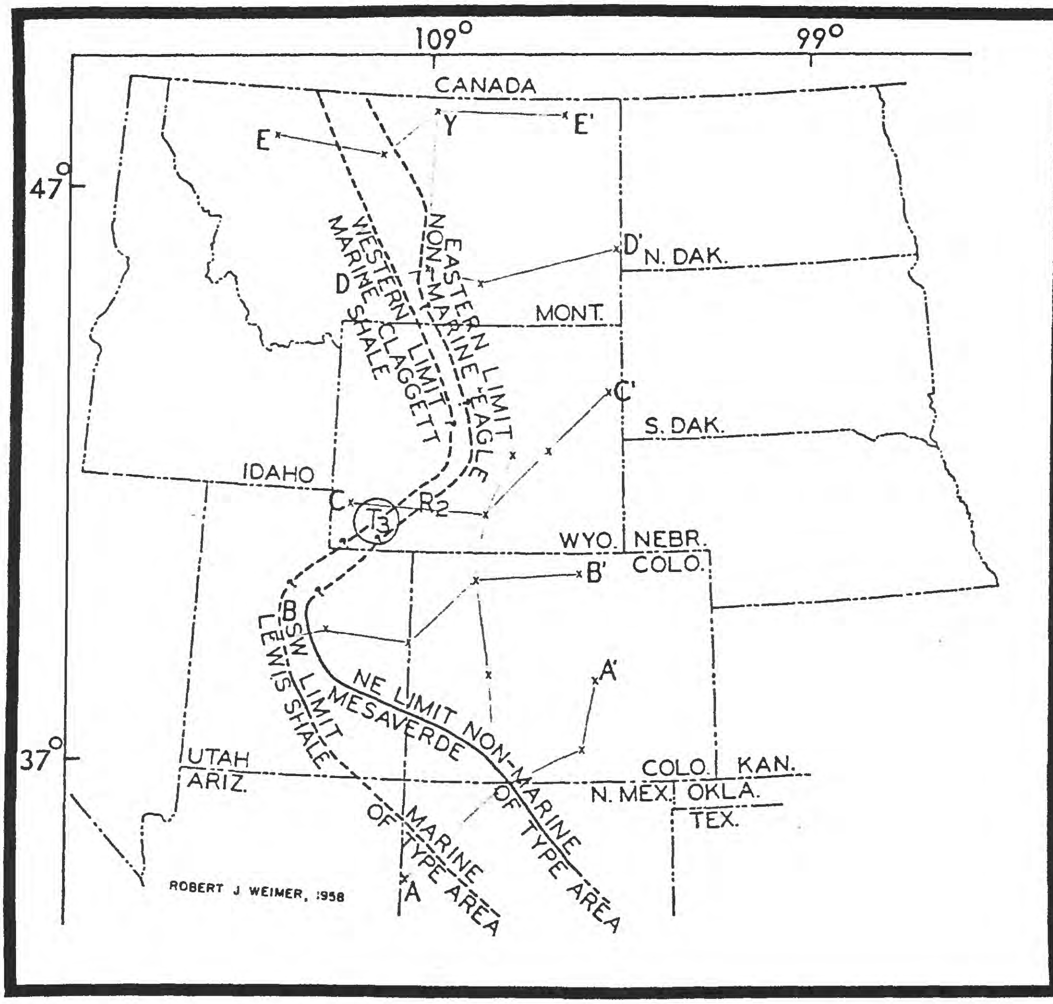


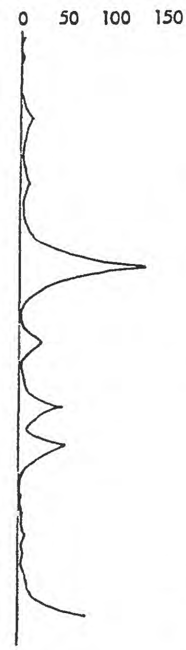
Figure 5. Approximate position of the maximum advance of middle late Campanian strandline (T3) of the Cretaceous Sea represented by Lewis Shale deposition in the San Juan basin. (From Weimer, 1960)

Figure 6. Outcrop of the upper part of the Lewis Shale at Carbon Junction, near Durango, Colorado. Photograph was taken looking northwest near Colorado Hwy. 160.

Figure 7. Top of the Lewis Shale at Carbon Junction, Colorado. The contact of the Lewis with the overlying Pictured Cliffs Sandstone (P.C. Ss) is gradational. Photograph was taken looking north near Colorado Hwy. 160.

Table 1. Summary of microfossil data from 29 rock samples collected from the upper 300 ft of the Lewis Shale at Carbon Junction, Colorado. Zero footage is the top of the Lewis Shale and -10 footage is a shale sample from the overlying Pictured Cliffs Sandstone.

Sample Number	Footage from top of Lewis Sh	Total No. of forams found	Diagram showing benthic agglut. foram abundance	Other micro-fossils found	Fraction of fines
0	-10 P.C.Ss	2		1 ostracode	1/32
1	0	1			1/8
2	10	0			entire
3	50	2			entire
4	60	13			entire
5	70	3			1/8
6	80	1			1/16
7	90	11		2 ostracodes	entire
8	100	1			entire
9	110	4			entire
10	120	17			entire
11	130	137		2 ostra., prism	entire
12	140	29			entire
13	150	3			entire
14	160	2			1/4
15	170	25		prisms	1/4
16	180	0			entire
17	190	11			entire
18	200	44			entire
19	210	6			entire
20	221	51			entire
21	230	5			1/2
22	240	0			entire
23	250	1			entire
24	260	9			1/4
25	270	6			entire
26	280	9		1 ostrocode	entire
27	290	16		prisms, 1 ostra.	entire
28	300	73		4 ostracodes & prisms	entire



Pictured Cliffs Sandstone and the Lewis Shale in figure 7. Splits of 150g from each rock sample were prepared for foraminiferal study using the standard kerosene technique (Kummel and Raup, 1965), which involves oven drying, a 15-hour soak in kerosene, decant, and a two-hour boil in Calgon and water. After mechanical breakdown in the kerosene process, each sample was sieved using A.S.T.M. sieves nos. 20 and 230. The amount of sediment that did not pass through the no. 230 sieve ranged from almost none to over 120g. This fraction was dried and then dry sieved using sieves nos. 20, 60, 80, and 100. Only a portion of the finer fraction was examined for foraminifers when the amount recovered was large. The portion of the finer fraction examined is shown on table 1 in the column headed, "Fraction of fines."

MICROPALEONTOLOGY

In general, the Lewis Shale foraminiferal population is very small with little diversity of species. The distribution of the foraminifers found in the study area is shown on figure 8. Preservation is poor, and most foraminifers are benthic with the exception of a single specimen each of *Hedbergella* sp., *H. planispira*, and *Archaeoglobigerina blowi*. Most of the benthics are arenaceous and are of the common and cosmopolitan genera of *Reophax*, *Miliammina*, *Haplophragmoides*, *Ammobaculites*, *Textularia*, *Trochammina*, and *Dorothia*. The benthic calcareous genera of *Nodosaria*, *Lagena*, *Lenticulina*, *Gavelinella*, and *Valvulineria* are rare and are usually represented by single tests.

Besides foraminifers, a few ostracodes and calcareous *Inoceramus* prisms were also recovered. Ostracodes and prisms together were found in only three samples at 130, 290, and 300 ft from the top of the Lewis (table 1, fig. 8). No ammonite parts were seen on outcrop or were found in the processed samples.

The abundance of arenaceous foraminifers (table 1) recovered from the strata in the lower part of this section, below 110 ft, reflects the preferred environment for these foraminifers. The population of foraminifers never established itself again in the upper 110 ft of the shale. Note that

SAMPLE No.	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Dorothia(?)																						1							
Dorothia sp.									1								3												
D. oxycona				5							1																		
Ammobaculites										1																			
Reophax(?) sp.									1							1		1											
Miliammina(?)																		1											
Tritaxia(?) sp.																									1				
Nonionella(?)		1															1	1											
Textularia(?)	1									1							1	2	1			2						1	
T. sp. 1	1																	1											
T. sp. 2																		1											
Astacolus sp.												1																	
Gavelinella san																1													
Valvulineria cf												1																	
V. lenticula	2	1															1	1											1
Lagena sp.	1																												
Lenticulina(?)															1	1	1	1											
L. sp. 1	4	1	4															1											
L. sp. 2	1																1	1											
L. sp. 3	1																												
Nodosaria sp.	1																												
Haplophragmoid (?)	18	4	2		2	1		2	16	2	11	1		2			10	24	4			1		1	1	2			
Haplophrag. sp					1																								
H. kirki			1																										
Trochammina(?)	5	8	2		3			2	22	1	30	7		19	1		7	15	11	2	1	3	1	1	9				
T. sp. 1					1																			1					
T. sp. 2																		1											
T. sp. 3												1																	
T. sp. 4																		1											
T. albertensis		1																											
T. rainwateri														1															
Hedbergella sp.																						1							
H. planispira																						1							
Archaeo. blowi																	1												
Unknown tests	38			1	2			1	11	1	2			3			3	85	1	2		2			2				1
TOTAL	73	16	9	6	9	1	0	5	51	6	44	11	0	25	2	3	29	137	17	4	1	11	1	3	13	2	0	1	2
Ostracodes	4	1	1															2				2							1
Prisms present	X	X												X				X											
Footage fr top of Lewis Sh	300	290	280	270	260	250	240	230	220	210	200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	10	0	
SAMPLE No.	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Figure 8. Distribution of middle late Campanian foraminifers recovered from the upper 300 ft of the Lewis Shale at Carbon Junction, Colorado.

no *Inoceramus* prisms occur in the upper 120 ft of the section, suggesting a reduction in or lack of a muddy-bottom environment.

Boersma (1978) suggested that ostracodes fill the ecological niche formerly occupied by foraminifers as an environment becomes unsuited for foraminiferal survival. There is no evidence from this study to support that suggestion; as shown in table 1, there is no increase in ostracodes coincident with decrease in foraminifers.

The Importance of Planktonic Foraminifers

Modern planktonic foraminifers are rare in the nearshore environment of the continental shelf and increase in abundance, diversity, and size with increased water depth toward the open sea. They are generally restricted to open-marine environments of normal oceanic salinity and clear water. Spinose, symbiont(algae)-bearing species require sunlit, near-surface waters, whereas the nonspinose, symbiont-barren species occupy deeper waters (Leckie, 1987) that are able to support their full life cycles.

The application of modern foraminferal distribution patterns is useful in the reconstruction of Cretaceous paleoenvironments. For example, Eicher (1969) and Eicher and Worstell (1970) have shown that the globular morphotypes (*Hedbergella* and *Heterohelix*) were the first planktonics to appear during transgression and the last to disappear during regression of the Cretaceous (Cenomanian-Turonian) epicontinental sea. Leckie (1987) supports these data with observed species distribution in modern shelf environments. The nonspinose globorotaliid morphotypes, (*Rotalipora* and *Praeglobotruncana*) keeled genera, are believed to have been the deepest dwelling of the mid-Cretaceous planktonic foraminifers.

The upper 300 ft of the Lewis Shale produced a single test each of *Hedbergella* sp., *H. planispira*, and *Archaeoglobigerina blowi*. These are all globular morphotype genera, and their presence supports Eicher's (1969) claim of their being the first and last of the planktonics to be present during Cretaceous transgression and regression, respectively. Whether these planktonic tests actually occupied these places in time remains speculative because the possibility of current transport is high. The fact that these three globular types are present with no globorotaliids suggests that the Lewis sea at that time and place was not a deep (<300 ft) open-marine environment.

PALEOENVIRONMENT AND BIOSTRATIGRAPHY

Little information is available on Campanian foraminifers from the Western Interior of the United States. A major contribution by McNeil and Caldwell (1981) dealt with Campanian foraminifers from the Manitoba Escarpment in Canada. However, the Canadian fauna and the upper Lewis Shale fauna do not appear to be the same.

The Upper Cretaceous marine rocks of the Western Interior have been stratigraphically zoned on the basis of ammonites. Cobban (1973) and Cobban and others (1974) have established ammonite zonation for the Lewis Shale in the San Juan basin. Fassett (1987) synthesized the ammonite data from these two papers for the upper part of the Lewis and added corrected radiometric ages (fig. 9). Fassett (1987, fig. 5) also constructed a bioisochrone map for the San Juan basin showing the boundary horizons for the ammonite zones present in the upper part of the Lewis (fig. 10). This map shows the boundary between the *E. jenneyi* and *D. cheyennense* zones to be very close to the Carbon Junction locality of this report. The 300 feet of Lewis Shale sampled for this study would thus be in the *E. jenneyi* and the upper part of the *D. stevensoni* ammonite zones (figs. 9 and 10).

McNeil and Caldwell (1981) established the *Haplophramoides fraseri* foraminiferal zone in western Saskatchewan. This zone, dated as late Campanian, probably extends from within the *D. stevensoni* zone of middle late Campanian age to about the *B. cuneatus* zone (fig. 11). Thus, the upper part of the Lewis studied in this report represents only about the lower half of the *H. fraseri* zone. The Canadian fauna from the Bearpaw Formation and the fauna from the Lewis Shale, however, are not the same. Although several genera are the same in the two faunas, there is no duplication of species. This lack of species duplication may be a function of the poor preservation of the Lewis fauna.

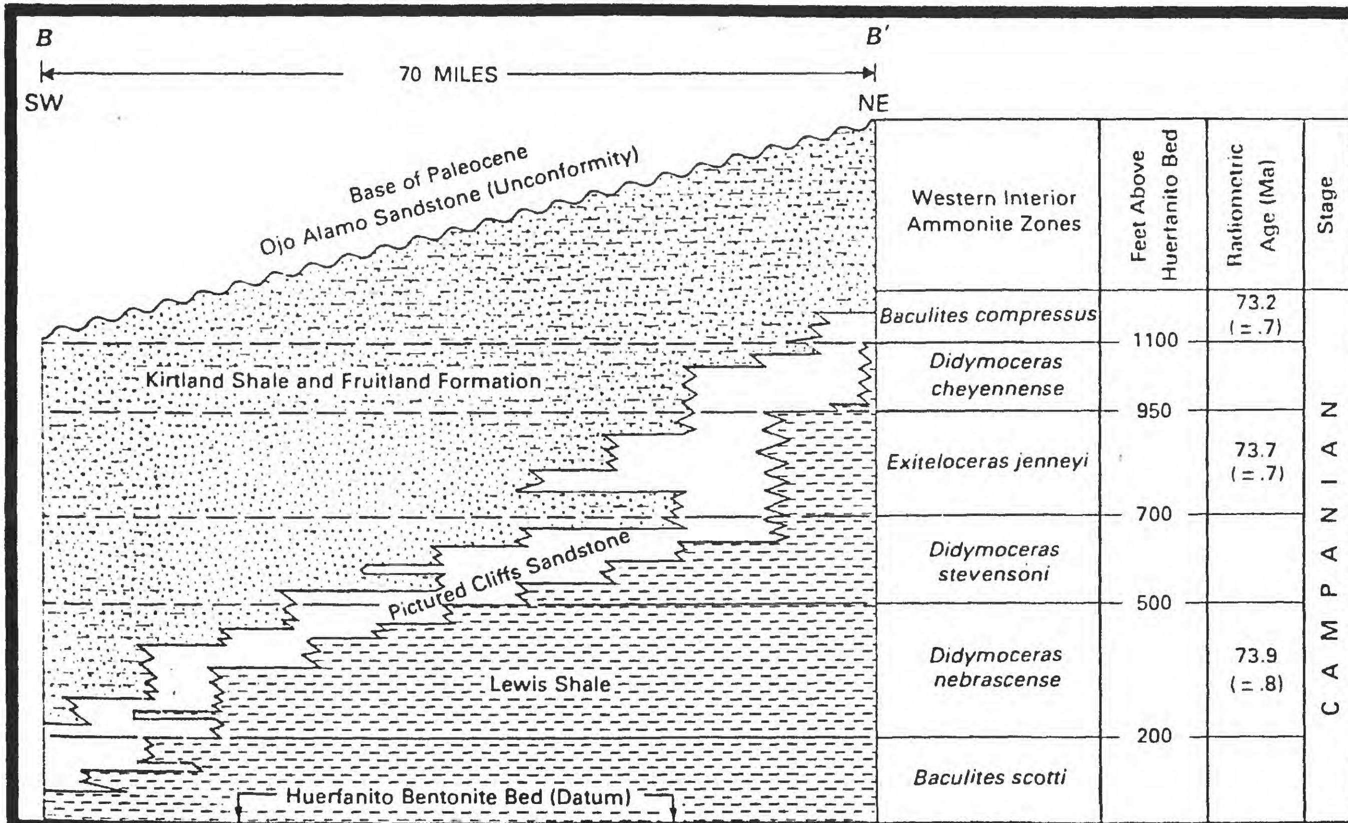


Figure 9. Northeast-trending stratigraphic cross section across the San Juan basin. Placement of Western Interior ammonite zone boundaries is based on data from Cobban (1973) and Cobban and others (1974). Ages of ammonite zones are from Obradovich and Cobban (1975) corrected mathematically to the new decay constants. Stratigraphy is modified from Fassett and Hinds (1971). (From Fassett, 1987)

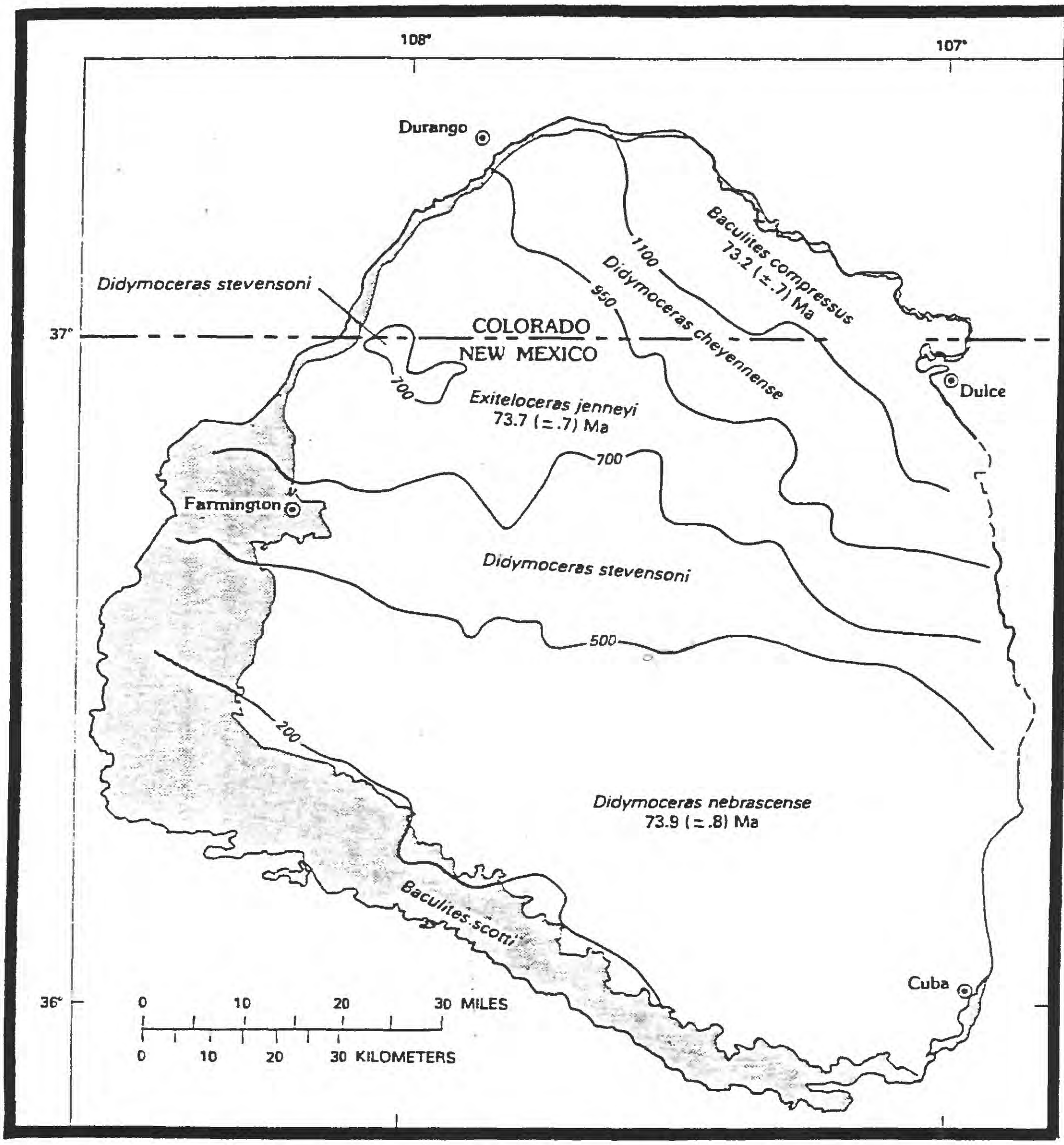


Figure 10. Bioisochrone map of the San Juan basin showing the projections to a horizontal plane of the intersections of the boundary horizons of the Western Interior ammonite zones with the top of the time-transgressive Pictured Cliffs Sandstone (the highest marine unit in the basin). The bioisochrones are: (1) lines of equal biological value (biozone boundaries), (2) lines of equal thickness of rock (each line is an isopach of the interval from the Huerfanito Bentonite Bed to the top of the Pictured Cliffs Sandstone), and (3) lines connecting points of equal time value. The corrected radiometric ages for three of these zones (from Obradovich and Cobban, 1975) are shown. This map should have value for predicting which of the various Western Interior ammonite (or equivalents) will be present in the Lewis Shale near the base of and at specific stratigraphic levels below the Pictured Cliffs around its outcrop in the San Juan basin. Shaded area represents the outcrop of the Fruitland Formation and Kirtland Shale. (Modified from Fassett, 1987.)

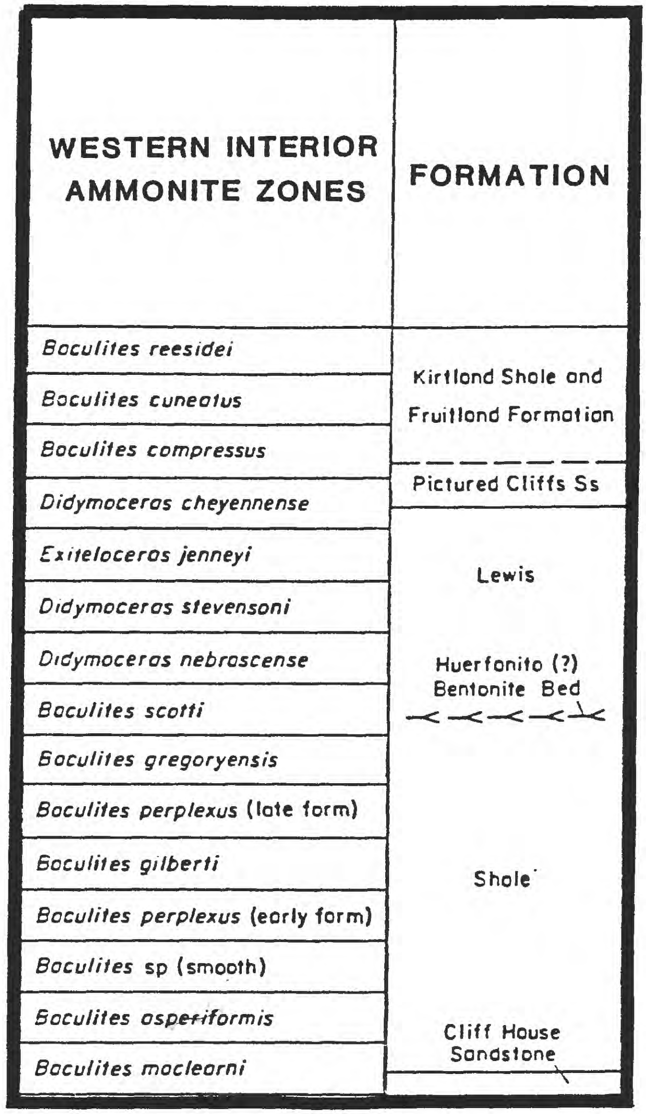


Figure 11. Chart showing the upper Campanian Western Interior ammonite zones found in the Lewis Shale of the northwest San Juan basin area. (Modified from Cobban, 1973). To date, *Baculites gregoryensis* has not been found in the San Juan basin.

Manfrino (1984) discussed the upper 249 ft of the Lewis in the Durango area (including the Carbon Junction section) and recognized two distinct lithologic units. Unit 1 consisted of the lower 148 ft of Lewis in her study area, which she described as shale with abundant calcareous concretions and interbedded shale, and silty claystone beds. Unit 2 was the upper 101 ft of the Lewis and represented the transition zone between the Lewis and overlying Pictured Cliffs Sandstone. This unit was described as shale, silty claystone, and very fine grained sandstone beds, and it contained more burrows than the unit below. Manfrino further stated that unit 1 of the Lewis represents a lower shoreface environment of deposition, and unit 2 represents the upper shoreface where the water depths ranged from a few hundred feet to a few tens of feet.

The present foraminiferal study supports the concept of two distinct environmental units in the upper part of the Lewis Shale in the Carbon Junction area. The foraminiferal abundance data in table 1 support the idea that the transition zone (Manfrino's unit 2) was a less desirable environment for foraminifers because of the greater abundance of sand and silt in this shallower water environment closer to the strandline. The upper 110 ft of the Lewis shows a decrease in foraminiferal population, and no *Inoceramus* prisms were found. The present study supports and applies the finding of Eicher (1969) and Eicher and Worstell (1970) to the Campanian fauna that the Cenomanian-Turonian globular morphotypes are the last of the planktonics to disappear during regression. *Hedbergella planispira* and *Hedbergella* sp. came from a sample at 90 ft from the top of the Lewis Shale and are the uppermost (last) planktonics recovered from the section.

Leckie (1987) was one of the few foram researchers to define Cretaceous shallow-water fauna, suggesting a depth figure of <330 ft. Leckie stated that *Hedbergella* and *Globigerinelloides* are the two major genera characteristic of open-marine pelagic waters. Applying Leckie's results to this study, *Hedbergella* is the only shallow-water morphotype present in the Lewis Shale. Leckie also associates *Clavihedbergella*, *Schackoina*, and *Ticinella* with his shallow-water fauna. None of these associated genera was found in the Lewis. Because none of Leckie's deep water fauna (>330 ft) represented by the keeled genera of *Rotalipora*, *Planomalina*, and *Praeglobotruncana*, is present, the Lewis in the study area was probably deposited in a shallow-water environment. The three planktonic specimens found in the 300 ft of section are certainly not definitive indicators of water depths; they only offer hints of suggested water depths.

The most abundant benthic genus present is *Trochammina*, which is characteristic of nearshore and offshore environments.

Some authors depend on statistics to determine the paleoenvironments. Because of the rare planktonic specimens, lack of test abundance and species diversity, and poor preservation of tests, there was no reason to calculate planktonic/benthic ratios, the foraminiferal number (number of forams in 1 gram of dry sediment), and species diversity, for the foraminifers recovered in this study. The general summary statement that can be supported by the data from this study is that the upper 300 ft of the Lewis Shale at Carbon Junction, Colorado was deposited in a shallowing sea (<330 ft) of normal marine salinity in an offshore-shelf environment.

A Note on Ostracodes

Two genera of ostracodes are represented in the upper 300 ft of the Lewis Shale: 1) *Cytherella* - (Pl. 4, fig. 16) lacks ornamentation and is a nondescript, very long ranging genus. It indicates normal marine salinity and relatively warm water and 2) *Haplocytheridea* - (Pl. 4, fig. 17) is a very common genus and ranged from the tropics to the arctic in the Late Cretaceous. This genus is most common in the inner shelf and estuarine environments but is not confined to them. This specimen is juvenile (E.M. Brouwers, oral commun., 1988). Specific identification was not possible due to the poor preservation of the valves. Both of the pictured ostracodes (Pl. 4) came from the same sample, 90 ft below the top of the Lewis Shale (table 1) and are interpreted as normal-marine indicators.

General Taxonomic Comments

The preservation of most of the tests found is far from optimal. In many cases it was difficult to generically assign the large numbers of very small tests. Given no other characteristics, if the coil of the test was trochospiral, the test was assigned to the genus *Trochammina*. If the coil was planispiral, the test was assigned to the genus *Haplophragmoides*. Some tests appeared to be "blobs" of agglutinated arenaceous material with collapsed chambers, no visible apertures, and thus remain "unknowns" in the distribution chart (fig. 8). On the other hand, the *Lenticulina* and *Dorothia* tests, though few in number, were easy to identify. The planktonic tests were the most diagnostic and greatly aided the paleoenvironmental interpretation, as did the many *Trochammina*.

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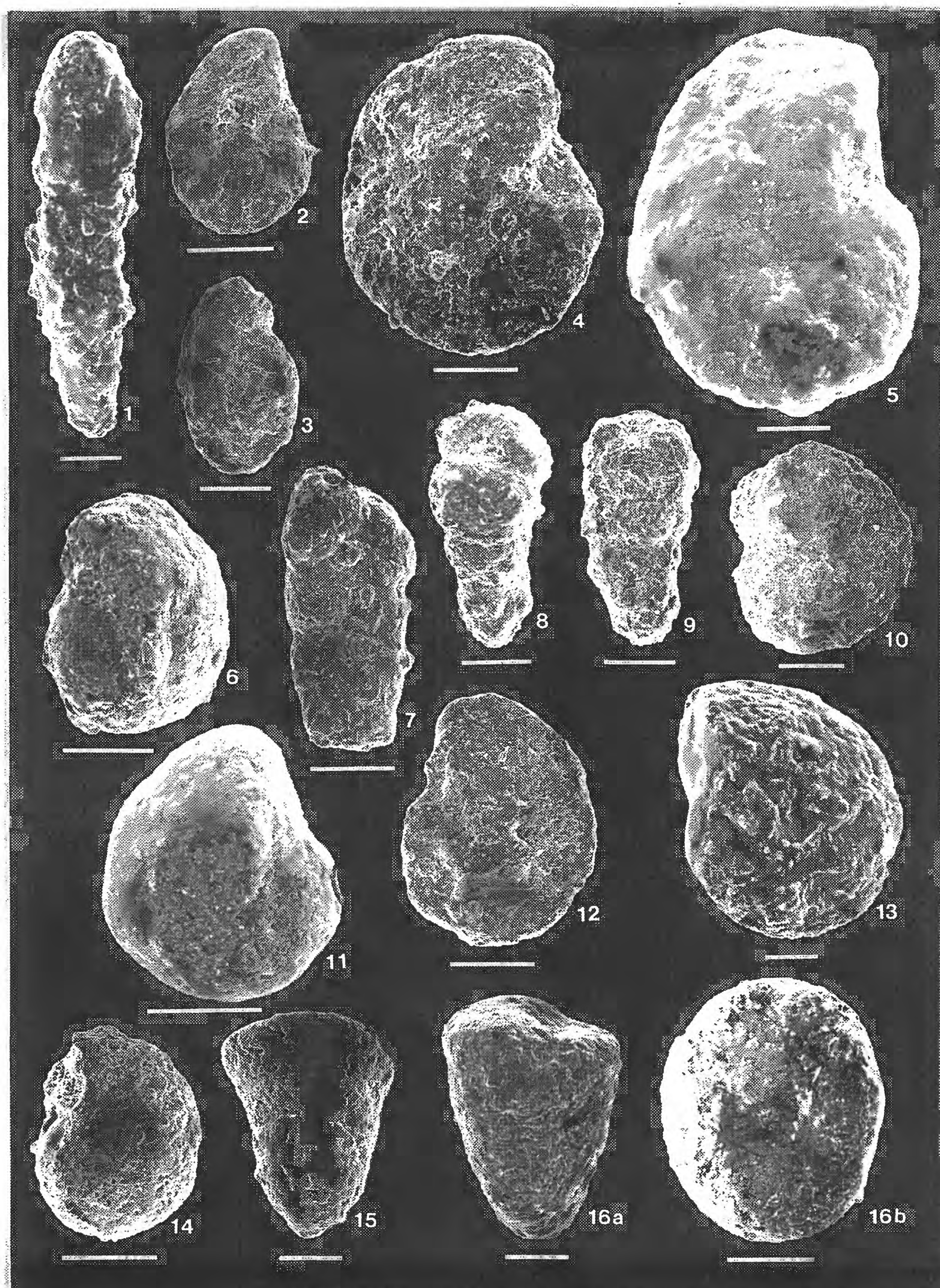

PLATE 2

Figure 1. *Ammobaculites* sp., scale 100um.

Figures 2a & b. *Lagena* sp.; 2a, 100um; 2b, 20um, enlargement showing crushed apertural area.

Figure 3. *Lenticulina* sp. 1., scale 200um, edge view.

Figure 4. *Lenticulina* sp. 2, scale 400um, side view.

Figures 5a & b. *Valvulineria* cf. *V. infrequens* Morrow, scale 100um; internal mold; 5a, side view; 5b, umbilical side.

Figure 6. *Tritaxia*(?) sp., scale 100um.

Figures 7a & b. *Nodosaria* sp., scale 7a, 100um; 7b, 20um, enlargement of apertural area.

Figure 8. *Nonionella*(?) sp., scale 100um.

Figure 9. *Archaeoglobigerina blowi* Pessagno, scale 100um.

Figure 10. *Hedbergella* sp., scale 100um. Heavily encrusted specimen.

Figure 11. *Hedbergella planispira* (Tappan), scale 100um, umbilical view.

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PLATE 2

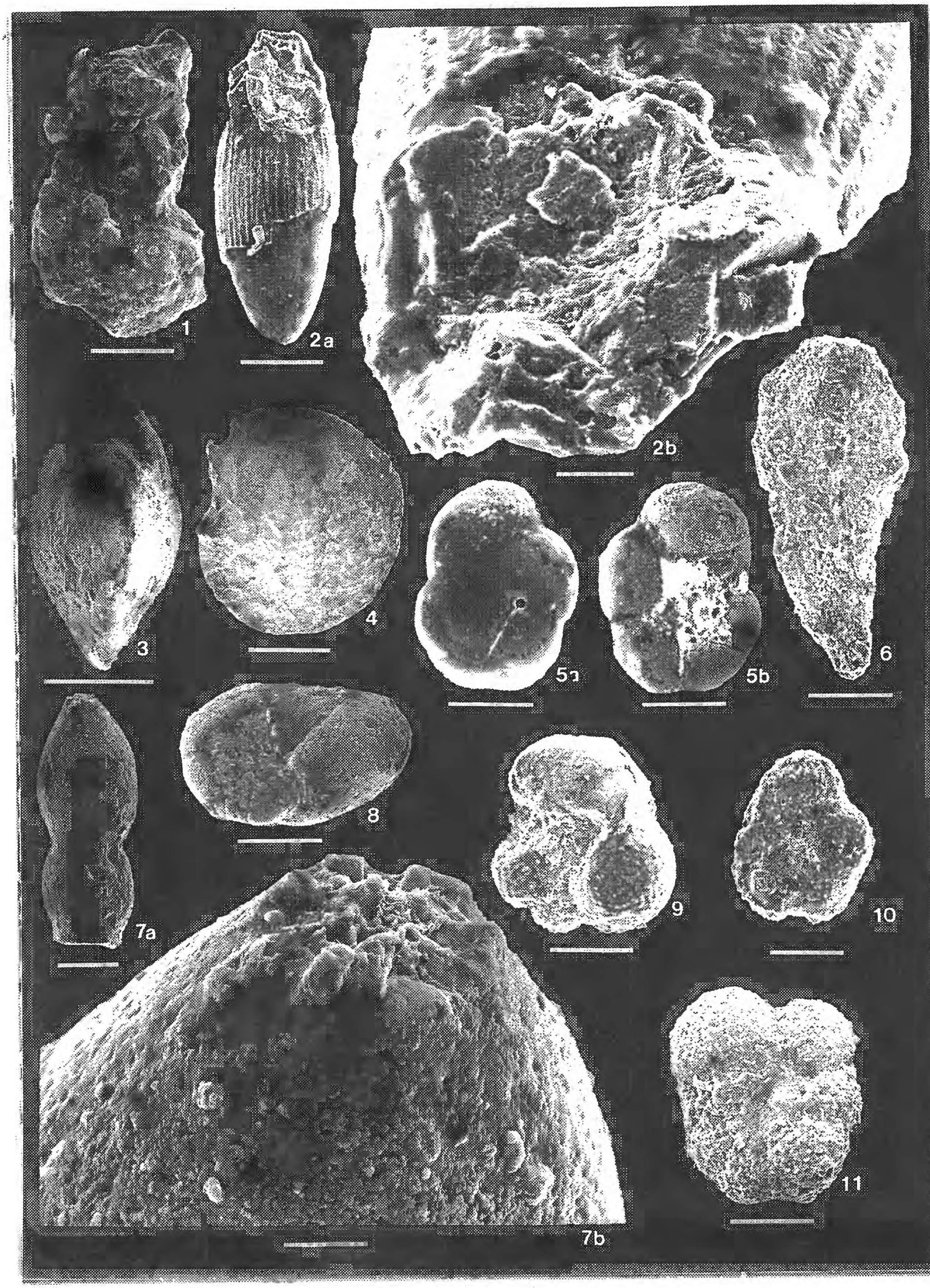

PLATE 3

Figures 1a & b. *Valvulineria lenticula* (Reuss), scale 100um; 1a, side view; 1b, spiral view.

Figure 2. *Lenticulina* sp.3, scale 100um.

Figure 3. *Trochammina*(?) sp., scale 200um.

Figure 4. *Trochammina rainwateri* Cushman and Applin, scale 200um.

Figure 5. *Trochammina* sp. 1., scale 200um.

Figure 6. *Trochammina* sp. 2, scale 200um.

Figure 7. *Trochammina*(?) sp., scale 100um.

Figure 8. *Trochammina* sp.3, scale 200um.

Figure 9. *Trochammina albertensis* Wickenden, scale 200um.

Figures 10-13. *Trochammina*(?) sp.; 10-12, 200um; 13, 100um.

Figures 14 & 15. *Trochammina* sp. 4, scale 200um.

Figures 16-19. Unknown, 16, 200um; 17-19, 100um.

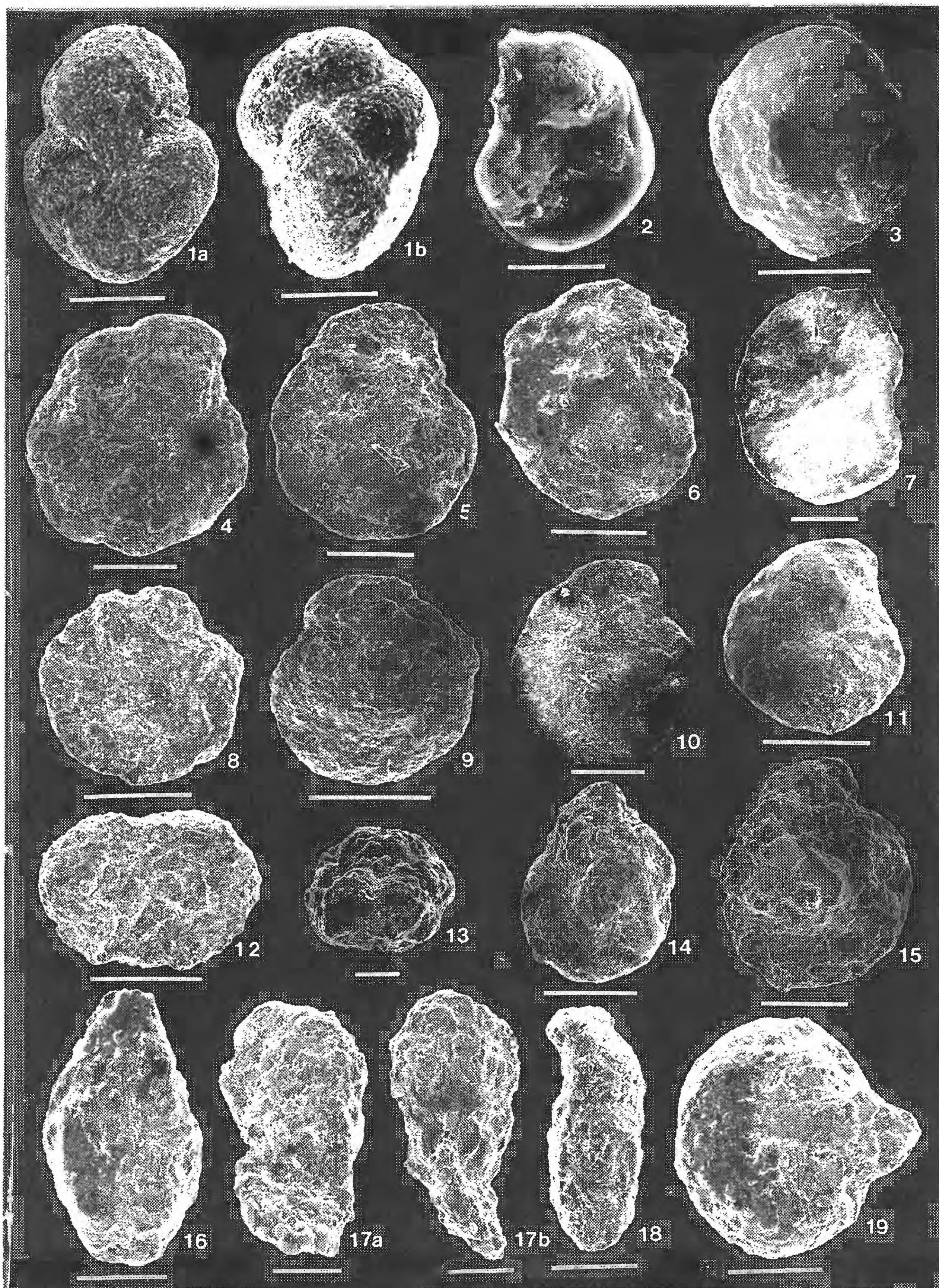
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PLATE 4

Figure 1. *Gavelinella sandidgei* (Brotzen), scale 200um.

Figure 2. *Haplophragmoides*(?) sp., scale 100um.

Figure 3. *Astacolus* sp., scale 100um.

Figures 4 & 5. Unknown, 4, 80um; 5, 200um.

Figures 6-8. *Haplophragmoides*(?) sp., 6, 200um; 7, 100um; 8, 100um, damaged and extremely encrusted specimen.

Figure 9. *Lenticulina*(?) sp., scale 100um.

Figure 10. *Dorothia*(?) sp., scale 100um.

Figure 11. *Haplophragmoides*(?) sp., scale 100um.

Figure 12. Unknown, scale 100um.

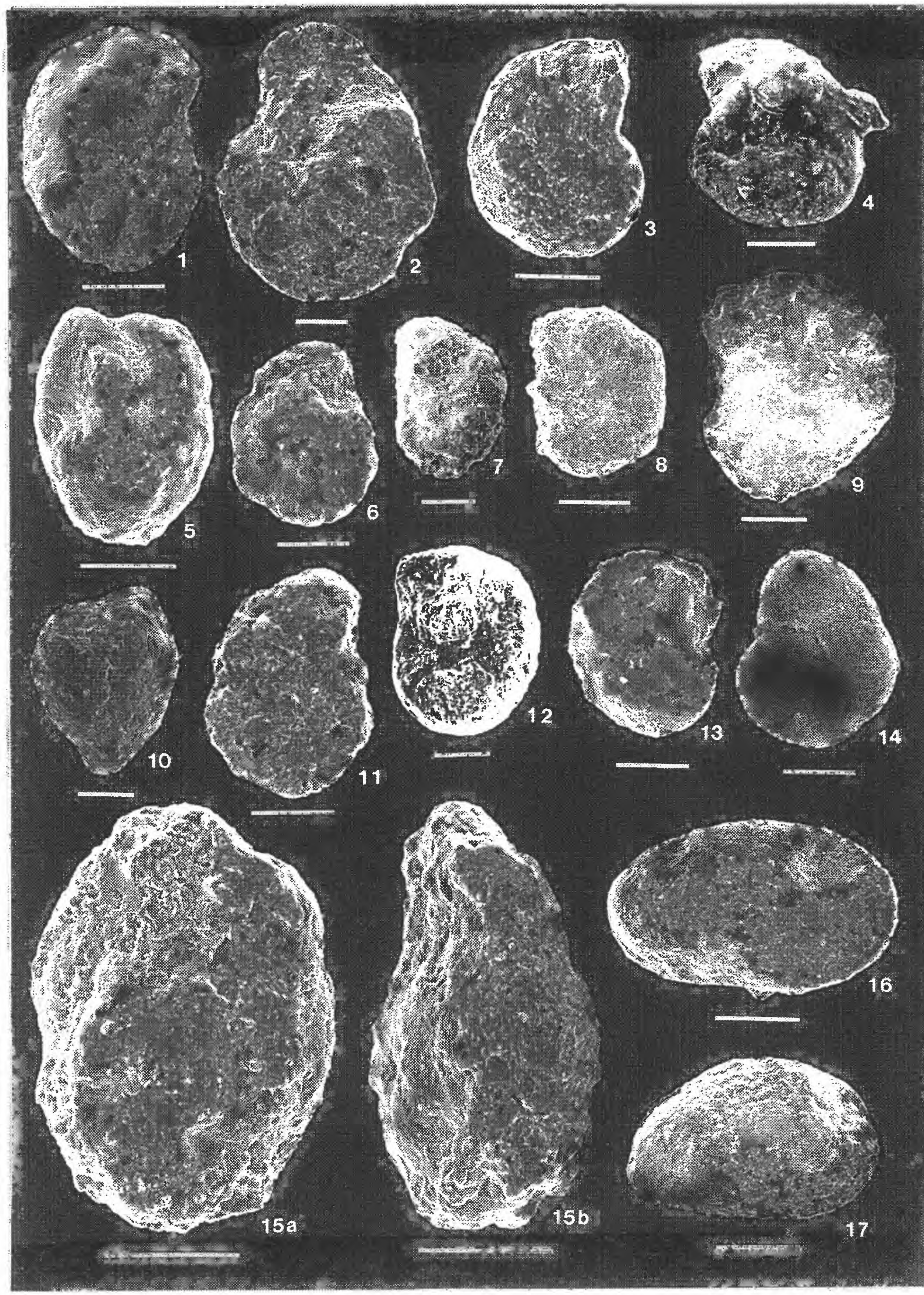
Figure 13. *Haplophragmoides*(?) sp., scale 100um.

Figure 14. *Valvulineria lenticula* (Reuss), scale 100um, spiral view.

Figure 15a & b. Unknown, scale 100um, 15a, frontal view; 15b, side view.

Figure 16. *Cytherella* sp., scale 200um. (ostracode)

Figure 17. *Haplocytheridea*(?) sp., scale 200um, juvenile specimen. (ostracode)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