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Foraminiferal Populations of the Goodland Formation, Tarrant County, Texas

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Introduction

Recent studies of foraminiferal populations of the Gulf of Mexico made by Phleger (1951 and 1954), Parker, *et al.* (1953), Lowman (1949), and Shepard and Moore (1955) show that different kinds of Foraminifera inhabit waters of different depth, salinity and temperature. These studies should provide evidence from which micropaleontologists may infer the nature of ancient environments, assuming always that fossil Foraminifera had the same habits as their nearest of kin in the modern assemblages. Albritton, *et al.* (1954) and Curtis (1955) have made quantitative studies of ancient populations, and have found that the Foraminifera tend to corroborate and supplement the chronicle of sedimentation as established on lithologic and other evidence.

Comparisons of ancient and recent populations are handicapped by the scarcity of quantitative studies. Micropaleontologists have given far more attention to defining species than to measuring the relative abundance of these as parts of populations. This is especially true of the fossil assemblages: there are fewer quantitative studies of the Foraminifera from the Cretaceous and Tertiary deposits bordering the Gulf of Mexico than there are quantitative studies of Recent populations in the present Gulf. Consequently, the usefulness of foraminiferal populations as records of ancient environments remains to be established, here as in other parts of the world.

Not all sections of ancient sedimentary rock will be suitable for studies of populations. According to Albritton, *et al.* (1954, p. 328) there are two prerequisites which should be fulfilled: (1.) The rocks should contain abundant Foraminifera, which are presumably of the same age as the matrix, and which bear at least a familial resemblance to living assemblages; and (2.) there should be local evidence for changing depths of water in the course of deposition, and these changes should be broadly decipherable on grounds other than the foraminiferal content itself. Since the time this was written, it has become apparent that the second prerequisite should be broadened, as follows: (2.) there should be local evidence for the changing of *sedimentary environmental conditions* in the course of deposition, etc. In any case, the present outlook in ecology suggests that temperature, salinity and turbidity may have been more fundamental controls of microfaunal populations than depth of water.

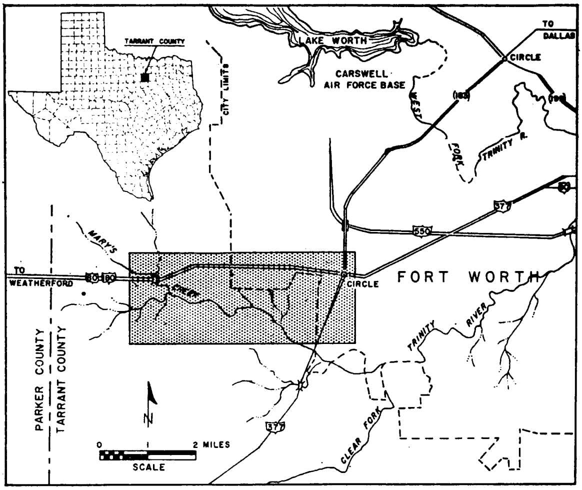


FIG. 1. Map of part of Tarrant County, showing location of area in which stratigraphic sections were measured.

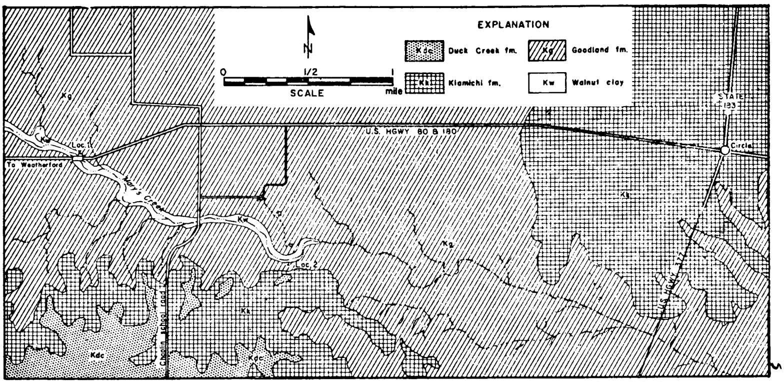
The Goodland (Lower Cretaceous) formation in western Tarrant County, Texas, satisfies both of these prerequisites. It contains abundant Foraminifera, the majority of which are extremely well preserved. Frequent changes in sedimentary environment are suggested by the numerous thin layers of alternating marl, marly limestone and limestone. Moreover, the formation contains abundant megafossils, some of which provide independent evidence of environment.

Two localities were selected for sampling and study. Locality 1 is along a low bluff on the east bank of the North Fork of Mary's Creek, at the concrete bridge on the Fort Worth - Weatherford highway, 11½ miles west of Fort Worth, Tarrant County, Texas. This is Station T-85-14 of Lozo (1944, p. 530). The lower 46 feet of the Goodland is exposed here.

Locality 2 is the long high bluff on the south bank of the North Fork of Mary's Creek, 2.6 miles west-south-west of the

Weatherford traffic circle, and is approximately 10 miles west of Fort Worth. Nearly all of the formation is here exposed, only the lower part being covered by sliderock.

A bed of limestone composed almost entirely of the oyster, *Gryphaea mucronata* Gabb, occurs toward the middle of the formation. As this bed appears at both localities, it was used to correlate the two sections.



after Bob F. Perkins

FIG. 2. Geologic map of area in which stratigraphic sections were measured. (*After Bob F. Perkins*).

Acknowledgments

I gratefully acknowledge the guidance which I have received throughout this study from Messrs. C. C. Albritton, Jr. and Bob F. Perkins of the Department of Geology, Southern Methodist University. Dr. Albritton has provided data gathered in a similar study of the Grayson marl, and has assisted in the identification of species. Dr. Perkins not only supervised the field work, but generously offered all of the information he has gathered on the stratigraphy and paleontology of the Fredricksburg group in northern Texas.

The Goodland Formation

Lithology

In western Tarrant County, the Goodland attains its maximum thickness of about 120 feet (See Sellards, *et al.*, 1932, p. 335.). To the north it thins along the outcrop to about 15 feet in southern Oklahoma. Southward, it grades laterally into the Edwards and Comanche Peak limestones, which are of different lithology and faunal facies (Stephenson, *et al.*, 1942, p. 443).

The formation is commonly called the Goodland limestone, but in western Tarrant County it is divisible into a lower marl member and an upper limestone member.

The lower marl member is 52 feet thick. At the localities examined, it consists of 32 beds of alternating marl, marly limestone, and limestone. The beds range in thickness between three inches and eight feet. Marl makes up 49 per cent of this member, marly limestone 34 per cent, and limestone 17 per cent.

The upper limestone member is 69 feet thick. At locality 2, it contains eleven beds six inches to 14 feet thick, made of alternating limestone, marly limestone and marl. Limestone makes up 51 per cent of the total thickness, marly limestone 37 per cent, and marl 12 per cent.[1]

COMPOSITE STRATIGRAPHIC SECTION OF THE GOODLAND FORMATION, MEASURED AT LOCALITIES 1 AND 2, IN WESTERN TARRANT COUNTY, TEXAS

Comanche Series: Fredricksburg group.

	Thickness, in feet
Kiamichi formation	
Marl, gray and brown; with few thin arenaceous limestone beds; top not exposed.	30.0+
Goodland formation	
Upper limestone member	
43. Limestone, white, hard, nodular with yellow marl seams; relatively unfossiliferous. (4% insoluble residue of clay, fine sand and pyrite.)	13.0
42. Marl, tan to yellow; weathers light tan. (11% insoluble residue of clay, fine sand, and pyrite.)	4.0
41. Marly limestone, tan; upper portion very fossiliferous, lower part nodular. (10% insoluble residue of clay, fine sand, pyrite and glauconite.)	1.25
40. Marly limestone, light gray; weathers light brown. (12% insoluble residue of clay, fine sand, pyrite and glauconite.)	5.75
39. Limestone, white, dense, nodular, highly fossiliferous; weathers gray with iron stains; calcite crystals common along bedding surfaces. (4% insoluble residue of clay, very fine sand, pyrite, and glauconite.)	0.50
38. Marly limestone, white; weathers gray to tan. (12% insoluble residue of clay, very fine sand, pyrite and glauconite.)	6.0
37. Marly limestone, gray, nodular; weathers yellow with iron stains. (13% insoluble residue of fine sand.)	6.5
36. Marl, gray, carbonaceous, fissile; weathers yellow. (43% insoluble residue of clay and very fine sand.)	4.5
35. Limestone, white, hard, nodular; weathers gray to buff;	

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[1] The lithologic nomenclature follows that used by Barth, Correns, and Escola (see Pettijohn, 1949, p. 291).

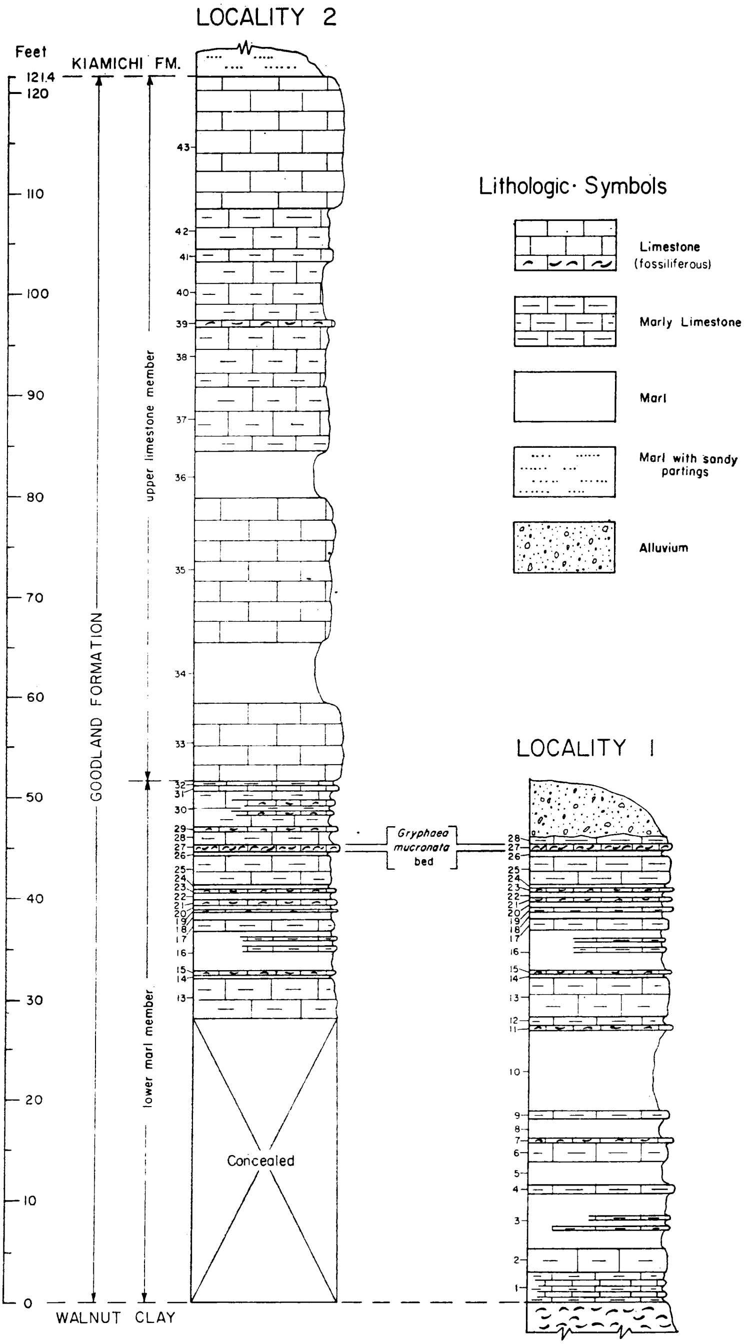

FIG. 3. Correlation of columnar sections at Localities 1 and 2.

numerous marl partings. (5% insoluble residue of clay, fine sand and pyrite.)	14.25
34. Marly limestone, blue-gray, relatively unfossiliferous. (24% insoluble residue of clay and very fine sand.)	6.0
33. Limestone, white, hard, nodular; calcite crystals common along bedding surfaces. (5% insoluble residue of clay and very fine sand.)	7.67
Lower marl member	
32. Marly limestone, tan. (14% insoluble residue of clay, fine sand and pyrite.)	0.42
31. Marly limestone, gray with iron stains on fresh exposure, fine textured. (7% insoluble residue of clay.)	0.25
30. Marly limestone, light brown; weathers gray; contains two fine-textured limestone layers approximately 3 inches thick; has abundant shell fargments. (8% insoluble residue of clay.)	3.67
29. Limestone, white, dense, hard, nodular, highly fossiliferous; weathers light gray. (5% insoluble residue of clay and fine angular sand.)	0.5
28. Marly limestone, gray, carbonaceous, fine to moderately laminated. (16% insoluble residue of clay and very fine sand.)	1.5
27. Limestone, gray, hard, dense, iron stained; made mostly of *Gryphaea mucronata;* irregularly ripple marked. (5% insoluble residue of clay and fine sand.)	0.42
26. Marl, gray, highly carbonaceous; swells and pinches; contains abundant fragments of pelecypod shells. (38% insoluble residue of clay, very fine sand and pyrite.)	0.25
25. Marly limestone, gray; interbedded with light gray marl. (12% insoluble residue of clay and very fine sand.)	3.0
24. Marly limestone, gray, highly fossiliferous. (16% insoluble residue of clay and very fine sand.)	0.5
23. Limestone, light gray, hard; contains abundant fragments of shells; weathers white; ripple marked—wave length 5 feet, height 1 inch. (5% insoluble residue of clay, very fine sand and pyrite.)	0.25
22. Marl, dark gray, carbonaceous. (33% insoluble residue of clay, very fine sand and pyrite.)	0.83
21. Limestone, light gray, hard, highly fossiliferous; weathers white; ripple marked—wave length 40 inches, height 6 inches. (5% insoluble residue of clay and pyrite.)	0.5
20. Marl, dark gray, fissile, carbonaceous. (36% insoluble residue of clay, very fine sand and pyrite.)	0.42
19. Limestone, gray, hard, very fossiliferous; ripple marked—wave length 6 feet, height 1 inch. (5% insoluble residue of clay, very fine sand and pyrite.)	0.25
18. Marl, dark gray. (27% insoluble residue of clay and fine sand.)	0.67
17. Marly limestone, light gray, nodular. (11% insoluble residue of clay, fine sand and pyrite.)	1.25
16. Marl, gray, carbonaceous, slightly fissile. Contains 3 marly	

limestone layers, light gray, weathering white at 9, 13, and 30 inches from top of unit. (Insoluble residue of marl is 58%, and of marly limestone layers is about 11% and is composed of clay and very fine sand.)	4.0
15. Marly limestone, light gray, highly fossiliferous. (7% insoluble residue of clay and fine sand.)	0.33
14. Marl, gray, carbonaceous, slightly fissile; has abundant shell fragments. (51% insoluble residue of clay and fine sand.)	0.25
13. Limestone, light gray, dense, nodular; weathers white. (5% insoluble residue of clay and fine sand.)	4.0
12. Marly limestone, gray. (20% insoluble residue of clay.)	1.0
11. Limestone, gray, dense, highly fossiliferous. (4% insoluble residue of clay.)	0.42
10. Marl, blue-black, highly carbonaceous, fissile. (54% insoluble residue of clay.)	8.0
9. Marly limestone, gray, hard; numerous marl partings. (14% insoluble residue of clay.)	0.75
8. Marl, gray, fissile; has infrequent ironstone nodules. (45% insoluble residue of clay and very fine sand.)	2.0
7. Limestone, gray, hard, highly fossiliferous; ripple marked—wave length 32 inches, height 2 inches. (4% insoluble residue of clay.)	0.25
6. Marly limestone, tan, nodular, iron stained with frequent marl partings. (13% insoluble residue of clay and pyrite.)	1.83
5. Marl, gray, fissile. (40% insoluble residue of clay.)	2.33
4. Marly limestone, gray. (20% insoluble residue of clay and pyrite.)	0.67
3. Marl, gray, with 1-2 inch limy bands. (26% insoluble residue of clay.)	5.5
2. Marly limestone, white, nodular, with sparse ironstone concretions; has abundant *Gryphaea* and *Exogyra* shells. (9% insoluble residue of clay.)	2.5
1. Limestone, gray, interstratified with blue marl; has abundant *Gryphaea* and *Exogyra* shells. (5% insoluble residue of clay.)	3.0
Total thickness of Goodland formation	121.4
Walnut Clay	
Limestone shell bed, gray, hard; contains abundant *Gryphaea mucronata* and *Exogyra texana*; base not exposed.	1.+

The Goodland rests conformably upon the Walnut formation, which is essentially a fossil oyster reef. The contact between the two units is gradational, and is arbitrarily drawn along the surface that separates the shell beds below from shelly marls above.

The Goodland grades upward into the Kiamichi formation. Very fine quartz sand, which appears with the clay in residues from the lower Goodland, becomes more abundant upward in the section and increases to fine grain size toward the top. Along the contact, sandy limestone of the Goodland is overlain by the basal arenaceous marls and limestones of the Kiamichi.

Conditions of Sedimentation as Indicated by Ripple Marks and Megafossils

The megafossils and primary structures suggest that the sediments of the Goodland formation were deposited upon a stable shelf, in water which was probably between five and 20 fathoms deep.

The upper surface of the *Gryphaea* conglomerate in the middle of the section (unit 27) is marked by large, round-crested pararipples, which are about four inches high at the crests and four to five feet between crests. Similar ripples, one to six inches high and as much as five feet from crest to crest, are present in units 7, 19, 21 and 23. Gayle Scott (1930, p. 56) discovered that these large ripples are common in the Fredericksburg group of northern Texas, and concluded that they could scarcely have been formed at depths greater than 10 to 15 fathoms. According to Scott, the ripples tend to be symmetrical in the Goodland, and asymmetrical in the Walnut Clay.

> It is possible to imagine that in Texas during Goodland time there was a broad, but relatively shallow sea where friction of the bottom might have caused an abnormal development of waves, particularly during storms. These activities might have shifted the particles of the shell bottom back and forth so as to "windrow" the shells in the fashion as described in these ripple marks.
>
> If the ripples were nearer the broad flat shore, as perhaps was true in the case of the Walnut, the back-wash might have produced a current significantly strong, even at a considerable distance from the actual shore line, to build up the asymmetrical type ripple mark found in the Walnut. (Scott, 1930, p. 56).

In any case, the presence of giant ripples developed on beds of shelly limestone argues for shallowness of water and frequent agitation of the bottom by strong currents.

Oyster beds, like those which make up most of the Walnut and some of the Goodland presumably originated under conditions similar to those found around oyster reefs in the present Gulf of Mexico. Along the Gulf coast of Texas, oyster reefs or abundant oyster shells characterize parts of the central bay areas (Shepard and Moore, 1955, p. 1463). The water in these bays is not over 13 feet deep and is characteristically below normal ocean salinity. Curtis (1955, p. 271) synthesized the available data and concluded that fossil oyster beds indicate: (1) fairly shallow water (perhaps 30 or less feet deep), (2) relatively clear, warm water, (3) water that tends to be below normal ocean salinity—like the water of many bays or estuaries, and (4) sedimentation slow enough not to interfere with growth of oysters.

Oyster beds, made largely of *Exogyra, Gryphaea,* and *Ostrea* occur in the lower Goodland, forming layers of limestone interstratified with marl. Units 1, 2, and 27 of the stratigraphic section might be cited as examples of shell beds which may have formed under conditions similar to those described by Curtis. On the other hand, the oyster beds of the Goodland are insignificant as compared with the larger accumulations of shells in the underlying Walnut. The problem is thus one of explaining the marked *decrease* in oyster bank building with the beginning of Goodland time.

Increased turbidity of water accompanying the deposition of clay may account for this decrease in oyster growth. Vast numbers of mud-burrowing clams (*Pholadomya, Cucullaea, Cyprimeria, Protocardia* and *Pinna*) are present in the clay-rich strata of the lower member. In the middle and upper part of this member these mud-burrowers are associated with brackish water clams (*Isocardia* and *Trigonia*), shallow water gastropods (*Aporrhais* and *Turritella*), shallow water echinoids (*Salenia* and *Enallaster*), and clear-water clams (*Modiola* and *Lima*).

The water in which the upper member of the Goodland was deposited need not have been any deeper than that in which the lower member was deposited, but the character of the megafauna suggests that the waters of late Goodland time were clear rather than turbid. Clearing of water in late Goodland time is suggested by the appearance of the solitary coral, *Parasmilia,* in the upper part of the section. Also there are fewer mud-burrowing clams and more clear water clams in the upper than in the lower Goodland. The presence of the ammonites, *Oxytropidoceras* and *Engonoceras,* suggests deposition in shallow epineritic waters, according to Scott (1940, p. 321). Thus if the absence of oyster reefs in the upper Goodland is not to be explained on the grounds of deepening waters, perhaps increases in the prevailing salinity or in the local rate of sedimentation were inhibiting factors.

FORAMINIFERA

Method of Study

Fifty-two samples of rock were taken from as many different horizons in the Goodland formation at localities 1 and 2. Thirty-two cubic centimeters of each sample was reduced to sludge by the Campbell method (Hussey and Campbell, 1951) and then washed through U. S. Standard sieve 200 (nominal opening 0.074 mm.). The material retained on the sieve was then dried and passed through the microsplit four times in order to obtain a residue which was representative of two cubic centimeters of the rock. This residue was spread thinly over micropaleontological slides of the kind ruled into numbered squares. The first 500 mature tests were identified as to genus and species; the remaining tests were simply counted. Most of the species have been described by Cushman (1936), Frizzel (1954), Lozo (1944), Loeblich and Tappan (1946 and 1949), and Tappan (1940 and 1943).

From these data the percentage composition by species and the number of tests per cubic centimeter of the original sample were calculated. Genera were assigned to families according to Cushman's classification. Figure 4 shows the relative abundance of families for the entire 121 feet of the Goodland formation. Dashed lines bridge the gaps left by lack of data from the hard limestone layers. The levels at which the samples were taken are shown by dots on the insoluble residue curve.

The reliability of the data for the families varies directly with the length of the bars at the right side of Figure 4, which show the number of tests per cubic centimeter of rock. The bar graph does not show the number of tests in the hard limestone beds. Even with the aid of the Campbell sample washer, these harder rocks could not be broken down without breaking many of the microfossils. However, it was apparent from the study of these limestone samples under the microscope that some limestones contained many tests, whereas other samples contained few or none.

Beautifully preserved ostracodes, together with spines and plates of echinoids, were common in most of the marl and marly limestone beds of this formation. No attempt was made by the author to identify or interpret the ostracode assemblage.[2]

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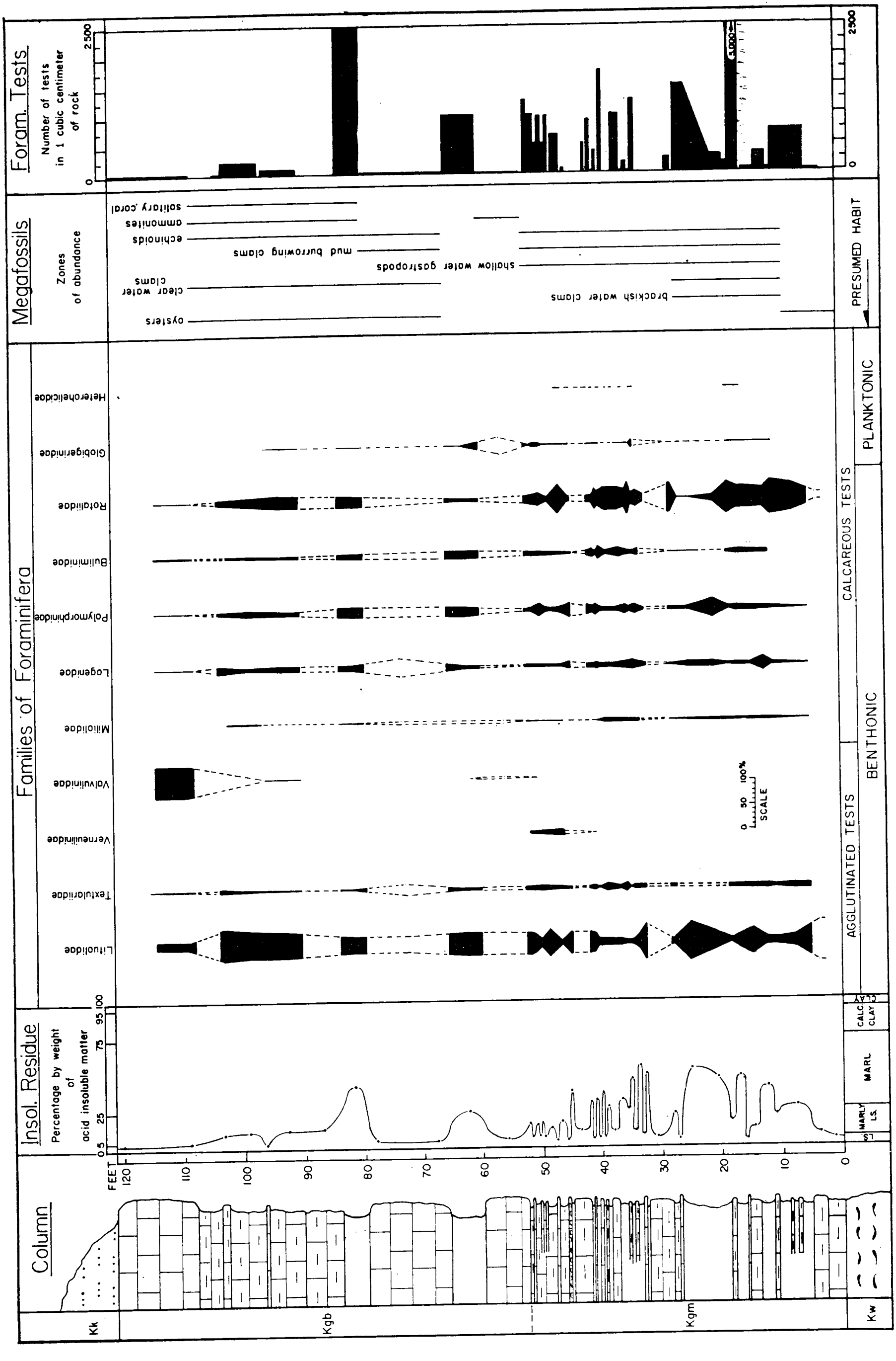
[2] Crude and washed samples used in this study, together with slides of species and data sheets showing generic analyses of each sample, are on file at the Laboratory of Micropaleontology, Southern Methodist University, and are available for examination.

FIGURE 4. Relative abundance of foraminiferal tests in different parts of the Goodland Formation.

In center: by families, according to total population.

In column at right, according to number of tests/cm^3.

In column at left: Kk = Kiamichi formation, Kg = Goodland formation, and Kw = Walnut clay.


Foram. Tests
Number of tests in 1 cubic centimeter of rock
0
2500
5,000+
Megafossils
Zones of abundance
solitary coral
ammonites
echinoids
mud burrowing clams
shallow water gastropods
clear water clams
brackish water clams
oysters
PRESUMED HABIT
Families of Foraminifera
Heterohelicidae
Globigerinidae
Rotaliidae
Buliminidae
Polymorphinidae
Lagenidae
Miliolidae
Valvulinidae
Verneuilinidae
Textulariidae
Lituolidae
0 50 100%
SCALE
PLANKTONIC
BENTHONIC
CALCAREOUS TESTS
AGGLUTINATED TESTS
Insol. Residue
Percentage by weight of acid insoluble matter
0.5
25
75
95
100
CLAY
CALC CLAY
MARL
MARLY LS.
LS
FEET
120
110
100
90
80
70
60
50
40
30
20
10
0
Column
Kk
Kgb
Kgm
Kw

Variation in Size of Populations

The number of foraminiferal tests ranges from 1/cm^3 to 5,000/cm^3. As a rule, the marls are more richly fossiliferous than the marly limestones and pure limestones.

The tests in the marls range from about 25/cm^3 to 5,000/cm^3 with an average of about 1150/cm^3. Blue-gray marls in the lower member contain the richest and also the most diversified microfauna in the formation. In the marly limestone beds the count ranges from 5/cm^3 to 1250/cm^3, with an average of about 375/cm^3. It was impossible to obtain reliable counts for the limestone beds.

General Character of the Foraminiferal Assemblage

Seventy-eight species belonging to 50 genera and thirteen families were found in the Goodland formation (See Table 2). Sixty-four of the species have been previously named and described by various authors. Of the remaining 14 species, several are undoubtedly new, but will probably be described in Dr. A. R. Loeblich's forthcoming monograph on the Foraminifera of the Lower Cretaceous of Texas.

The principal benthonic families, according to numbers of individual tests, are the Lituolidae, Textulariidae, Verneuilinidae and Valvulinidae among the agglutinated forms, and the Miliolidae, Lagenidae, Polymorphinidae, Buliminidae and Rotalidae among the calcareous (See Figure 4.)

Among the presumably planktonic Foraminifera, there are representatives among the Globigerinidae and Heterohelicidae, but planktonic forms are comparatively rare.

The following chart shows the number of genera and species that represent each family:

Family	*Number of genera*	*Number of species*
Lituolidae	8	14
Saccamminidae	1	1
Textulariidae	3	7
Verneuilinidae	1	1
Valvulinidae	1	1
Miliolidae	3	3
Lagenidae	12	26
Polymorphinidae	8	8
Buliminidae	1	2
Rotaliidae	7	8
Anomalinidae	3	3
Globigerinidae	1	3
Heterohelicidae	1	1

Foraminifera of the Lower Marl Member

In general, calcareous tests are more abundant than agglutinated tests in the lower member of the Goodland. Considering all the tests that were identified from this member, 36 per cent of the total number are agglutinated and 64 per cent are calcareous. Table 1 shows that the relative number of calcareous tests decreases upward in the section.

Discorbis minima Vieaux and *D. floscula* Loeblich & Tappan of the family Rotaliidae are the most abundant calcareous benthonic species within the lower member. Both of these species become less abundant toward the upper part of this member. Other common calcareous benthonic species are *Globulina exserta* (Berthelin), *Pseudoglandulina scotti* Tappan, *Virgulina primitiva* Cushman and *V. subcretacea* Cushman. *Patellina subcretacea* Cushman & Alexander is restricted to the upper part of the marl member.

Lituolidae, most abundantly represented by *Ammobaculites laevigatus* Lozo and *A. subcretaceus* Cushman & Alexander, make up the largest per cent of the agglutinated tests. *Ammobaculites torosus* Loeblich & Tappan is apparently restricted to the lower part of the marl, whereas *Verneuilinoides schizeus* (Cushman & Alexander) was found only in the upper part. Throughout the lower marl member there seems to be an inverse relationship between the families Rotaliidae and Lituolidae; an increase in numbers of *Ammobaculites* is usually accompanied by a decrease in abundance of *Discorbis* (See Figure 4.)

Planktonic tests account for only 0.7 per cent of the total foraminiferal population. *Globigerina washitensis* Carsey is the most common species.

Foraminifera of the Upper Limestone Member

Agglutinated tests are more abundant in the upper member than in the lower. Fifty-one per cent of all the tests counted from this member were agglutinated, and 49 per cent were calcareous (Table 1.)

The same calcareous benthonic species which are predominant in the lower member are also the commonest in the upper member.

Lituolidae are the predominant family and are represented principally by *Ammobaculites goodlandensis* Cushman & Alexander, *A. subcretaceus* Cushman & Alexander, *Flabellamina alexanderi* Cushman, *Haplophragmoides globosus* Lozo, and *Trip-*

lasia goodlandensis (Cushman & Alexander.) The last two species were found only in the upper member. *Textularia rioensis* Carsey is more common in this member than in the lower member. *Coskinolinoides texanus* Keijzer appears in astonishing numbers in the uppermost limestone beds.

TABLE 1. SHOWING THE INCREASE IN PERCENTAGE OF AGGLUTINATED TESTS TOWARD THE TOP OF THE GOODLAND FORMATION.

	Bed no.	% insoluble residue	% agglutinated tests	% calcareous tests	No. of tests/cm^3
	43	4	91	9	31
	42	6	*	*	*
	41	10	72	28	16
	40	12	64	36	250
	39	4	*	*	*
	38	12	57	43	127
	37	13	*	*	*
Upper member	36	43	34	66	2500
	35	5	54	46	25
	34	24	49	51	1000
	33	5	50	50	27
	32	14	*	*	*
	31	7	57	43	1250
Lower member	30	8	47	53	750
	29	5	*	*	*
	28	16	23	77	650
	27	5	*	*	*
	26	38	43	57	52
	25	12	*	*	*
	24	16	49	51	500
	23	5	*	*	*
	22	33	47	53	990
	21	5	14	86	72
	20	36	19	81	375
	19	5	*	*	*
	18	27	31	69	1750
	17	11	15	85	31
	16	58	20	80	1350
	15	7	*	*	*
	14	51	76	24	18
	13	5	*	*	*
	12	20	22	78	222
	11	4	*	*	*
	10	54	56	44	1500
	9	14	13	87	159
	8	45	30	70	5000
	7	4	*	*	*
	6	13	51	49	51
	5	40	20	80	350
	4	20	12	88	46
	3	26	36	64	750
	2	9	83	16	3
	1	5	*	*	*

*Indicates hard rocks from which tests were unobtainable.

Planktonic tests are even rarer than they are in the lower member. *Globigerina* and *Gumbelina* were not found in the upper 25 feet of the Goodland. Altogether floating forms account for 0.06 per cent of the total population of the upper member (See Figure 4 and Table 2.).

Inferences on Conditions of Sedimentation as Drawn from Foraminifera

The outstanding characteristics of the foraminiferal populations of the Goodland formation are:

1. The rarity of planktonic tests throughout the formation.
2. The predominance of Rotaliidae among the calcareous tests
3. The decrease in relative numbers of calcareous tests upward in the section.
4. The general abundance of agglutinated tests throughout the formation, with an increase in number of individuals and species toward the top.
5. The appearance of *Coskinolinoides* in great numbers at the very top of the formation.

Absence of planktonic tests.—Planktonic species now live mostly in the normally saline upper waters of the open oceans, although their empty tests are transported by ocean currents to other environments. Barrier islands ordinarily prevent currents from bringing empty tests into the waters between them and the shore. This is the situation along parts of the Mississippi Sound area (Phleger, 1954) and around San Antonio Bay (Phleger, 1953).

The subnormal salinities that prevail in upper levels of near shore water due to the influx of fresh water from rivers are also unfavorable to the planktonic Foraminifera. Phleger (1954, p. 604) suggests that the low frequencies of planktonic Foraminifera along the inner shelf in the Mississippi Sound is due to the fact that the upper waters are subsaline and cannot support planktonic assemblages.

Thus the virtual absence of planktonic tests in the Goodland suggests: (1) a near shore environment along some bay, sound, or inner shelf and (2) below normal ocean salinity of the upper waters.

Abundance of Rotaliidae—Norton (1930, p. 331) studied the ecological relations of Foraminifera from the Florida and West Indian regions and divided them into intergrading bathymetric zones. Rotaliidae, represented primarily by *Discorbis* and *Spirillina,* are most common in his Zone B, which extends from

5 to 60 fathoms and has a temperature variation between 68° and 80° F.

Phleger (1953 and 1954) and Lowman (1949) both found that the shallow, near shore, open-gulf assemblage outside the barrier islands is composed mostly of calcareous Foraminifera, of which Rotaliidae is one of the principal families.

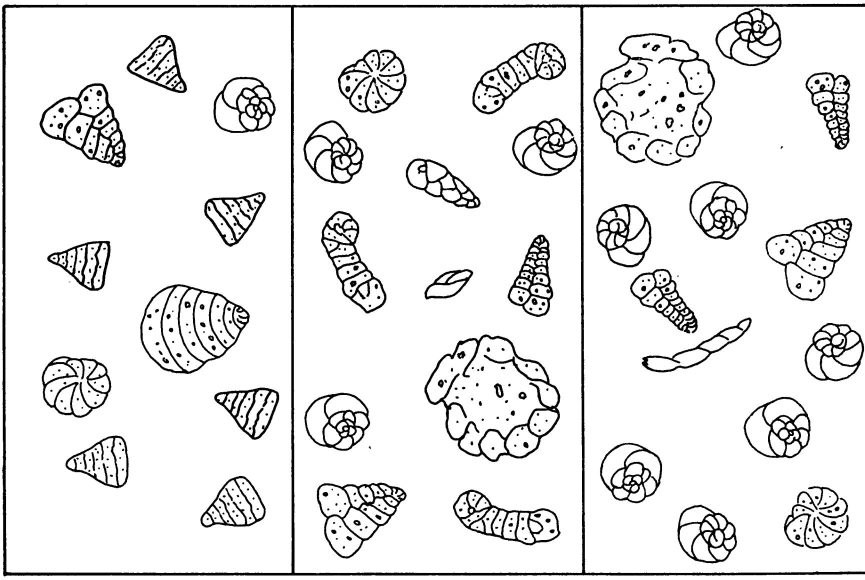


FIG. 5. Typical benthonic foraminifera in the Goodland Formation. *Left*: Assemblage characterized by abundance of agglutinated tests (stippled) of *Coskinolinoides* and Lituolidae (*Flabellamina* and *Ammobaculites*). Typical of upper limestone in Goodland. *Middle*: Assemblage characterized by abundance of Lituolidae (esp. *Ammobaculites*), Rotaliidae (*Discorbis*). Typical of middle marl and marly limestone units. *Right*: Assemblage characterized by abundance of Rotalidae (*Discorbis*). Typical of lower marl units.

The abundance of the family Rotaliidae, especially in early Goodland time, suggests a near shore environment in open-gulf waters.

The shift in relative proportions of calcareous and agglutinated tests.—In the Mississippi Sound area Phleger observed that the open-gulf population is composed of 90 per cent or more calcareous species, whereas the sound fauna is almost entirely arenaceous, except where offshore elements have been introduced. Wherever there is no barrier island to separate the sound from the gulf, there is a mixture of the two kinds of tests.

Table 1 shows that calcareous tests are more abundant than agglutinated tests in the lower Goodland, but that agglutinated tests become more abundant in the upper Goodland. This could be interpreted in at least two different ways. Shoalling of the waters throughout Goodland time may have permitted subsaline waters gradually to extend from the surface to the bottom. Essentially the same effect could have been established without shoalling, by the establishment of a barrier or bar, behind which the upper Goodland sediments were deposited.

General abundance of agglutinated tests.—The Lituolidae are the principal family of agglutinated tests and are predominately represented by the genus *Ammobaculites.* Lowman (1949, p. 1956) found that in the area of the Mississippi Delta, *Ammobaculites* occurs in the greatest numbers near shore in brackish waters. Phleger (1953 and 1954) found that this same genus is characteristic of near shore bay, marsh and sound facies. Both Lowman and Phleger agree that *Haplophragmoides*, which is only found in the upper member, is characteristic of the marsh facies. Lituolidae are commonest in Norton's bathymetric Zones A and B, which represent depths between the beach and 60 fathoms.

The agglutinated tests in the Goodland suggest conditions of sedimentation which are characteristic of shallow, near shore, and perhaps brackish water of the kind found in bay, sound, marsh and inner shelf environments.

Appearance of Coskinolinoides at the top of the Goodland.—In the Florida and West Indian regions, Norton found that the Valvulinidae are characteristic of Zone A, which lies between the beach and 5 fathoms and has a temperature range of between 70° and 90° F. The occurrence of *Coskinolinoides* in such great numbers in the upper limestone bed of the Goodland might suggest a warm, near shore, clear water environment, much like that along the western coast of Florida.

Summary of Conditions of Sedimentation as Indicated by Ripple Marks, Megafossils and Foraminifera.

Depth of water.—Larger-fossil data and ripple marks suggest that the sediments of the Goodland formation were deposited in shallow epineritic waters, which were probably between five and 20 fathoms deep. The fossil oyster banks in the lower part of the formation might indicate depths of a few feet in view of the ecology of modern oyster accumulations. The foraminiferal assemblage also indicates a shallow water environment ranging in depth from a few feet to perhaps 60 fathoms. A slight shoalling of the water in late Goodland time is suggested by the increase in abundance of agglutinated tests toward the top of the formation.

Clarity of water.—Foraminifera which are characteristic of bay, sound, and open-gulf assemblages, are present in the lower part of the Goodland and might indicate more turbid, muddy conditions than the assemblage in the upper part of the formation, which is characteristic of a clear water environment much like that along the western coast of Florida. The abundance of mud-burrowing clams along with the great amount of clay in the lower marl member contrasted with the occurrence of a solitary coral, ammonites and clear water clams along with thick beds of hard, white limestone in the upper limestone member suggest more strongly that the water in late Goodland time was clearer than in early Goodland time.

Salinity.—The fauna of the Goodland suggest that below-normal ocean salinity prevailed throughout most of Goodland time. The general abundance of Lituolidae and the virtual absence of planktonic tests throughout the formation along with the presence of oyster shells, especially in the lower member of the Goodland, tends to corroborate below-normal ocean salinity. However, the decrease in abundance of oysters coupled with the abundance of *Coskinolinoides* in the upper part of the formation may indicate an increase in the prevailing salinity, at least in the upper layers of water, in late Goodland time.

Temperature.—A warm, sub-tropical climate seems to have been present throughout the deposition of the Goodland. The presence of oysters suggests a minimum water temperature of about 63° F. (Curtis, 1955, p. 271). The microfauna in the Goodland seem to be characteristic of Norton's Zones A and B (1930, p. 331), in which the temperature may vary between about 70° and 90° F. Scott (1941, p. 1201) suggested that the popularipples could have been formed by abnormal waves during tropical storms and thus inferred a warm climate during Goodland time.

Conclusions

Based upon studies of the ecology of Recent populations, the interpretation of this quantitative foraminiferal population study of the Goodland formation essentially concurs with the chronicle of sedimentation as inferred independently by lithology, ripple marks and megafossils. Both lines of evidence agree as to the following elements in the paleoecology of the Goodland formation:

1. The sediments of the Goodland were deposited in shallow water which probably ranged in depth from a few feet to about 20-60 fathoms.
2. The waters of the upper limestone member were clearer and perhaps less turbid than those of the lower marl member.
3. Below normal ocean salinity prevailed during the deposition of most of the formation, however, there are suggestions that there was an increase in salinity, at least in the upper layers of water, in late Goodland time.
4. The water was warm and probably ranged in temperature from about 70° to 90° F.
5. The sediments of the Goodland represent near shore deposits of the type found in bay, sound and inner shelf environments.

The Foraminifera of the Goodland formation are quantitatively and qualitatively different from those found in the Grayson marl (Late Comanchean, Lower Cretaceous) by Albritton, *et al.* (1954). The Grayson is characterized by a flood of planktonic tests throughout most of the formation. The benthonic population is primarily calcareous and is represented by assemblages distinctly different from the Goodland fauna.

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TABLE 2.

Distribution of Foraminifera in Per Cent of Total Population in the Goodland Formation.

See Chart Inserted

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BED	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
TOTAL POPULATION IN 1 cc. OF ROCK	*	3	750	46	350	51	*	5000	159	1500	*	222	*	18	*	1350	31	1750	3	375	72	990	*	500	*	52	*	650	—	750	1250	1250	27	1000	25	2500	*	127	*	250	16	*	31
SPECIES	PERCENTAGE DISTRIBUTION OF FORAMINIFERA IN EACH SAMPLE																																										
Ammobaculites goodlandensis Cushman & Alexander			4	P	P	5		2	1	1		3		70		P		1		2		4		2		14		5		20	20	20		5		3		2		28	60		7
A. laevigatus Lozo		67	10		P	37		P	P	P						P			67	3	10	5		P		18				2													2
A. sp.			P		P															P																							
A. torosus Loeblich & Tappan			2		P	10		P	P	P														P						P	P	P											
A. subcretaceus Cushman & Alexander			3	11	17	P		21	5	56		4				11	4	1		12		24		40							3	3		35		21		10					
Ammobaculoides whitneyi (Cushman & Alexander)			P													P				P		P		P										P									
Ammomarginulina loricata Loeblich & Tappan			P													P				P		P																					
Anomalina petita Carsey									P																																		
Buccicrenata subgoodlandensis (Vanderpool)			P									P																		P	P	P									P		
Bullopora sp.										P						P				1		P		4		P		P						P									
Cibicides sp.				P		P						P																															
Citharina intumescens (Reuss)			P		P	P		P	P	P		P		2		P		P		P	1	P		P		1		P		1	P	P		P		P				P			
C. kochii (Roemer)			P		P	P		P	P	P						P				P		P												P		P							
C. marginulinoides (Reuss)																P														P	P	P				P							
Conorbina conica Lozo						P		P				P					5	P		1		P		1		P		2		2	P	P				P		P		P			2
Coskinolinoides texanus Keijzer																														P			5					2					65
Dentalina communis (d'Orbigny)			3		4	3		2	P							P				1		P								1	3	3			P	5							
D. cucumis Loeblich & Tappan								P	P	P						P				P										P			P	P									
D. debilis (Berthelin)					P			P	P	P						P		P		P	1	1		2									P	P		2		2					
D. spp.			P					P	P	P						P				P		P		P							P	P	P	P	10								
Discorbis floscula Loeblich & Tappan			19	22	34			45	68	6		60		16		45	34	30		4	38	P		P		P				15	16	16		6		20		20		10	8		2
Di. minima Vieaux		13	40	50		47											22	7		8		16		13		9		6															
Flabellamina alexanderi Cushman			P					P	P	P		P				P	2			1		2		2		12		2		7	20	20	40	10	20	7		10		20			9
F. spp.										P																																	
Globigerina planispira Tappan					P				P	P						P				P		P								P			35										
G. sp.																P								P																			
G. washitensis Carsey			P	3	P			1	P	P		P				P	2			1	1	1		1		2		1		2	1	1		P		P		P					
Globulina exserta (Berthelin)			1		P	P		3	3	8		1				7	5	2		13	23	4		10		18		10		11	10	10	5	12		22		7		6	4		2
Gümbelina washitensis Tappan				P	P			P	P							P		P		P		P				P		P						P									
Guttulina symploca Loeblich & Tappan					P			P		P						P				P		P								P													
Gyroidina cf. *G. loetterlei* Tappan				P	P																																						
Haplophragmoides globosus Lozo																												P		P	P	P				2				4			3
Histopomphus redriverensis (Tappan)								P		P						P						P		P				P								P							
Kyphopyxa christneri (Carsey)						P																																					
Lagena apiculata (Reuss)																														P						P							
L. spp.									P							P					1			P						1						P		6		P			
L. sp. cf. *L. hispida* Reuss																					P			P						P						P		P		P			
Lenticulina cyprina (Vieaux)																				P	6	P				4		P		P	2	2		2		P				P	12		
Len. aff. *L. gaultina* (Berthelin)									P									P		P										P													
Len. sp.												P																															
Lingulina furcillata Berthelin					P			P		P						P				P		P		P				P			P	P				P							
Li. nodosaria Reuss var. *nodosaria* Reuss								P		P																																	
Li. sp.								P		P																																	
Lituola camerata Lozo																															P	P								4			
Lit. subgoodlandensis (Vanderpool)										P										P		P									P												
Marginulina paucicosta Tappan																P		P		P		P		P		2		1		P	P	P		P									
M. spp.			P					P	P											P		P				P		P		P						P				P			
Massilina spp.					P											P								P																			
Nodosaria barkeri Vieaux					P			P										P								1								P									
N. rigentia Loeblich & Tappan					P			P												P		P																					
N. sp.								P																																			
Palmula leai Loeblich & Tappan									P																																		
Patellina subcretacea Cushman & Alexander																P		1		4		P		P				37		2	P	P		P		P				P			
Pseudoglandulina cf. *mutabilis* (Reuss)																				P		P																					
P. scotti Tappan			P	8	19	P		1	2	8		P				2		5		7	2	7		7		6		3		3	2	2		4	15					6	4		2
Pseudopolymorphina ? roanokensis Tappan			1		12	P		7	5	12		7		2		3		2		P		P		P		P		P		P	P			P		P				P			
Quinqueloculina minima Tappan					P					P						P		P																									
Ramulina muricatina Loeblich & Tappan								P		P						P	4			4		3		4		9		1		8	P	P		8		P				3			
Saccammina sp. cf. *S. sphaerica* M. Sars			P																																								
Spirillina minima Schacko			P		3					1		P				5				2		1		1		1		12		2				1		P							
Spiroplectammina alexanderi Lalicker			9	1	3	P		7	5	P		5		6		5	4	16		4	3	8		3		1		3		5	P			2						3	8		
S. goodlandana Lalicker												P																															
S. nuda Lalicker										P																										P							
S. scotti Cushman & Alexander										P																																	
S. spp.									P											P											P					P							
Stichocibicides subcretaceus Tappan																P				P		P								P													
Textularia rioensis Carsey			6		P	P		P	P			3				P	5	9		P		P		1		P		2		3	7	7	5	1	15	3		3		2	P		4
Triloculina meotica Loeblich & Tappan			P	6	3				3	2		4				5		9		P	1	P						P		1	1	1	5		5	P				2			2
Triplasia goodlandensis (Cushman & Alexander)																P								P					100	2	2	2	5			3		30		2	4		
Tristix quadrata (Vieaux)			P					P												P										P													
Trochamminoides coronus Loeblich & Tappan			P									4				2	2	10				3								1	2	2		P									
Turrispirillina subconica Tappan								P												P		P						2		P						P							
Valvulineria spp.			P	P	P			P	P	P		P		2		P		P		P								P		P	P	P		P		2							
Verneulinoides schizeus (Cushman & Alexander)												2				P				4		1						10		1	3	3											
Virgulina primitiva Cushman			P					8		1						12		9		20	6							1		10	9	9		18		10		4		6			2
V. subcretacea Cushman			P	P	4				5			P					14		33			17		7		4		1															
Vitriwebbina laevis (Sollas)								P								P				P		P		P												P							
Washitella aff. *W. typica* Tappan																				P																							

SYMBOLS

P indicates presence of species in small numbers (less than 1% of total population).

* indicates stratum of hard limestone from which it was impossible to extract Foraminifera.