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SYNECOLOGY AND FAUNAL SUCCESSION OF THE UPPER MISSISSIPPIAN GREAT BLUE LIMESTONE, BEAR RIVER RANGE AND WELLSVILLE MOUNTAIN, NORTH-CENTRAL UTAH

by

Alan P. Sweide

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

Approved:

Major Professor

Committee Member

Committee Member

Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1977

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Alan P. Sweide

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ABSTRACT

Synecology and Faunal Succession of the Upper Mississippian Great Blue Limestone, Bear River Range and Wellsville Mountain, North-Central Utah

by

Alan P. Sweide, Master of Science
Utah State University, 1977

Major Professor: Dr. Richard R. Alexander
Department: Geology

The late Mississippian Great Blue Limestone was studied at four locations around Cache Valley, Utah. One location was at Dry Lake in the Pisgah Hills to the west of Cache Valley. Three locations were in the Bear River Range to the east of Cache Valley. From north to south the locations are: 1) Beirdneau Peak, 2) Logan Peak, and 3) the ridge to the north of East Fork Canyon. The Dry Lake location represents the upper, middle, and some of the lower part of the section. The base of the section is covered. Locations in the Bear River Range represent the lower and middle parts of the Great Blue Limestone. The upper part of the section has been removed by erosion. The sections at the four locations are correlated with one another by the *Lithostrotion-Turbophyllum* Zone present at all four locations at the top of the lower part.

Field work included measuring each section and collecting samples, for insoluble-residue analysis, at regularly spaced intervals at each location. Slab samples representative of the faunal assemblages were collected for laboratory analysis. Orientations of recumbent rugose coralla on exposed bedding planes of the *Lithostrotion-Turbophyllum* Zone at the four locations were measured for paleocurrent analysis.

Laboratory work included: 1) flume experiments, 2) analysis of slabs for faunal composition, preserved orientations, species associations, density, diversity, and species morphology, 3) insoluble-residue analysis, and, 4) X-ray diffraction to determine the characteristic mineralogy. Statistical analysis of the data collected in the field and from slabs included calculations of: 1) index of affinity and generation of faunal association dendograms, 2) mean, mode and angular deviation of the coral orientational data, 3) mean, skewness, and kurtosis of size-frequency distributions of rugose corals and the opportunistic species *Rugosochonetes loganensis* and, 4) species equitability-diversity.

The Great Blue has been divided into three units on the basis of lithology. The lower Great Blue is a massive, thick-bedded, dark-gray, microcrystalline limestone. The Long Trail Shale is a thin-bedded, light-brown shale. The upper Great Blue is a massive, thick-bedded, dark-gray, microcrystalline limestone. These units correspond to units 2, 3, and 4 of the Brazer Formation.

Seven faunal zones were identified in the Great Blue. In the lower Great Blue the *Turbophyllum* Zone and the *Lithostrotion-Turbophyllum* Zone are present. The Brachiopod-Pelecypod Zone is present in the Long Trail Shale. In the upper Great Blue the Coral-Cephalopod, *Caninia*, *Rugosochonetes-Orthotetes*, *Rugosochonetes-Paladin*, and Crinoid Bryozoan Zones are present.

Orientations of the apical ends of recumbent rugose corals in the *Lithostrotion-Turbophyllum* Zone of the lower Great Blue were used to reconstruct paleocurrent directions and intensities. Results of the survey indicate a preferred orientation of the apical ends of the rugose coralla in the direction which is now southeast. Results of the flume experiment indicate that rugose coral coralla subjected to unidirectional currents became oriented with the apical end pointed into the current. The modal orientations of the long axis of the coralla exposed on the bedding-plane surfaces suggest the existence of currents, predominantly from the south. The paleocurrent analysis suggests gentle tidal currents, with a stronger ebb component, operating for long periods of time.

Micritic lithologies within the *Turbophyllum* Zone were deposited during a transgression. The zone is populated by high and very-high filter-feeders, but species diversity is low. The faunal and lithologic evidence from the *Lithostrotion-Turbophyllum* Zone suggest an offshore environment, at or near effective wave base, inhabited by a few species which were low, high, or very-high filter-feeders. The Brachiopod-Pelecypod Zone contains a faunal assemblage associated with terrigenous lithologies suggestive of a nearshore environment that resulted from a regression. Species diversity in this zone is high. The Coral-Cephalopod Zone contains a sparse fauna and includes dark, micritic lithologies interpreted to have been deposited under conditions of almost no current activity, in possibly the deepest water, relative to the other zones. A rapid transgression and poorly oxygenated conditions above the substrate did not allow the development of a coral-crinoid community similar to the *Lithostrotion-Turbophyllum* Zone. Lithologic and faunal evidence in the *Caninia* Zone suggest a gradual regression that resulted in a shoaled environment similar to that of the *Lithostrotion-Turbophyllum* Zone. The zone is habited by low, high, and very-high level filter-feeders. Species diversity is high. The *Rugosochonetes-Orthotetes* Zone contains a fauna similar to the Brachiopod-Pelecypod Zone, but the fauna is not as abundant or diverse. Terrigenous lithologies and faunal evidence suggest a shallower environment that resulted from a continuation of the regression initiated during deposition of the lithologies within the Coral-Cephalopod and *Caninia* Zones. The succeeding calcilutites of the *Rugosochonetes-Paladin* Zone were deposited at a water depth greater than the underlying terrigenous muds of the *Rugosochonetes-Orthotetes* Zone. The zone displays high dominance and low diversity. The biospartic lithology of the Crinoid-Bryozoan Zone represents an environment situated in deeper water than the *Rugosochonetes-Paladin* Zone. Species diversity is very low and only the very-high filter-feeding niches are occupied.

The succession of the communities appears to be controlled by the nature of the substrate and the associated turbidity, current agitation, and sedimentation rate during deposition. The insoluble-residue survey indicates zones of terrigenous influx which influenced the nature

of the substrate and permits inferences concerning proximity to the source area. Asymmetrical cycles of rapid transgression and gradual regression over shallow shelf habitats controlled the faunal successions and retrogressions.

(168 pages)

INTRODUCTION

Objective and Procedure

The objective of this study is to reconstruct the depositional environments and faunal successions in the Mississippian Great Blue Limestone in the Dry Lake area of Wellsville Mountains and in the East Canyon, Logan Peak and Beirdneau Peak areas of the Bear River Range, north-central Utah (Figure 1).

In the field, the straitigraphic sections were measured at each location and lithologic samples collected at regularly spaced intervals. Faunal zones were delimited and compass orientations of macrofauna, particularly solitary, rugose corals, were recorded through successive strata at each locality. Weathered-free specimens and fossiliferous slabs from regularly spaced intervals in the section were collected. Faunal associations, including spatial and mutually exclusive relationships in successive horizons, were recorded.

Laboratory work included: 1) a graphic representation of the compass orientations of the fauna from each locality and calculations of randomness, radial deviation, and mean vector for each diagram; 2) a flume study on the effects of unidirectional currents on models of rugose coral forms found in the Great Blue; 3) graphic representation of the insoluble residue from the collected lithologic samples;

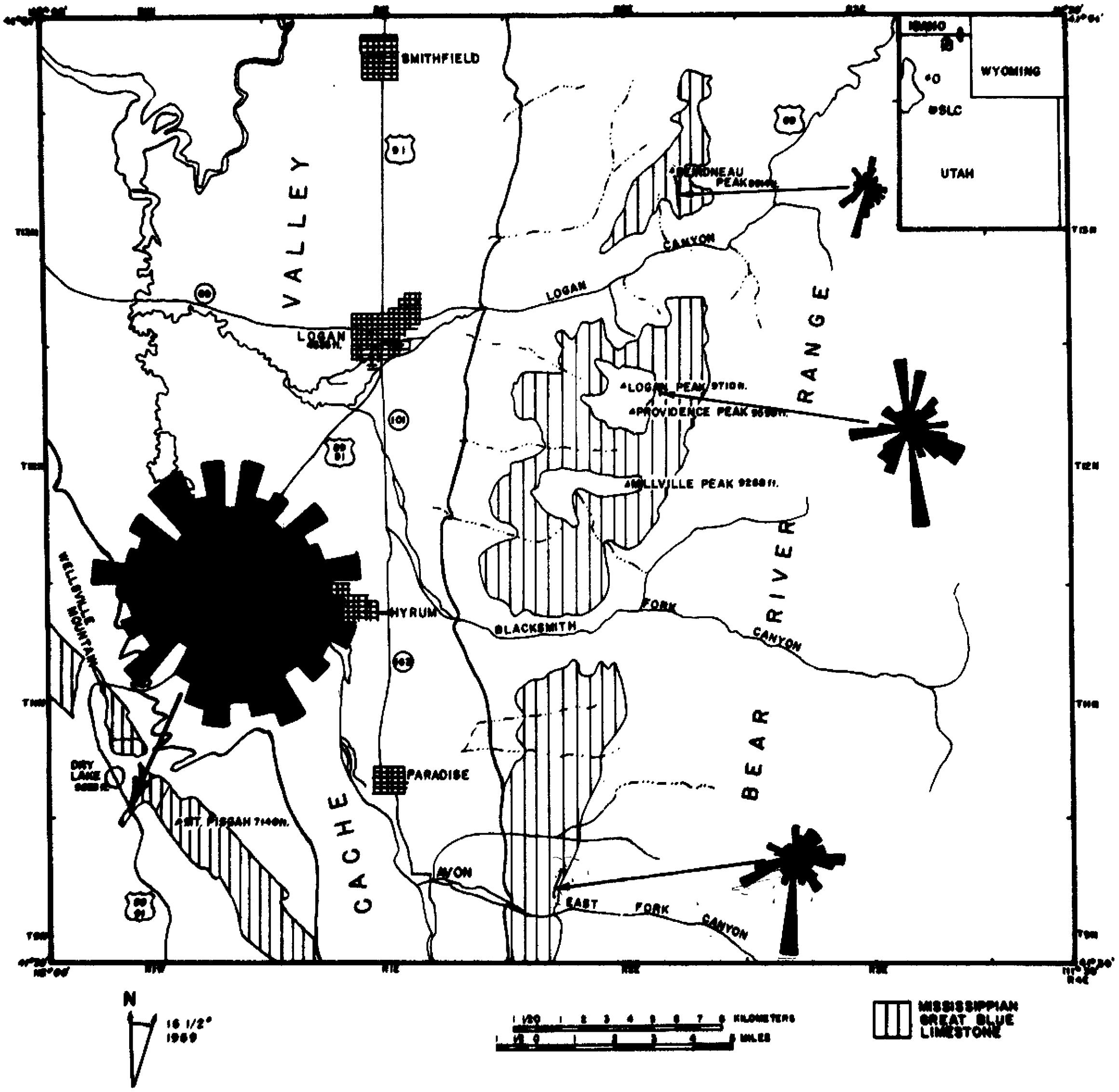


Figure 1. Index map showing the study area locations of the four study sections and rose diagrams of the orientations of recumbent rugose coralla.

4) statistical analyses of specimens in fossiliferous slabs for quantifications of the parameters of species diversity, density, and shell orientation; 5) graphic representations of the size-frequency distribution for each abundant, identifiable species; 6) calculation of an index-of-affinity matrix for each sample site and cluster analysis to determine the faunal associations within the faunal zones.

A synthesis of these data provided the basis for inferences concerning sedimentation rates and influx of terrigenous detritus, paleocurrent directions and intensities, competitive exclusions, trophic structures, population dynamics and sere succession. Collectively, these elements form the nucleus of the synecological reconstruction of the designated unit and area.

Location and Accessibility

The Great Blue Limestone was examined at four locations around the south end of Cache Valley in north-central Utah. The locations are the Dry Lake area, Beirdneau Peak, Logan Peak and the ridge to the north of East Fork Canyon (Figure 1).

The Dry Lake location is in the Mount Pisgah Quadrangle. The quadrangle is located between Logan and Brigham City. The Great Blue Limestone crops out in T. 10 N., R. 1 E., secs. 28 and 33. To the south of Dry Lake U.S. Highway 89-91 is parallel to the strike of the beds and a road cut between Sardine Summit and Dry Lake exposes shingled bedding-planes of the lower Great Blue dipping to the east at 40° (Figure 2). To the north of Dry Lake the Great Blue crops out to the

Figure 2. Bedding-surfaces of the lower Great Blue in the *Lithostrotion-Turbophyllum* Zone at Dry Lake, exposed by a road cut of U. S. Highway 89-91: view south.

east of U. S. Highway 89-91 on Babbit Shanty Hill (Figure 3). Most of the sections of the Great Blue may be observed along the road cut for the now-abandoned Sardine Canyon road.

The three other locations, Beirdneau Peak, Logan Peak and the ridge to the north of East Fork Canyon, are in the Bear River Range to the east of Logan, Utah. The locations are on peaks or ridges along the axis of the north-south trending Logan Peak Syncline (Figure 4). The bedding planes exposed at these locations are nearly horizontal, stair-step like, ledge exposures. The Beirdneau Peak location is in the Mount Elmer Quadrangle, to the north of Logan Canyon and U. S. Highway 89. The Great Blue crops out at the peak and on three ridges to the southwest, southeast and north-northeast of the peak above 6,800 feet (2,073 meters). The Logan Peak location is in the Logan Peak Quadrangle, to the south of Logan Canyon and U. S. Highway 89. The Great Blue crops out to the east of Logan Peak between 7,800 feet (2,277 meters) and 9,200 feet (2,804 meters). In the location to the north of East Fork Canyon, south of Logan and to the east of Avon, the Great Blue crops out between East Fork Canyon and Paradise Dry Canyon from 5,000 to 6,400 feet (1,524 to 1,951 meters).

The Dry Lake location is accessible from Brigham City or Logan, Utah by U. S. Highway 89-91. Most of the stratigraphic section is exposed along the road cut of the abandoned, rock-strewn Sardine Canyon road. The Beirdneau Peak location is accessible from U. S. Highway 89, in Logan Canyon, by foot via Beirdneau Hollow or by foot from the unimproved road in Green Canyon. The Logan Peak location may be reached

Figure 3. Faunal zones and stratigraphic units of the Great Blue on Babbit Shanty Hill at Dry Lake: view north. (1 = lower Great Blue, 2 = Long Trail Shale, 3 = upper Great Blue, T = *Turbophyllum* Zone, L-T = *Lithostrotion-Turbophyllum* Zone, B-P = Brachiopod-Pelecypod Zone, C-C = Coral-Cephalopod Zone, Can = *Caninia* Zone, R-O = *Rugosochonetes-Orthotetes* Zone, R-P = *Rugosochonetes-Paladin* Zone, C-B - Crinoid-Bryozoan Zone)

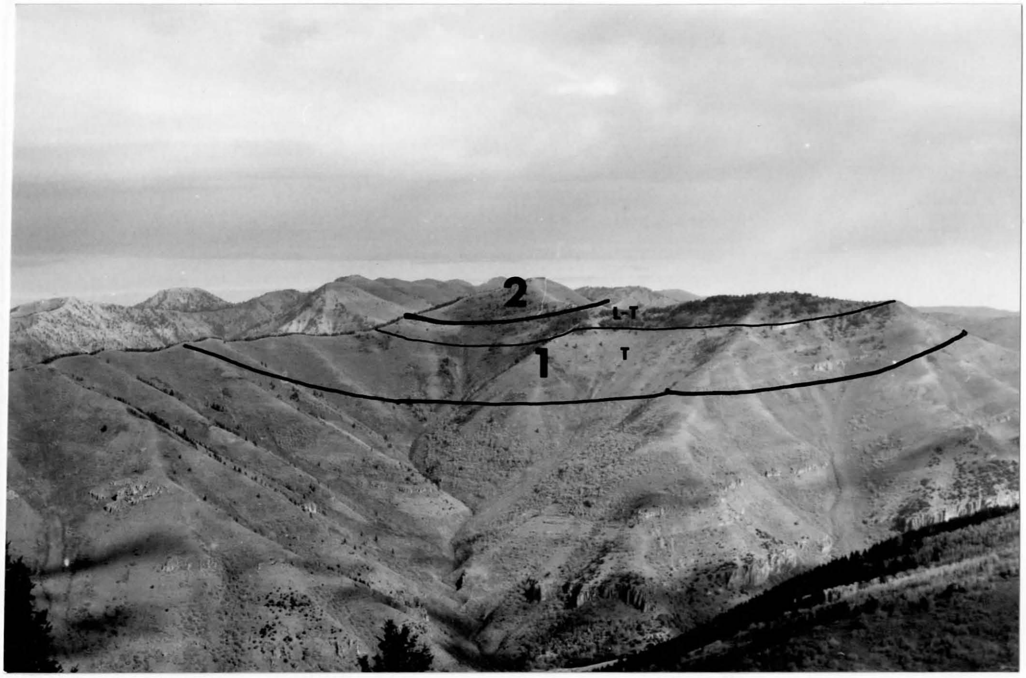


Figure 4. Beirdneau Peak location showing the faunal zones, stratigraphic units of the Great Blue, and the cross section of the Logan Peak Syncline: view north. (1 - lower Great Blue, 2 = Long Trail shale, T = *Turbophyllum* Zone, L-T = *Lithostrotion-Turbophyllum* Zone).

by unimproved roads and trails from U. S. Highway 89 in Logan Canyon, by way of Right Hand Fork Canyon, Providence Canyon or Blacksmith Fork Canyon. The location north of East Fork Canyon is accessible by foot from the unimproved roads leading up the canyons to the east of Avon, Utah.

Previous Work

Spurr (1895) informally applied the name Great Blue to a series of limestones in the Oquirrh Mountains of Utah. The Great Blue Limestone was originally described by Gilluly (1932, pp. 29-31). Three members were recognized: the lower Great Blue limestone, the Long Trail shale member, and the upper Great Blue limestone. The name Great Blue was applied to late Mississippian limestones in the Promontory Range of Utah by Olson (1956), in the Deep Creek Mountains of Idaho by Carr and Trimble (1961), and at Samaria Mountain, Utah-Idaho by Beus (1968).

Previously in the study area, the late Mississippian limestones were designated Brazer Formation (Williams, 1943, p. 596), in which five members were recognized. The Brazer Formation was first described by Richardson (1913) in the Randolph Quadrangle, Utah. Subsequently, Mansfield (1927, pp. 63-71) applied the name Brazer to late Mississippian limestones in southeastern Idaho. In northeastern Utah, Brazer was applied to late Mississippian limestones by Williams (1943; 1948), Eardley (1944), Williams and Yolton (1945), Parks (1951), Holland (1952), Strickland (1956), Beus (1958), and Sando, Dutro and Gere (1959).

Sadlick (1954, p. 12; 1955, p. 51) and Williams (1958) tentatively correlated units 2, 3, and 4 of the Brazer with the lower Great Blue Limestone, the Long Trail Shale, and the upper Great Blue Limestone, respectively. Crittenden (1959, p. 68) found this correlation to be reasonable but felt that the term Great Blue should not be used outside the Oquirrh Mountains due to questions on the extent and relations of the Long Trail Shale member.

Workers who measured the sections in detail include: Beus (1958, 1968) and Sando, Dutro and Gere (1959). Workers who illustrated sections include: Parks (1951), Holland (1952) and Sando, Dutro and Gere (1959). Faunal lists from the Brazer Formation of the Dry Lake area, Utah, were compiled by Yolton (1943), and by Williams and Yolton (1945), and from the Samaria Mountain, Idaho by Beus (1968). These authors used index fossils for age determination and/or biostratigraphic correlation. Beus (1968) listed important species, recorded their stratigraphic positions, and mentioned faunal associations, but did not assign them to faunal communities. Coral zonations and faunal associations within the Great Blue, at Dry Lake and Leatham Hollow, were delimited and discussed by Parks (1951), Sando and Dutro (1960), and Dutro and Sando (1963). The latter also established brachiopod zones and provided an extensive list of fossil positions within the stratigraphic section in the Portneuf Quadrangle, Idaho, but did not assign the fauna to communities.

LITHOLOGY

Rock Description

Lithologies of the various parts of the Great Blue have been described by many workers in and around the study area. Yolton (1943, pp. 10, 12, 13) described the C, D and E members of the Brazer Formation, north of Dry Lake, as follows:

> The C Member. The C member is composed of thick bedded limestones. In color the beds range from medium to dark gray. The texture of these rocks is also variable, being either compact or crystalline.
>
> The D Member. The deposits of the D member consist almost entirely of limestones. The lower portion of the unit is argillaceous and occurs in beds of thin to medium thickness. This rock is olive gray in color but, on weathering, assumes a somewhat more subdued olive buff shade. This silty limestone alternates with thin units of medium to thick bedded limestone; the texture of the latter being compact to crystalline. In some parts of the member the silty limestone grades into fuscous black shale which, on weathering, alters to an olive buff hue.
>
> The E Member. The lower 200 feet of this member consists of thin bedded limestones containing much smoke gray chert with liesegang banding. Upward the limestones are medium thick bedded and, as in the lower portion, an abundance of smoke gray chert is found.

Williams and Yolton (1945, p. 1145) described units 2, 3 and 4 of the Brazer formation, at Dry Lake, as follows:

		Feet
4.	Medium- to thick-bedded crystalline to compact dark gray limestones with considerable smoke-gray and black chert. Lower 200 feet thinner bedded, with much smoke-gray chert showing Liesegang banding. *Caninia* common throughout Top of unit forms crest of hill	950

		Feet
3.	Thin- to medium-bedded grayish olive argillaceous limestone weathering olive buff, alternating with thin units of medium- to thick-bedded compact crystalline limestone. In some parts, silty limestone grades into fuscous-black shale weathering olive buff. High in unit is a bed of limestone packed with shells of *Striatifera brazeriana*	470
2.	Thick-bedded medium- to dark gray crysatlline to compact limestone. *Lithostrotion whitneyi* common	400

At the same location as Williams and Yolton (1943), Williams (1948, p. 1,142) described units 2, 3, and 4 of the Brazer Formation, as follows:

Unit Dry Lake section	Thickness feet	
4	950	Medium-bedded dark-gray cherty limestone
3	470	Argillaceous ls. weathering olive buff. Some black sh.
2	400	Thick-bedded dark-gray ls.

Gelnett (1958), in a section measured in T. 11 N., R. 2W., sec. 13, one mile southeast of Deweyville, Utah on the south side of the first major canyon, described the Brazer Formation, as follows:

		Feet
4.	Sandy limestone, medium gray, weathers medium gray to light brown, interbedded with thin medium-gray crystalline limestone beds containing black chert nodules; slope forming	276
3.	Limestone, dark gray, weathers medium gray with a rough sandy surface, medium-bedded, contains nodules and stringers of black chert aligned with the bedding planes, chert increases in abundance upwards, includes an eight inch bed of greenish-gray shale at the base. Silicified corals and brachiopods abundant	320

2.	Limestone, medium gray, weathers medium light gray, coarsely crystalline, grades into oolitic limestone near the top, medium-bedded, cliff forming, contains corals and crinoid stems . . . . (p. 48)	Feet 398

Mullens and Izett (1964) described members B and C of the Brazer Formation, in the Paradise Quadrangle, as follows:

> In most places, member B is dark-gray limestone, but dolomite and sandstone occur locally.
>
> Limestone in member B is dark gray, fine grained, dense, fetid, and locally fossiliferous. Dolomite, megascopically similar to the limestone, occurs here and there in the limestone and is the dominant rock type near faults. Small nodules and thin layers of dark-gray chert and large (1 to 1-1/2 in. in diameter) horn corals belonging to the genus *Faberophyllum* are abundant but erratically distributed in the upper two-thirds of the limestone. ... Sandstone occurs mainly near the base of member B where it intertongues and intergrades with member A.
>
> Member C ... the member is mainly thin-bedded dolomitic cherty siltstone in exposures south of Paradise Dry Canyon and thin- to medium-bedded limestone in exposures north of Hyrum Canyon. (pp. S9-S10)

The relationships between these above described lithostratigraphic units and the biostratigraphic units will be discussed elsewhere.

Insoluble-Residue Analysis

Procedure

For determination of percent insoluble residue, lithologic samples were collected at intervals of ten stratigraphic feet (3 meters) through the entire section at each of the four locations. Each sample weighed approximately 50 grams. At Dry Lake, Beirdneau Peak, Logan Peak and East Fork Canyon, 297, 90, 70 and 80 samples were collected respectively. Much of each section in the Bear River Range was covered interval (Plate 1). Every second sample of the sequence was processed to determine the percent of insoluble residue present. Approximately 30 grams of each sample was crushed, in a steel mortor with a pestle, in order to speed dissolution. The sample was weighed to the nearest one-tenth gram and placed in a solution of 10 percent hydrochloric acid. When the visible reaction had stopped the acid was decanted, and fresh acid solution was added. This procedure was repeated until no reaction was visible when fresh acid solution was added. The sample then was washed with distilled water which was decanted and the sample was placed in an oven, at 85°C, to dry. When dry, the sample was again weighed to the nearest one-tenth of a gram. The weight of the residue was calculated as a percent of the original sample and the results recorded. The results are presented graphically in Plate 1. For each value which did not correspond to the trend of previous sample values and for each covered interval the samples on either side were also processed.

Results

The percent of insoluble residue ranges from less than 1 percent, in the detritus free limestone, to 99 percent in the Long Trail Shale. The percent of insoluble residue is indicative of the amount of terriginous material in the lithified substrate. At the Dry Lake location the lower Great Blue is a massive crystalline limestone, averaging 20 percent insoluble residue. Near the top of the lower unit, in samples 35 to 75, the insoluble residue percent drops to 5 percent. The Long Trail

Shale, samples 76 to 115, is a fine-grained, light-brown to olive shale averaging in excess of 90 percent insoluble residue. The upper Great Blue, samples 116 to 300, has a variable lithology and percent of insoluble residue. Samples between 120 and 181 have insoluble-residue contents averaging 40 percent. These samples are from a lithology of medium- to dark-gray limestone with black chert nodules. Samples 182 to 285, also in the upper Great Blue, are from dark-gray, fine grained, detritus-free limestone. The average insoluble residue for this interval is 10 percent. The shale bed of the *Rugosochonetes-Orthotetes* Zone includes samples 285 and 286. The dark-brown shale averages 95 percent insoluble residue. Samples 289 to 292 are from the crinoidal limestone of the uppermost upper Great Blue. These samples average 50 percent insoluble residue.

The graphs of the percentages of insoluble residue of the samples collected at the locations in the Bear River Range do not show the same clear relationships of insoluble residue to lithostratigraphic unit as the samples from the Dry Lake location (Plate 1). The samples from Beirdneau Peak show a significant upward stratigraphic increase in the percentages of insoluble residue except for the interval between samples 50 and 103 where the insoluble residue is less than 20 percent. The *Lithostrotion-Turbophyllum* Zone is between samples 135 and 147. The upper 200 feet (61 meters) show some similarity to the Long Trail Shale.

At Logan Peak the lower Great Blue is within the interval of samples 1 to 141. Most of the samples of this interval contain less than 10 percent insoluble residue. The Long Trail Shale is expressed by the values of 90 percent plus insoluble residue in the interval between samples 143 and 159. The *Lithostrotion-Turbophyllum* Zone is between samples 115 and 141.

At East Fork Canyon the lower Great Blue is within the interval of samples 1 to 135. The Long Trail Shale is represented in the interval of samples from 137 to 147, where 2 samples exceed 90 percent insoluble residue. The *Lithostrotion-Turbophyllum* Zone is between samples 93 and 35.

X-ray Mineralogy

Whole-rock samples and samples of insoluble residues were used to determine the major mineralogy of the different lithologic units and faunal zones. X-ray diffractograms were made of selected lithologic samples from each of the various faunal zones. For each sample a diffractogram was made from the powdered rock, the insoluble residue of the rock, and for clay minerals, a slurry-oriented sample of the insoluble residue. The results are presented in Table 1.

X-ray diffractograms from the samples at Dry Lake show the major mineralogy of the various units. The lower Great Blue contains calcite, quartz and possibly chlorite. The red shale beds in the lower Great Blue contain calcite, quartz, illite, muscovite and a small amount of feldspar. Samples from what are believed to be algal structures in the lower Great Blue contain calcite, quartz, illite, muscovite and chlorite. Samples from the Long Trail Shale contain quartz, illite, muscovite, feldspars and chlorite. Samples from the upper Great Blue include limestones and shale. The limestones contain calcite and small

Table 1. Mineralogy of selected samples of the Great Blue from X-ray diffractograms

Sample No. and type			Unit	Lithology	Calcite	Quartz	Feldspars	Muscovite	Illite	Chlorite	Dolomite
1	RK	(30DL)	1	Ls	X	X					
2	IR	(30DL)	1	Ls		X					
2a	IR-SL	(30DL)	1	Ls						X	
5	Rk	(101DL)	2	Sh		X	X	X	X		
6	IR	(101DL)	2	Sh		X	X	X	X	X	?
6a	IR-SL	(101DL)	2	Sh					X		
7	RK	(229DL)	3	Ls	X	X					
8	IR	(229DL)	3	Ls		X					
8a	IR-SL	(229DL)	3	Ls					?		
9	RK	(261DL)	3	Sh	X	X					
10	IR	(261DL)	3	Sh		X					
10a	IR-SL	(261DL)	3	Sh				X	X	X	
12	RK	(77DL)	2	Ls	X	X	X	X	X		
13	IR	(77DL)	2	Ls		X	X	X	X		
13a	IR-SL	(77DL)	2	Ls				X	X		
16	Rk	(53DL)	1	red-Sh	X	X		X	X		
17	IR	(53DL)	1	red-Sh		X		X	X		
17a	IR-SL	(53DL)	1	red-Sh				X	X		

Numbers in ( ) indicate insoluble residue survey number (Plate 1) and DL indicates Dry Lake. (Unit 1 = lower Great Blue, Unit 2 = Long Trail shale, Unit 3 = upper Great Blue, Ls = limestone, Sh = Shale, red-Sh = red shale, Rk = rock sample, IR = insoluble residue sample and IR-SL = insoluble residue slurry sample) amounts of quartz. The shale contains calcite, quartz, chlorite and samll amounts of illite and muscovite.

STRATIGRAPHY AND BIOSTRATIGRAPHY

General Statement

Through the use of fauna the Great Blue has been dated as late Mississippian (Meramecian-Chesterian) in age. Williams and Yolton (1945, pp. 1,148-1,149) noted fauna of Meramec age, including the brachiopod *Cleiothyridina hirsuta* and the cephalopods *Goniatites, Girtyoceras, Bactrites, Tripterceroides, Discitoceras* and *Solenochilus* in unit 2 of the Brazer Formation (lower Great Blue). *Pugnoides ottumwa* and *Cleiothyridina hirsuta,* brachiopods of Meramec age, were found in unit 3 of the Brazer Formation (Long Trail Shale). *Spirifer leidyi* and *Composita trinuclea,* brachiopods of lower and middle Chester age, were noted in unit 4 of the Brazer Formation (upper Great Blue).

Measurement of the section of the Great Blue, at each of the four locations, was undertaken to obtain a uniform sample spacing for the insoluble-residue survey, and to determine, more accurately, the positions of the various faunal zones within the study area. The measurements were made with a Jacobs staff and a Brunton compass.

Dry Lake Location

Measurement at the Dry Lake location began on the west side of U. S. Highway 89-91 at the bottom of the section where the valley fill is in contact with the limestone of the lower Great Blue. The section proceeded east approximately along the ridge to the north of the Mount

Pisgah Road to the Manning Canyon Shale (Figure 5). The total measured thickness is 2,236 feet (682 meters). Williams and Yolton (1945) measured the thickness of the section north of Dry Lake on Babbit Shanty Hill. The thickness of Units 2, 3 and 4 of the Brazer Formation was determined to be 1,820 feet (555 meters). Parks (1951, p. 174) measured the exposed part of the Brazer to the south of Dry Lake and recorded a thickness of 2,100 feet (640 meters).

Williams (1948) placed the contact of Unit 5 of the Brazer, now correlated with the Manning Canyon Shale, and Unit 4, now correlated with the upper Great Blue, at the base of the shale bed containing the proposed *Rugosochonetes-Orthotetes* Zone. The shale bed, approximately 20 feet (6 meters) thick, is overlain by approximately 140 feet (43 meters) of dark-gray, crinoidal limestone, similar to the underlying upper Great Blue. If the contact proposed by Williams (1948) is used, the upper Great Blue is shortened 165 feet (50 meters), and the total thickness is shortened by the same amount, for a total of 2,071 feet (631 meters). On the basis of lithologic similarity with the underlying upper Great Blue and the faunal abundance in the shale bed and the overlying limestone, the lower part of the Manning Canyon Shale of Williams (1948) was included in the study as upper Great Blue.

All three units of the Great Blue are present at the Dry Lake location. The lower Great Blue is more than 516 feet (152 meters) thick. The exposed part of this lower unit contains part of the proposed *Turbophyllum* Zone and all of the proposed ~~*I*~~L*ithostrotion-Turbophyllum* Zone.

Figure 5. Faunal zones and stratigraphic units of the Great Blue at the Dry Lake location: view south. (1 = lower Great Blue, 2 = Long Trail Shale, 3 = upper Great Blue, T = *Turbophyllum* Zone, L-T = *Lithostrotion-Turbophyllum* Zone, B-P = *Brachiopod-Pelecypod* Zone, C-C = Coral-Cephalopod Zone, Can = *Caninia* Zone, R-O = *Rugosochonetes-Orthotetes* Zone, R-P = *Rugosochonetes-Paladin* Zone, C-B = Crinoid-Bryozoan Zone.)

The Long Trail Shale is 301 feet (92 meters) thick. The proposed Brachiopod-Pelecypod Zone occupies the upper half of the unit, and has two dense faunal assemblages, one between 170 and 180 feet (52 and 55 meters) and the other between 295 and 300 feet (89 and 92 meters) above the base of the unit.

The upper Great Blue is 1,419 feet (433 meters) thick. Five faunal zones are proposed for the upper Great Blue in this paper. The Coral-Cephalopod Zone extends from the base of the unit to 1,000 feet (305 meters). The *Caninia* Zone extends from 1,000 feet (305 meters) above the base of the unit to 1,800 feet (550 meters) above the base. The *Rugosochonetes-Orthotetes* Zone is in a shale layer 25 feet (8 meters) thick. Parks (1941, p. 174) noted 30 feet (9 meters) of shale between 1,880 and 1,910 feet (573 and 582 meters) in his illustration of the Dry Lake section. The *Rugosochonetes-Paladin* Zone lies 20 feet (6 meters) above the top of the shale bed and is approximately 5 feet (2 meters) thick. The Crinoid-Bryozoan Zone makes up the remainder of the unit above the *Rugosochonetes-Paladin* Zone.

Bear River Range Locations

In the present study the proposed *Lithostrotion-Turbophyllum* Zone was used to correlate rocks in the three locations in the Bear River Range with the Dry Lake section. The proposed *Lithostrotion-Turbophyllum* Zone is present at all four locations in the study area. The locations in the Bear River Range contain the complete lower Great Blue, the lower part of which is covered or missing at the Dry Lake location.

Parks (1941, p. 174) measured 1,000 feet (305 meters) of the lower Great Blue in Leatham Hollow. Seven hundred feet (213 meters) were below the *Lithostrotion whitneyi-Faberophyllum leathamense* Zone. This zone is 100 feet (31 meters) thick at this location. Mullens and Izett (1963) measured 801 feet (244 meters) of the Great Blue in Blacksmith Fork Canyon and 374 feet (114 meters) in Hyrum Canyon, both in the Bear River Range to the east of Hyrum, Utah.

At the Beirdneau Peak location the measured thickness of the Great Blue is 1,600 feet (448 meters). The base of the proposed *Lithostrotion-Turbophyllum* Zone is 1,350 feet (412 meters) above the base of the Great Blue. The proposed *Lithostrotion-Turbophyllum* Zone is 120 feet (37 meters) thick at this location.

At the Logan Peak location the section is 1,600 to 1,800 feet (488 to 549 meters) thick. The proposed *Lithostrotion-Turbophyllum* Zone is 1,200 feet (366 meters) above the base of the Great Blue and is 270 feet (82 meters) thick.

At the East Fork Canyon location the thickness of the section is 1,500 feet (452 meters). The proposed *Lithostrotion-Turbophyllum* Zone is 950 feet (290 meters) above the base of the Great Blue. The proposed *Lithostrotion-Turbophyllum* Zone is 370 feet (112 meters) thick at this location.

Mega-Faunal Zones

Zonation of the mega-fauna of upper Mississippian age is based mainly on field observations and the results of the laboratory analysis of the slab samples. The coral zones designated by Parks (1951) are used to some extent in this study. Faunal zones similar to the zones in the study area were described by Dutro and Sando (1963a, 1963b) in the Chesterfield Range Group in southwest Idaho, and by Sando (1967b) in southeast Idaho, west-central Wyoming and northern Utah. A compilation and correlation of these works was made by Sando, Mamet and Dutro (1969) in which the major mega-faunal zones were compared to those presented by Sando (1967b). The zones of Sando (1967b), and Sando, Mamet and Dutro (1969) are closely correlated to the coral zones proposed by Parks (1941) for the Great Blue of north-central Utah (Figure 6).

The proposed *Turbophyllum* Zone correlates with the *Faberophyllum occultum-Faberophyllum araneosum* Zone of Parks (1941), the upper part of Zone F of Sando, Mamet and Dutro (1969); Sando (1967b); and Dutro and Sando (1963a). The range of *Faberophyllum* defines the limit of this range zone (Sando, 1967b, p. D10). However, this is not the case as *Turbophyllum* is found in many zones of the Great Blue.

The proposed *Lithostrotion-Turbophyllum* Zone correlates with the *Lithostrotion whitneyi-Faberophyllum leathamense* Zone of Parks (1951), the upper part of Zone F of Sando, Mamet and Dutro (1969); Sando (1967b); Dutro and Sando (1963a), and the *Striatifera brazeriana* Zone of Dutro and Sando (1963b). The rugose corals of the *Lithostrotion-Turbophyllum* Zone were differentiated from those of the lower *Turbophyllum* Zone by Parks (1951, pp. 177-179). The phaceloid rugose coral *Lithostrotion* and the colonial tabulate coral *Syringopora* are present in the *Lithostrotion-Turbophyllum* Assemblage Zone in modest quantities.

The proposed Brachiopod-Pelecypod Assemblage Zone is within the lower part of Zone pre-K of Sando (1967b), and the lower part of the *Spirifer brazerianus* Zone of Dutro and Sando (1963a). Parks (1951, p. 183) listed *Chonetes, Gigantella, Composita* and *Dictyoclostus* as present above the *Lithostrotion whitneyi- Faberophyllum lethamense* Zone. The brachiopods *Rugosochonetes loganensis, Pugnoides ottumwa, Linoproductus tenuicostus, Cleiothyridina hirsuta, Orthotetes kaskaskiensis, Punctospirifer* and the pelecypods *Paleoyoldia, Schizodus,* and *Schuchertella* are present in modest numbers.

The proposed Coral-Cephalopod Zone is equivalent to the upper part of Zone pre-K of Sando, Mamet and Dutro (1969); Sando (1967b), and is within the lower *Spirifer brazerianus* Zone of Dutro and Sando (1963a). The *Triplophyllites* Zone of Parks (1951) is in this zone. Parks (1951, p. 174) designated the zone that is proposed as the Coral-Cephalopod Zone as an interval of few corals. Sando, Mamet and Dutro (1969, p. #11) also described this zone as being poorly fossiliferous. The most abundant taxon is the rugose coral *Turbophyllum.* Cephalopods, possibly belonging to the genus *Eumorphoceras,* are present but rare (Figure 7). The number of taxa and individuals increase towards the top of the interval.

The proposed *Caninia* Range Zone is equivalent to the lower part of the *Caninia* Zone of Parks (1951, p. 183) and Zone K of Sando, Mamet and Dutro (1969); Sando (1967b); and Dutro and Sando (1963a). The zone is named for the large rugose coral *Caninia* which is moderately abundant. Other organisms present are crinoids, brachiopods and trilobites.

SYSTEM (INTERNATIONAL)	SYSTEM (NORTH AMERICAN)	NORTH AMERICAN SERIES	NORTHERN UTAH FORMATIONS	PARKS (1951)	DUTRO AND SANDO (1963a)		DUTRO AND SANDO (1963b)		SANDO (1967b)	THIS PAPER
				NORTHERN UTAH	SE. IDAHO		SW. MONTANA and W. WYOMING		SE. IDAHO W-C WYOMING N. UTAH	NORTHERN UTAH
UPPER CARBONIFEROUS	PENN.									
	MISS.	CHESTER	MANNING CANYON FM.						POST-K	
			UPPER GREAT BLUE LIMESTONE	*Caninia*	K	*Spirifer brazerianus*	K	*Spirifer brazerianus*	K	*Crinoid-Bryozoa*
										Rugosochonetes-Pugilis
										Rugosochonetes-[illegible]
										Caninia
LOWER CARBONIFEROUS										
									PRE-K	*Coral-Cephalopod*
			LONG TRAIL SHALE							*Brachiopod-Pelecypod*
		MERAMEC	LOWER GREAT BLUE LIMESTONE	*Triplophyllites*	F		*Striatifera brazeriana*		F	*Lithostrotion Turbophyllum*
				Lithostrotion whitneyi-F. leathamense						
				Faberophyllum occultum-Faberophyllum araneosum		*Striatifera brazeriana*				*Turbophyllum*
			HUMBUG FM.	*Exvasophyllum inclinatum*	E				E	

Figure 6. Chart correlating previous and proposed faunal zones within the Great Blue Limestone.

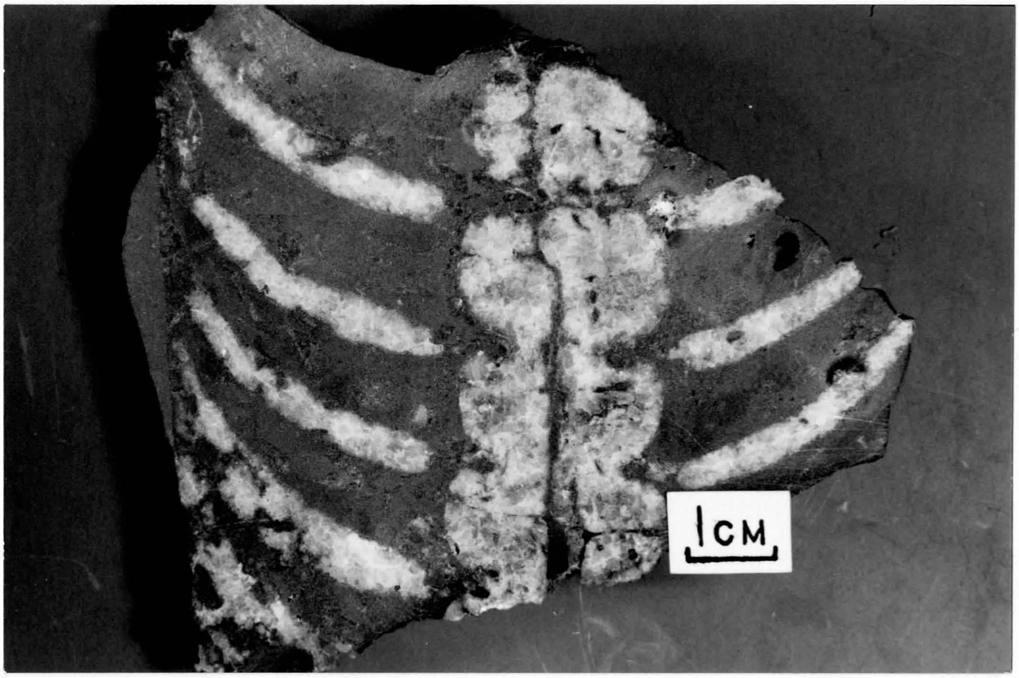


Figure 6. Longitudinally cut section of part of a cephalopod, possibly *Eumorphoceras*. The sample was collected at Dry Lake sample site 4 and is part of slab 4-1.

Distribution of the fauna appears to be patchy and suggests "nests." Zone K is a widely distributed biostratigraphic unit (Sando, Mamet and Dutro, 1969, p. E11).

Three stratigraphically narrow faunal zones are proposed for the uppermost part of the upper Great Blue. These zones, not previously described, are in the upper part of the *Caninia* Zone (Parks, 1951) and the upper part of Zone K (Sando, Mamet and Dutro, 1969; Sando, 1967 1967b; Dutro and Sando, 1963a). The proposed *Rugosochonetes-Orthotetes* Zone is in a thin, brown, shale unit. Parks (1951, p. 174) noted shale between 1,880 and 1,910 feet (573 and 583 meters) at the Dry Lake section. No corals are present, however, *Chonetes loganensis* and *Composita trinuclea* are mentioned in the description of the *Caninia* zone (Parks, 1951, p. 183). Brachiopods and pelecypods are common in this assemblage zone. *Rugosochonetes loganensis* is the most abundant taxon followed, in order of decreasing abundance by *Schuchertella Orthotetes kaskaskiensis*, and the pelecypod *Paleoyoldia*.

Immediately above the shale bed is the proposed *Rugosochonetes-Paladin* Zone. This zone contains a large number of densely packed *Rugosochonetes loganensis* (Figure 8) and a modest number of the trilobite *Paladin*, crinoids and other brachiopods. The zone is a peak zone for *Rugosochonetes loganensis* and an assemblage zone for *Rugosochonetes loganensis* and *Paladin*.

Above the proposed *Rugosochonetes-Paladin* Assemblage Zone and below the Manning Canyon Shale is the proposed Crinoid-Bryozoan Zone. This zone is in a dark-gray limestone composed of crinoid and bryozoan debris.

Figure 8. Slab of part of the *Rugosochonetes-Paladin* Zone showing the abundance and packing of *Rugosochonetes loganensis*. The slab was collected at Dry Lake sample site 16 and is slab 16-25.

FAUNAL ANALYSIS

Field Observations, Slab Sampling and Slab Analysis

Rock-slab samples, containing fossils, were collected from outcrops at the four locations in the study area. The most complete section and the most fossiliferous area is exposed at the Dry Lake location. Consequently, the majority of the samples were collected at this location. Two hundred and ninety-three slab samples were collected from 16 sample sites at Dry Lake (Figure 9). The sample sites were distributed as follows: lower Great Blue, four sample sites; Long Trail Shale, five sample sites; upper Great Blue, seven sample sites. Some of the samples were collected from the same horizon but at geographically separated sites. An attempt was made to collect slabs that represented each of the faunal zones. Fewer slab samples were collected from the lower Great Blue than at the other three locations. In addition to the slab samples, notes were made in the field concerning faunal associations, diversity, dominance, and abundances for exposures.

The slabs to be analyzed were washed with water and a scrub brush. When dry, the slabs were numbered in paint for future reference. The first number refers to the sample site and the second number to the number of the slab from that sample site. For example, Slab number 15-12 is slab sample number 12 from sample site number 15. The size of the slab and the lithology were noted. Taxa were identified as

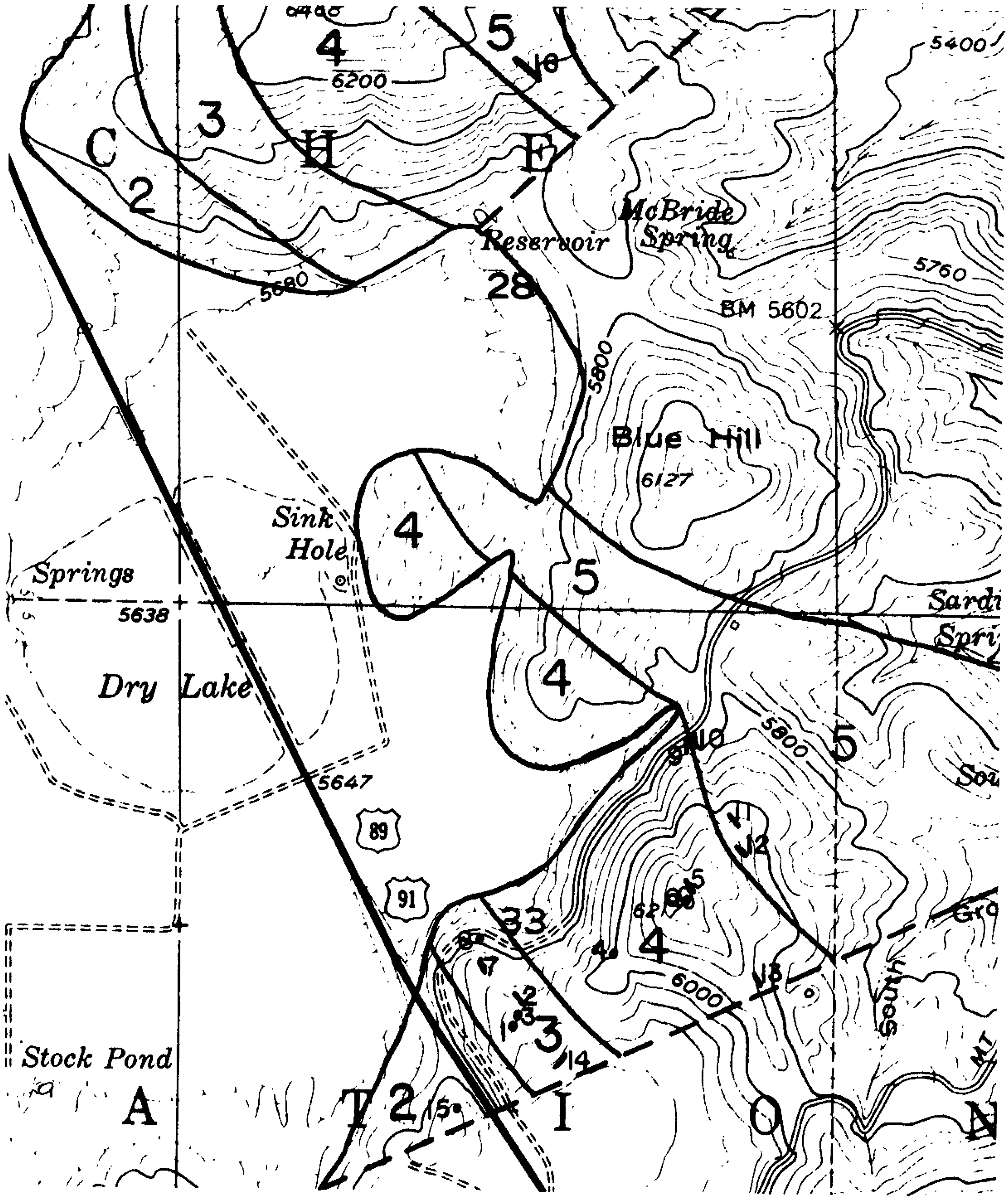


Figure 9. Map of the location of the sample sites at the Dry Lake section. The geology is from Williams, 1948. The large numbers 1, 2, 3, 4, and 5 represent corresponding Brazer Formation units that are correlated to the Humbug formation, the lower Great Blue, the Long Trail Shale, the upper Great Blue, and the Manning Canyon Formation, respectively.

closely as possible. Coelenterates, brachiopods, mollusks and arthropods were identified at least to the genus level and to the species level where possible. The bryozoans were identified to the phylum level and the echinoderms to the class level. The number of individuals of each taxon was counted and their size range was measured. The number of individual brachiopods and pelecypods showing a convex-up or -down orientation was recorded. Observations concerning the degree of abrasion, articulation, mineralization, packing, morphologic features, evidence of predation, and growth abberations were also recorded. The Department of Geology at Utah State University serves as the repository for the slab samples.

Faunal Associations

Index of affinity

The major objective of the slab analysis was to determine the faunal associations within the faunal zones. The first step was to produce a similarity matrix from the index of affinity for all possible associations. The index of affinity is calculated from the formula for Fager's similarity coefficient, S_f (Fager and McGowan, 1963), described as follows:

$$S_f = \frac{C}{\sqrt{N_1 \ N_2}} - \frac{1}{2\sqrt{N_2}}$$

where C is the number of occurrences of taxa N_1 and N_2 together; N_1 the total number of occurrences of taxon N_1; N_2 the number of occurtences of taxa N_2, and $N_1 > N_2$. The index of affinity consists of both positive and negative numbers. By adding the additive inverse of the smallest negative number of the index of affinity to all of the numbers of the index of affinity the result is an index of affinity composed of positive numbers. To generate a dendogram of the faunal associations it is necessary to invert the index of affinity so that the smallest numbers represented the closest associations.

Cluster analysis

Two clustering methods were used, namely, clustering by single linkage (Sneath's method) and clustering by average linkage (the Group methods of Sokal and Michner). These techniques are discussed by Sokal and Sneath (1963, pp. 180-185). The faunal association dendograms presented are the result of the clustering by average linkage. Where chaining was found, the dendogram of the clustering by single-linkage analysis is presented. Clusters with an index of affinity less than .25, or in some cases less than .30, were considered to be significant associations.

Faunal associations within the faunal zones

Turbophyllum Zone. The only taxon observed in the *Turbophyllum* Zone was the rugose coral *Turbophyllum*. However, Parks (1951, p. 182) noted the presence of *Ekvasophyllum turbinum*, *Triplophyllites*, *Syringopora* and *Gigantella brazeriana*.

Lithostrotion-Turbophyllum Zone. Three associations are suggested by the dendograms of the faunal associations (Figures 10-13), namely, a *Turbophyllum*-Crinoid-*Syringopora* association, an *Orthotetes*-Bryozoan association and a *Rugosochonetes-Linoproductus* association.

UNIT #1 Site #15 Dry Lake

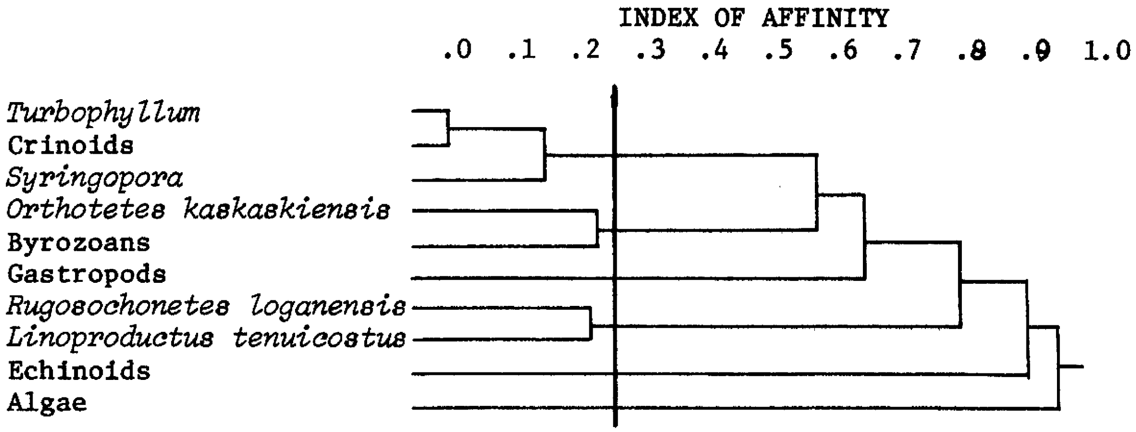


Figure 10. Dendogram of faunal associations at sample site 15 in Unit 1, the lower Great Blue, by average linkage. Clusters considered to be significant appear to the left of the .25 value for the index of affinity.

UNIT #1 Site #17 Beirdneau Peak

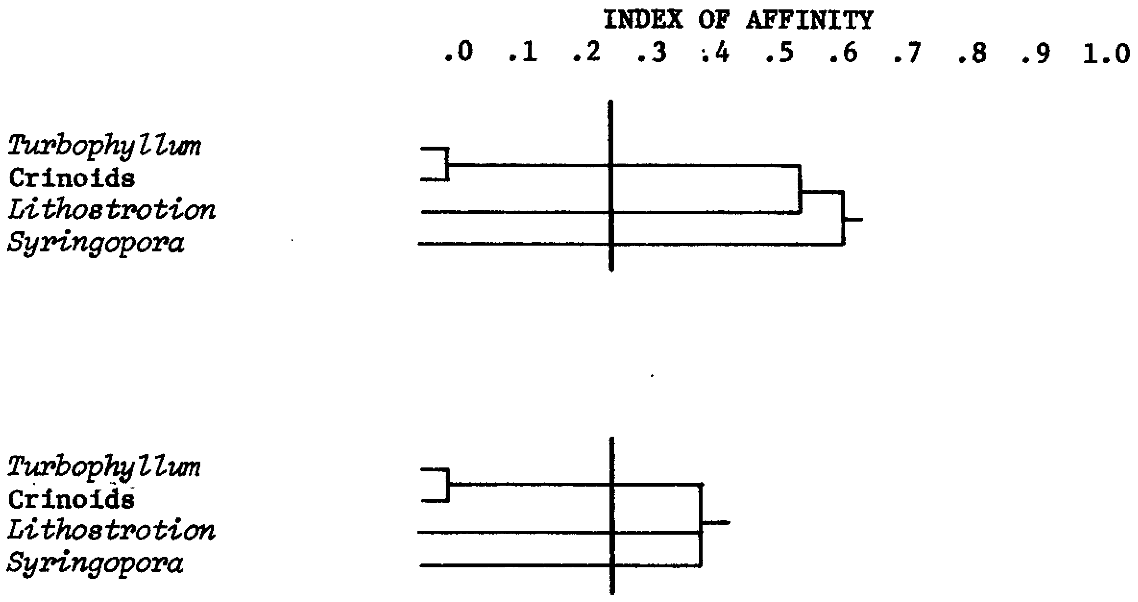


Figure 11. Dendograms of faunal associations at sample site 17 in Unit 1, the lower Great Blue. Upper dendogram by average linkage and lower dendogram by single linkage. Clusters considered to be significant appear to the left of the .25 value for the index of affinity.

UNIT #1 Site #18 Logan Peak

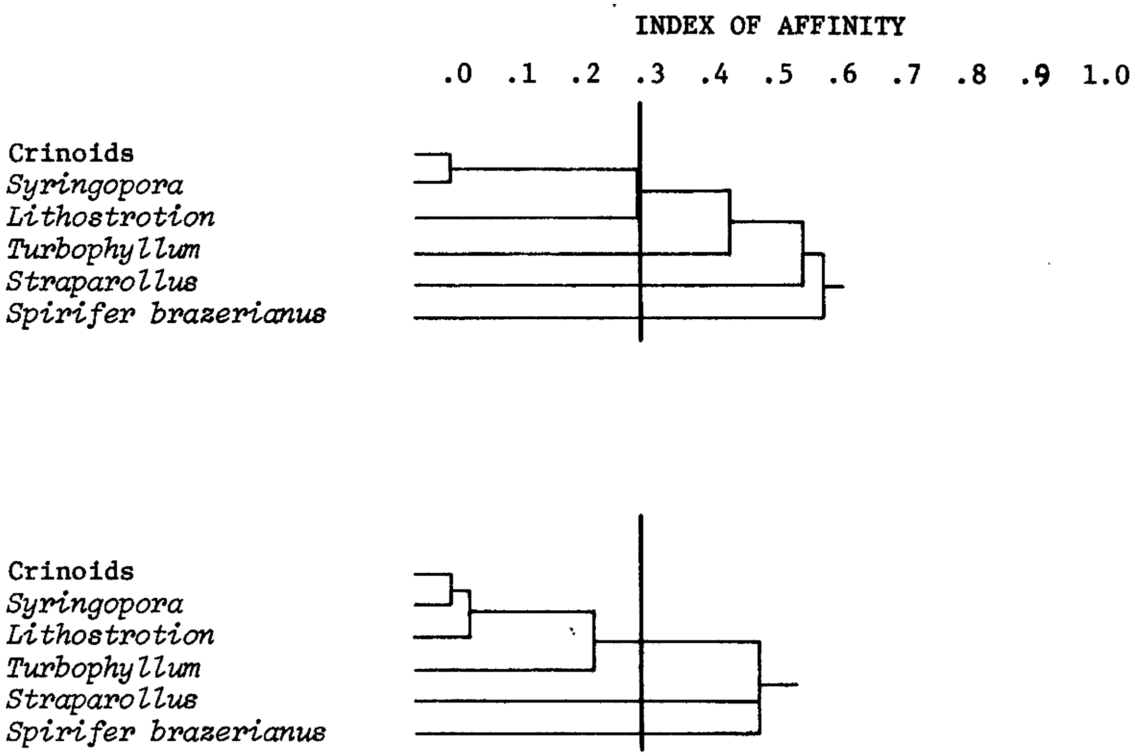


Figure 12. Dendograms of faunal associations at sample site 18 in Unit 1, lower Great Blue. Upper dendogram by average linkage and lower dendogram by single linkage. Clusters considered to be significant appear to the left of the .30 value for the index of affinity.

UNIT #1 Site #19 East Fork Canyon

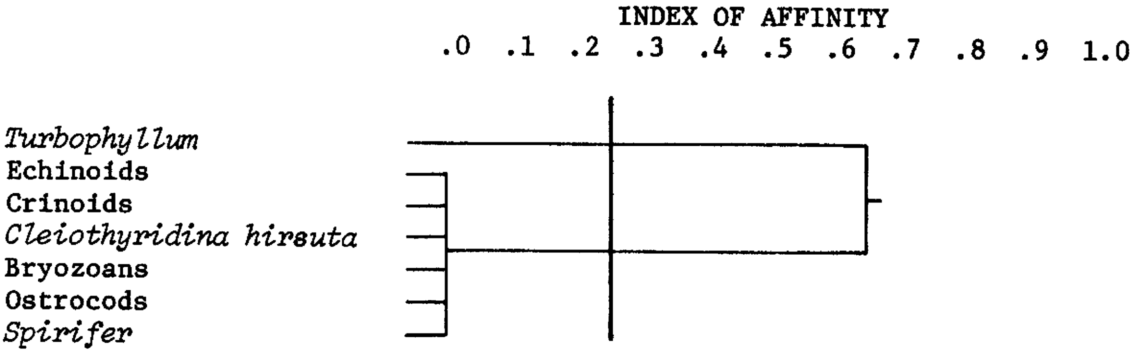


Figure 13. Dendogram of faunal associations at sample site 19 in Unit 1, the lower Great Blue, by average linkage. Clusters considered to be significant appear to the left of the .25 value for the index of affinity.

Brachiopod-Pelecypod Zone. Within this zone the faunal associations are abundant (18 associations) and variable (Figures 14-18). Only two associations are present at more than one sample site. The associations, by site, are as follows. Site 1 (Figure 14), *Rugosochonetes loganensis*-bryozoan; *Pugnoides ottumwa-Linoproductus tenuicostus;* and *Orthotetes kaskaskiensis*-crinoids. Site 3 (Figure 15), *Myalina-Rhipidomella-Punctospirifer-Girtyella; Composita sulcata-Caneyella; Inflatia inflatus-Eumetria-Centronella; Pugnoides ottumwa-Linoproductus tenuicostus-Schuchertella; Rugosochonetes loganensis-Orthotetes kaskaskiensis-Cleiothyridinia hirsuta;* and *Martinia-Aviculopecten-Paleoyoldia-Schizodus.* Site 7 (Figure 16), *Deltopecten-Lingula-Schizodus-Aviculopecten-Cleiothyridinia hirsuta; Myalina-Composita sulcata; Allorisma-Inflatia inflatus;* and *Orthotetes kaskaskiensis-Schuchertella;* Site 8 (Figure 17), *Pugnoides ottumwa-Deltopecten, Composita sulcata-Inflatia inflatus-Punctospirifer-Martinia; Lingula-Allorisma-Paleoyoldia; Rugosochonetes loganensis-Cleiothyridinia hirsuta-Orthotetes kaskaskiensis*-crinoids. Site 14 (Figure 18), crinoids-*Echinoconchus alternatus; Composita sulcata-Streptacis-Parallelodon; Paleoyoldia-Schuchertella-Straporallus-Streblopteria-Orthotetes kaskaskiensis-Inflatia inflatus.*

The Brachiopod-Peleoypod Zone is dominated by low filter-feeders, brachiopods, followed by less abundant, deep-infaunal deposit-feeders, pelecypods. The absence of high filter-feeders may be the result of an excess of suspended mud and silt-size particles in the water which would have clogged their feeding mechanism.

UNIT #2 Site #1 Dry Lake

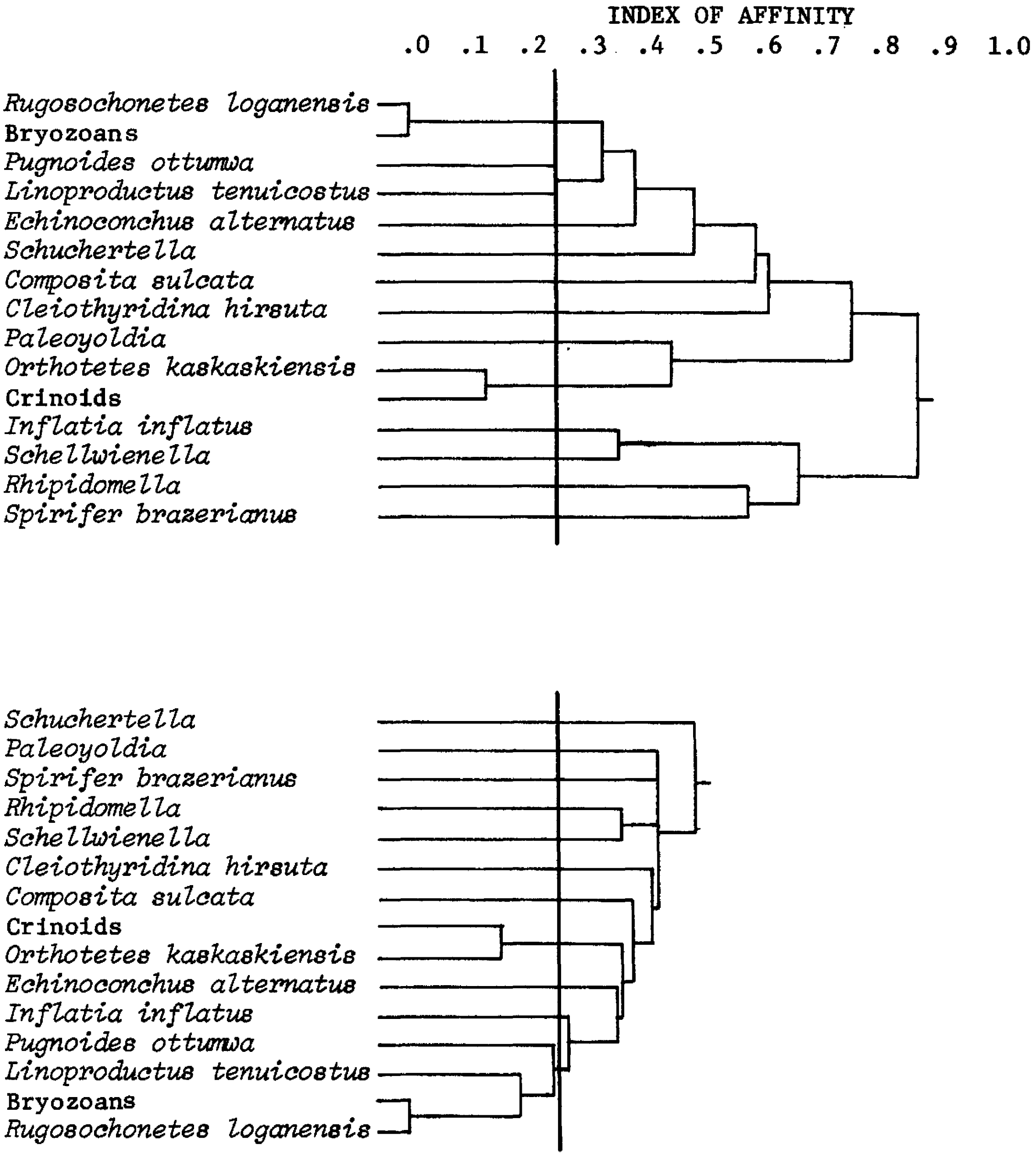


Figure 14. Dendogram of faunal associations at sample site 1 in Unit 2, the Long Trail Shale. Upper dendogram by average linkage and lower dendogram by single linkage. Clusters considered to be significant appear to the left of the .25 value for the index of affinity.

UNIT #2 Site #3 Dry Lake

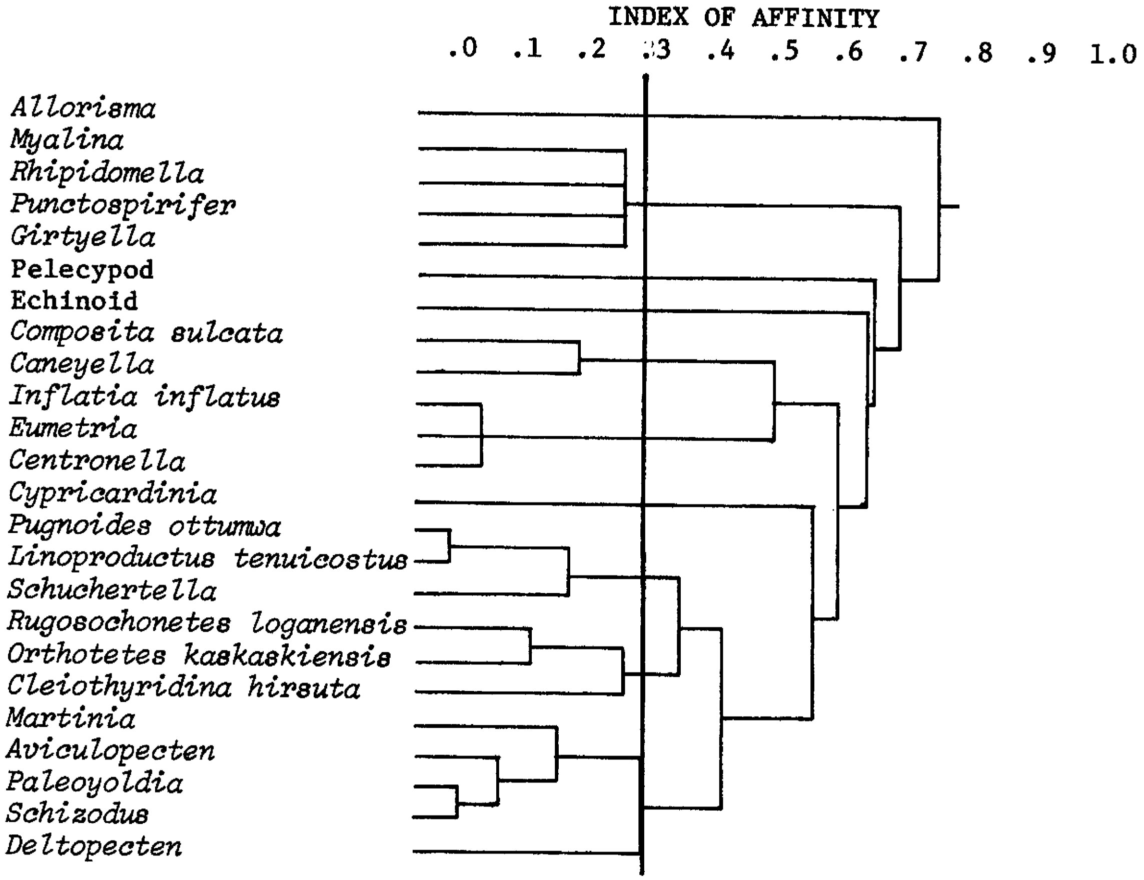


Figure 15. Dendogram of faunal associations at sample site 3 in Unit 2, the Long Trail Shale, by average linkage. Clusters considered to be significant appear to the left of the .30 value for the index of affinity.

UNIT #2 Site #7 Dry Lake

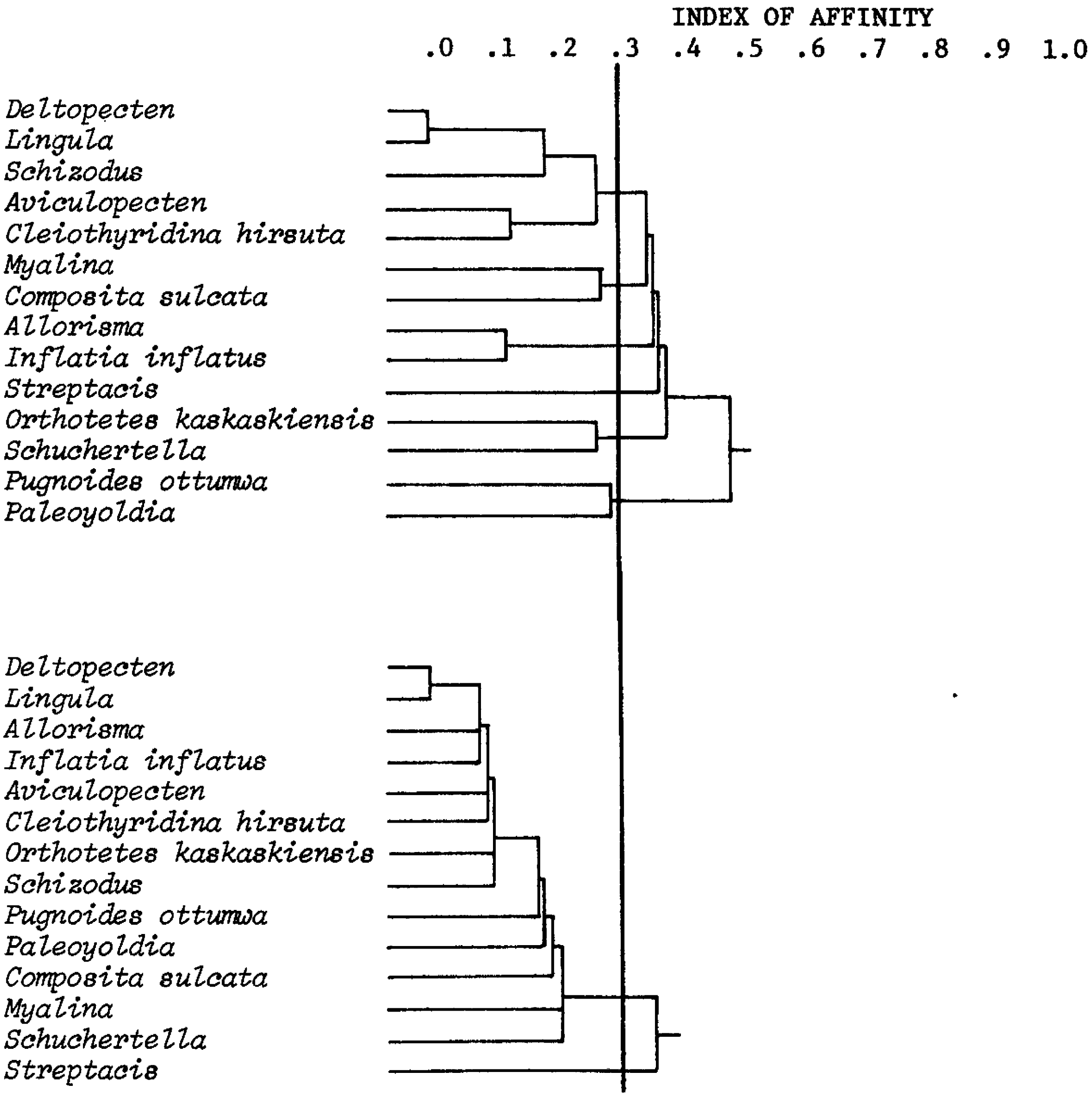


Figure 16. Dendogram of faunal associations at sample site 7 in Unit 2, the Long Trail Shale. Upper dendogram by average linkage and lower dendogram by single linkage. Clusters considered to be significant appear to the left of the .30 value for the index of affinity.

UNIT #2   Site #8   Dry Lake

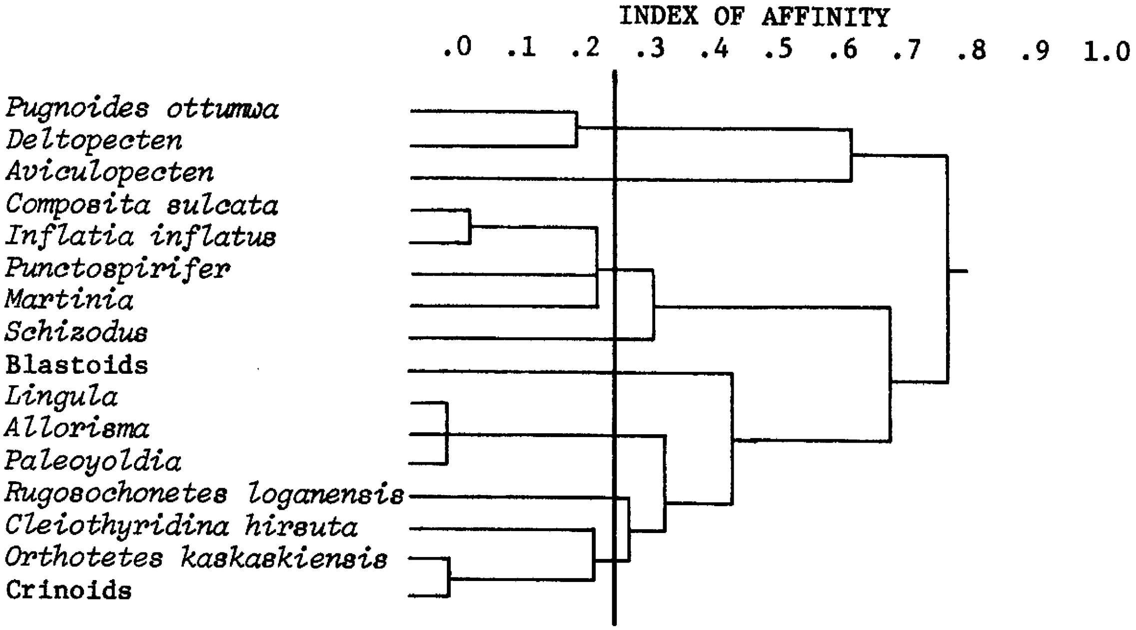


Figure 17. Dendogram of faunal associations at sample site 8 in Unit 2, the Long Trail Shale, by average linkage. Clusters considered to be significant appear to the left of the .25 value for the index of affinity.

UNIT #2 Site #14 Dry Lake

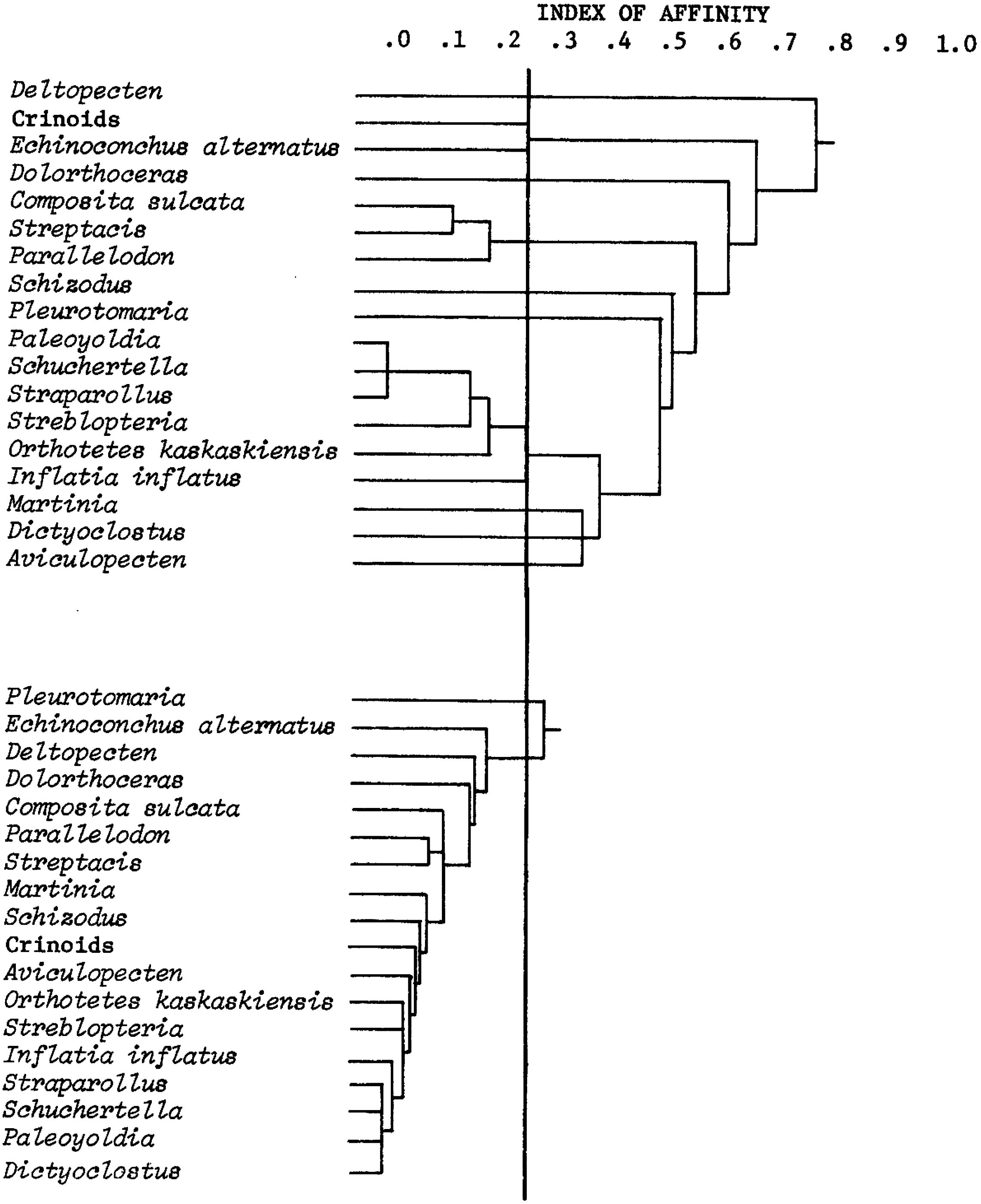


Figure 18. Dendogram of faunal associations at sample site 14 in Unit 2, the Long Trail Shale. Upper dendogram by average linkage and the lower dendogram by single linkage. Clusters considered to be significant appear to be left of the .25 value for the index of affinity.

Coral-Cephalopod Zone. Observations within this zone suggest a sparsely populated interval with no apparent faunal associations. Parks (1951, p. 183) listed four brachiopods at Dry Lake from the zone between his *Lithostrotion whitneyi-Faberophyllum leathamense* Zone and his *Caninia* Zone.

Caninia Zone. The solitary rugose coral *Caninia* is most abundant in this zone. However, no marked associations with other taxa are noted. Two associations are suggested by the dendograms of faunal associations (Figure 19). Two associations are *Turbophyllum*-crinoids-*Spirifer brazerianus;* and *Eumorphoceras-Composita sulcata.* The zone is dominated by filter-feeding taxa. The *Turbophyllum*-crinoid-*Spirifer brazerianus* association is a good example of the trophic-level model discussed by Walker (1972).

Rugosochonetes-Orthotetes Zone. This zone is similar in many ways to the Brachiopod-Pelecypod Zone of the Long Trail Shale. There is an abundance of variable faunal associations (Figures 20 and 21). The dominant organisms are the low filter-feeders, brachiopods, followed in abundance by the deep-infaunal, deposit-feeding, pelecypods. The associations at sample site 9 (Figure 20) are: *Eumetria-Inflatia inflatus; Orbiculoidea-Leptodesma-Aviculopecten-Streptorhynchus; Leiorhynchus-Bellerophon-Composita sulcata; Dielasma-Leda; Schuchertella-Schizodus;* and *Rugosochonetes loganensis-Orthotetes kaskaskiensis-Paleoyoldia.* The associations at sample site 12 (Figure 21) are: *Schuchertella-Cleiothyridina; Orthotetes kaskaskiensis-Paleoyoldia;* and *Streptorhynchus-Rugosochonetes loganensis.*

UNIT #3 Site #5 Dry Lake

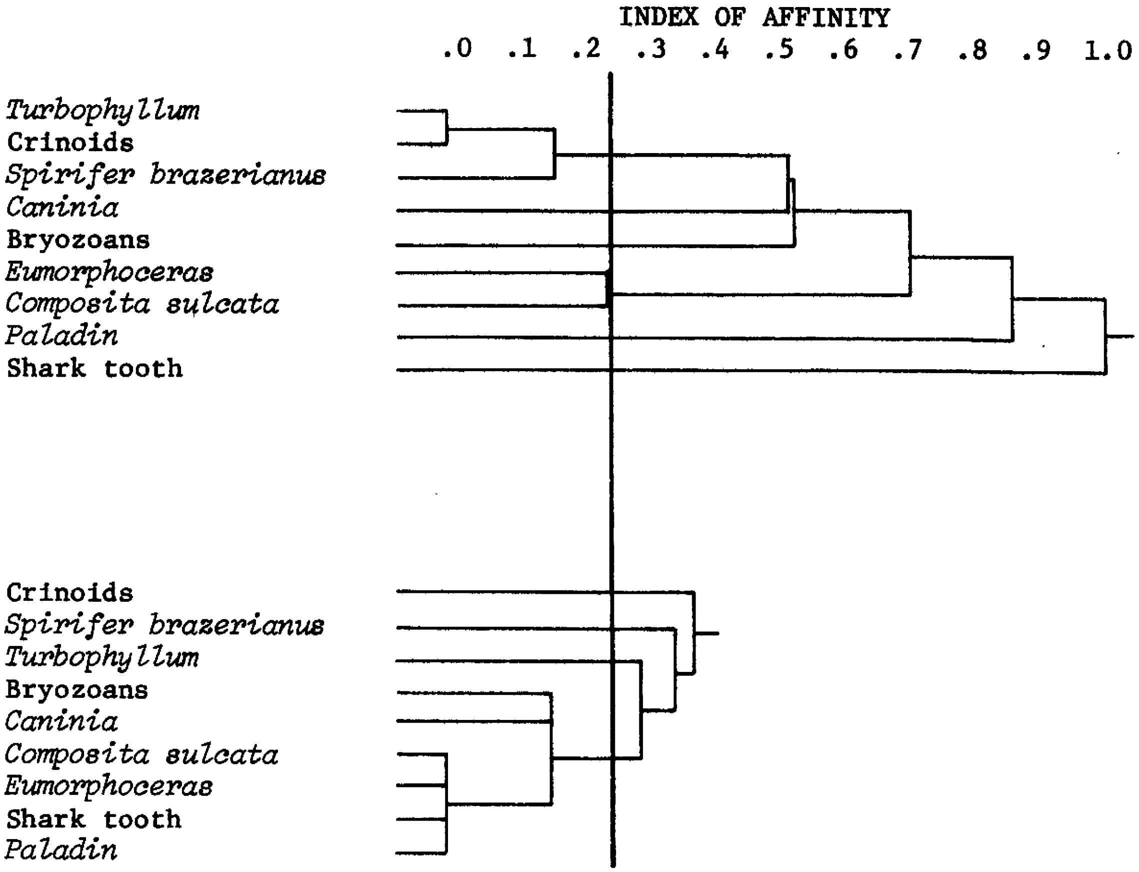


Figure 19. Dendogram of faunal associations at sample site 5 in Unit 3, upper Great Blue. Upper dendogram by average linkage and lower dendogram by single linkage. Clusters considered to be significant appear to the left of the .25 value for the index of affinity.

UNIT #3 Site #9 Dry Lake

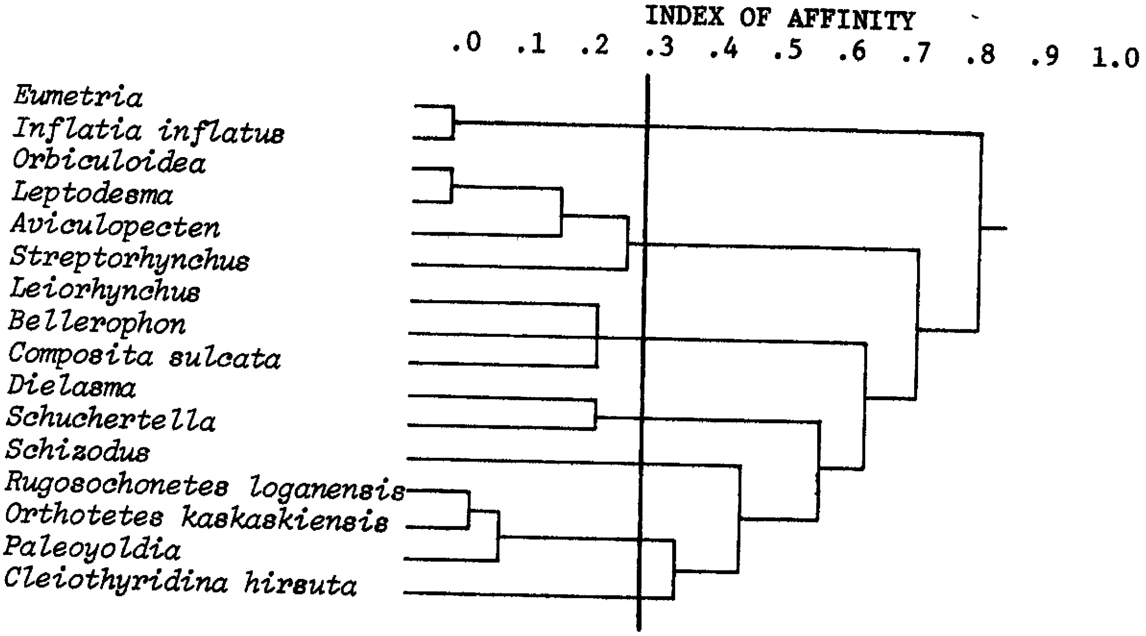


Figure 20. Dendogram of faunal associations at sample site 9 in Unit 3, upper Great Blue, by average linkage. Clusters considered to be significant appear to the left of the .30 value for the index of affinity.

UNIT #3 Site #12 Dry Lake

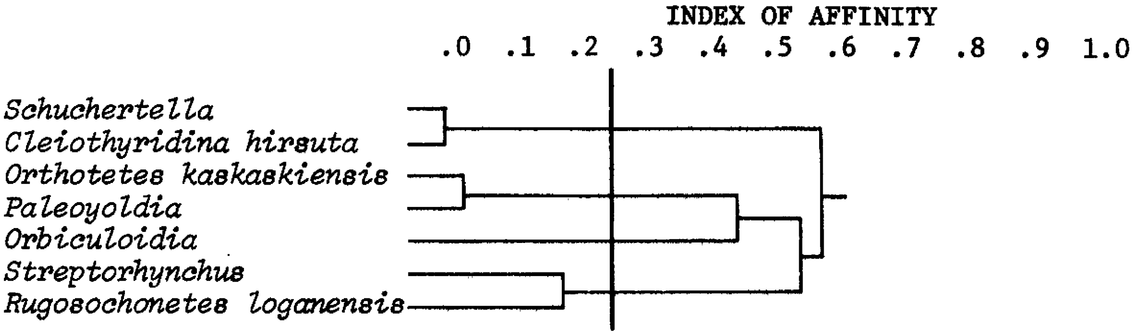


Figure 21. Dendogram of faunal associations at sample site 12 in Unit 3, upper Great Blue, by average linkage. Clusters considered to be significant appear to the left of the .25 value for the index of affinity.

Rugosochonetes-Paladin Zone. This zone is named for the most abundant taxon and the presence of the trilobite *Paladin*, which is not found in the rest of the section. The associations in the zone include *Martinia-Straparollus; Echinoconchus alternatus-Cleiothyridinia hirsuta;* crinoids-*Rugosochonetes loganensis*-bryozoans at sample site 11 (Figure 22) and bryozoans-crinoids-blastoids-*Paladin* at sample site 16 (Figure 23).

Crinoid-Bryozoan Zone. Fauna of this zone are represnted by the high percentage of debris of fenestellid bryozoans and crinoid columnals and little else. The zone is dominated by taxa of the very high filter-feeder trophic-level.

UNIT #3 Site #11 Dry Lake

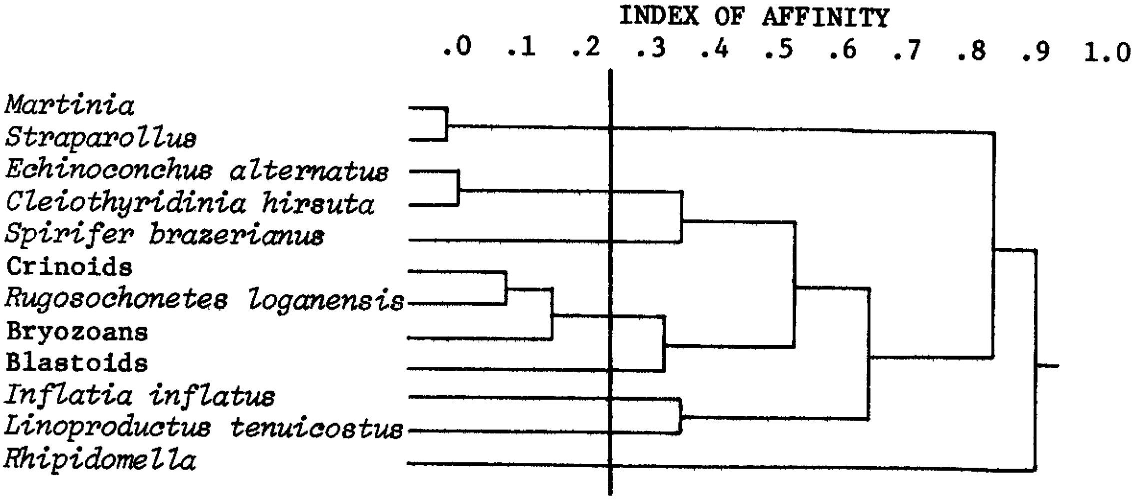


Figure 22. Dendogram of faunal associations at sample site 11 in Unit 3, upper Great Blue, by average linkage. Clusters considered to be significant appear to the left of the .25 value for the index of affinity.

UNIT #3 Site #16 Dry Lake

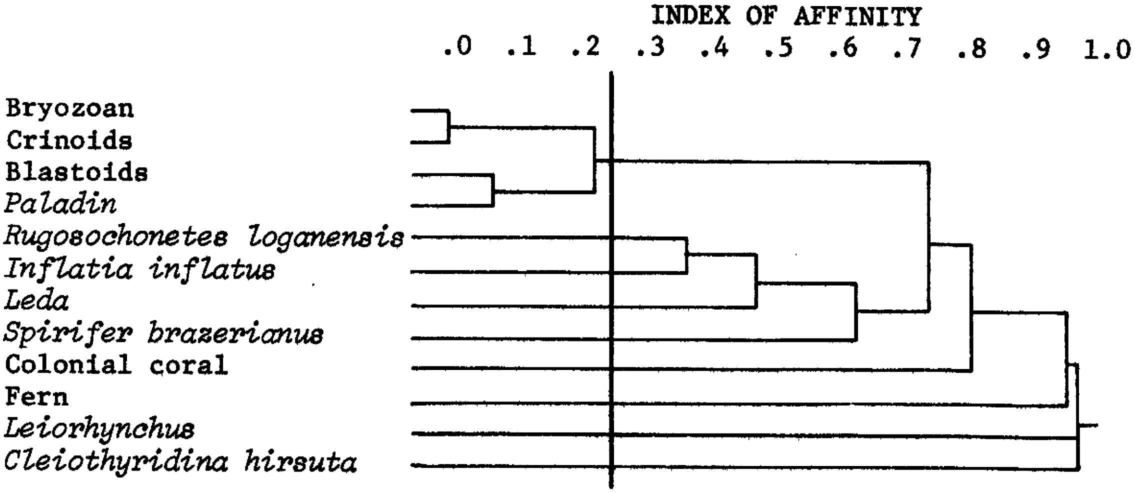


Figure 23. Dendogram of faunal associations at sample site 16 in Unit 3, upper Great Blue, by average linkage. Clusters considered to be significant appear to the left of the .25 value for the index of affinity.

PALEOGEOGRAPHY

The general paleogeography of the northern Cordillera has been described by Rose (1976) and by Sando, Mamet, and Dutro (1976). To the east of the study area is the stable craton and a positive area. To the west are the shallow shelf and barrier reef. Still farther west is a deep trough and the Antler positive area. These features trend north-south. Three basins occupied the area of the shelf. To the north were the Big Snowy-Williston Basin and the Wyoming Basin and to the south was the Uinta Basin.

Deposition of carbonates on the shelf is described by Rose (1976) and by Sando (1976). The environments within the basins are controlled to a large degree by the paleogeography of the area. Rose (1976, p. 459) described shelf carbonates of the Great Blue as the upper depositional complex. This "complex reflects sedimentation in a relatively narrow, rapidly subsiding miogeosyncline confined between an emergent craton on the east and the active Antler orogenic belt on the west" (Rose, 1976, p. 459). Sando (1976, p. 138) indicated that the miogeosyncline included shelf and deeper water trough sedimentation of carbonates and terriginous detritus. The term miogeosyncline refers to a tectonic element of greater instability than that of the craton. The Cache Valley area appears to be on the outer, deeper water margin of the Wyoming Basin. The relatively thick sequence of limestone suggests deposition along the eastern edge of the tectonically more active miogeosyncline.

PALEOCURRENTS

The Effect of Unidirectional Current on the Orientation of Rugose Corals

Procedure

This study compared the responses of several forms of rugose coralla to a unidirectional current. The results are used to aid the reconstruction of the paleocurrents of the shallow marine shelf in northern Utah, during late Mississippian time.

Five different coral forms were modeled (Figure 24), including: (A) a straight form, using *Streptelasma rusticum* Billings (Ordovician), (B) a small, curved form, and (C) a large, curved form using *Faberophyllum leathamense Brazer* (Mississippian). Two geniculate forms were modeled, including (D) a form which had a point of geniculation at the apical end, and (E) a form which had a point of geniculation about midway along the length axis. All the models were cast from a mixture of plaster of Paris (specific gravity = 2.32) and powdered galena (specific gravity = 7.60) in a ratio of 90.65 g to 9.35 g to approximate the density of calcite (2.81 g/cc). To recreate the void left by the decomposed tissue the calical areas were hollowed out with a knife when the models were dry.

The models were painted with red or yellow enamel paint to seal them and to increase their visibility when they were submerged in the flume.

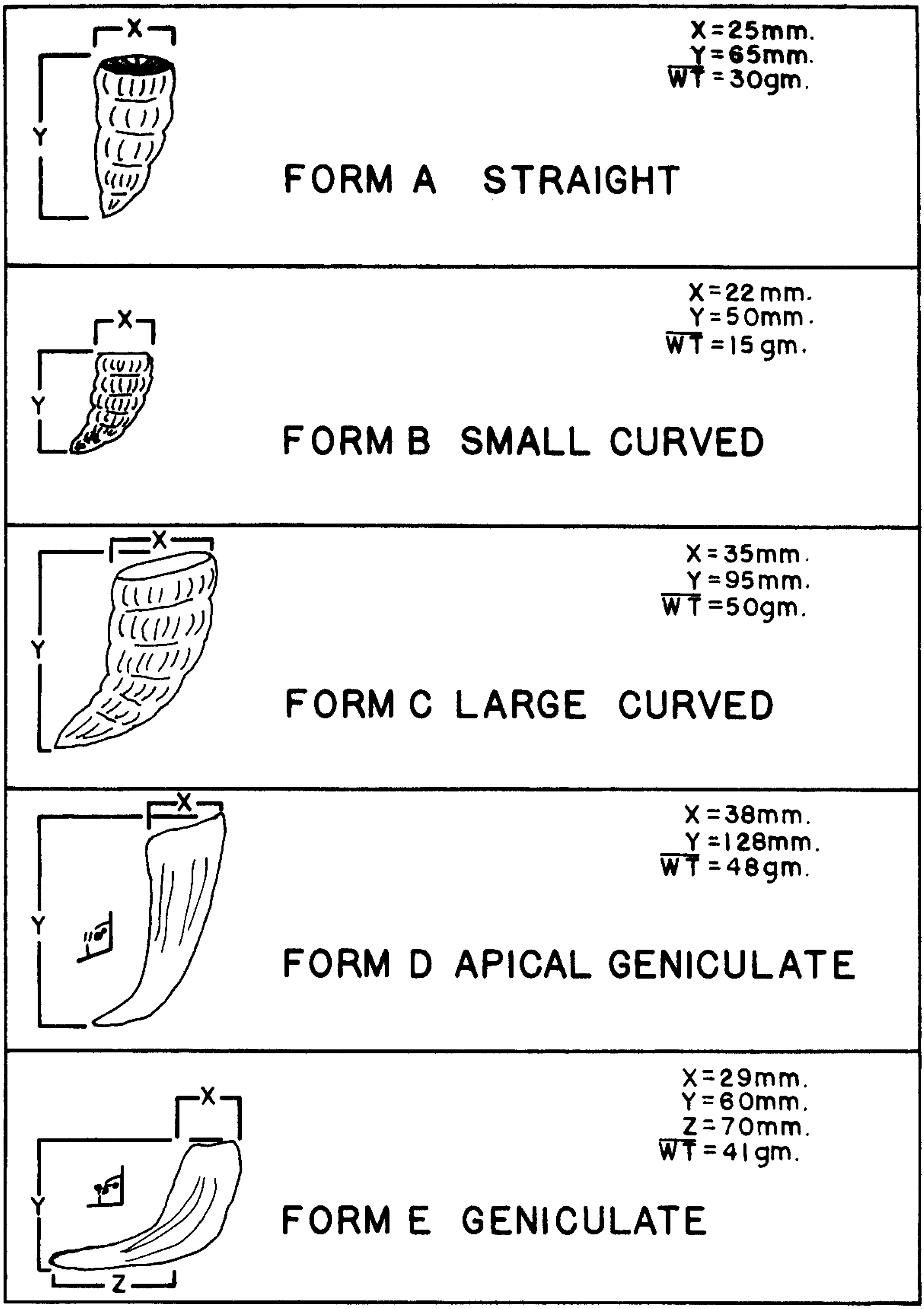


Figure 24. Model-forms used in the flume experiment.

The experiment was conducted in a flume 60 cm by 60 cm in cross-section and 5 m in length. A weir was used to control the water depth, which was maintained at approximately 20 cm. The substrate consisted of very fine grained ($m_z = +3.20\phi$), moderately well-sorted ($\alpha_I = 0.96$) sand, 75 mm to 100 mm thick.

Hubbard (1970, p. 203) indicated the ideal position for living caninioid corals was perpendicular to the sediment with all of the calice and not more than one third of the corallum exposed above the sediment-water interface. The geniculate forms were similarly positioned and the apical end oriented downstream. For each run four to six models of the indicated form were positioned in an upright life orientation, 3 to 5 cm deep, or toppled on the substrate. Positioning took place with the water standing at 15 cm. A gentle current was maintained to clear the suspended material. The original orientations were recorded and the current increased to about 1 to 1.5 m/sec, with a depth of approximately 20 cm, and maintained until the models had reoriented or had been buried. The flow was then stopped, and the water was allowed to drain. The new orientations were then measured with a hand compass, and a photograph was taken. The substrate was then leveled, the flume filled for the next run, and the specimens reoriented. A total of 24 runs was made.

Results

The substrate conditions, original orientations, coral form and final orientation for each run appear in Table 2. A run is considered to be that portion of the experiment where one or more of the

Table 2. Flume experiment conditions and results

Run	Form (see Fig.24)	Substrate surface	Original orientation	Movement and final orientation
1	A	Flat	Life (length-axis perpendicular or oblique to the substrate, and partially imbedded)	The models were scoured on the upstream side and supported on the downstream side causing a rotation and toppling into the current. 75% of the final orientations were perpendicular to the current and trapped in ripple troughs. (Figure 25)
2	A	Flat	Calice inclined upstream	Results were the same as Run 1.
3	A	Flat	Calice inclined downstream	Toppling similar to that in Run 1 occurred. Final orientations were approximately parallel to the current, with the calice pointing downstream.
4	A	Flat	Toppled-random	83% of the models rotated into a final orientation perpendicular to the current.
5	A	Flat	Toppled-calice pointing downstream	This is a stable orientation with no movement.
6	A	Flat	Toppled-calice pointing upstream	60% of the models rotated to a final orientation perpendicular to the current. One model rotated 180° and one remained static.
7	B	Uneven	Life	Due to the relief the small models were not affected as the force of the current was deflected over them.

Table 2. Continued

Run	Form (see Fig.24)	Substrate surface	Original orientation	Movement and final orientation
8	C	Uneven	Life	This is a stable orientation. The ripples deflect the current over the models.
9	C	Uneven	Life	Due to reduced relief of substrate, 3 of the 5 models toppled and reoriented approximately perpendicular to the current.
10	C	Flat	Life	4 of the 5 models toppled and reoriented at an angle into the current with the calice upstream. This result may be due to a boundary effect along the side of the flume.
11	C	Flat	Toppled-random	4 of the 5 models reoriented approximately perpendicular to the current.
12	C	Flat	Toppled-calice pointing downstream, apex curving away from sediment surface	All of the models rotated to a final orientation perpendicular to the current. Due to the rapid rate of reorientation this is considered to be an unstable position.
13	C	Flat	Toppled-calice pointing downstream, apex curving into substrate	All of the models rolled to their sides but did not reorient the length axis.
14	C	Flat	Toppled-calice pointing upstream	No movement occurred. This is a stable position.)
15	E	Flat	Life	This is a stable orientation for short duration of intense currents. A longer run may have induced toppling as in one model.

Table 2. Continued

Run	Form (see Fig.24)	Substrate surface	Original orientation	Movement and final orientation
16	E	Flat	Toppled-random	This form tends to slide and rotate into an orientation with the angle of the geniculation pointed upstream.
17	B	Flat	Toppled-random	After extended exposure (30 min.) to the current 60% of the models reoriented perpendicular to the current. The other 40% reoriented parallel to the current with the calice pointing downstream.
18	D	Flat	Life	80% of these specimens toppled and reoriented perpendicular to the current.
19	D	Falt	Toppled-calice pointing upstream	80% of these specimens rotated about the apical end and reoriented perpendicular to the current. One model remained stationary.
20	D	Flat	Toppled-calice pointing downstream, apex away from the substrate	The models rotated about the calical end until perpendicular to the current.
21	D	Flat	Toppled-calice pointing downstream, apex curving into the substrate	The models toppled or rolled to their sides then begin to rotate.
22	A	Flat	Toppled-random	Under strong wave action the models oriented parallel to the wave and ripple crests.

Table 2. Continued

Run	Form (see Fig.24)	Substrate surface	Original orientation	Movement and final orientation
23	A	Flat	Toppled-random	The wave action was too weak to cause reorientation.
24	A,B,C, D,E,	Flat hard	Toppled-random	This run shows the relative stable orientations of the various forms on a hard, low friction substrate with moderate-to high velocity of currents. All forms rotated to an apex upstream position (Figure 26).

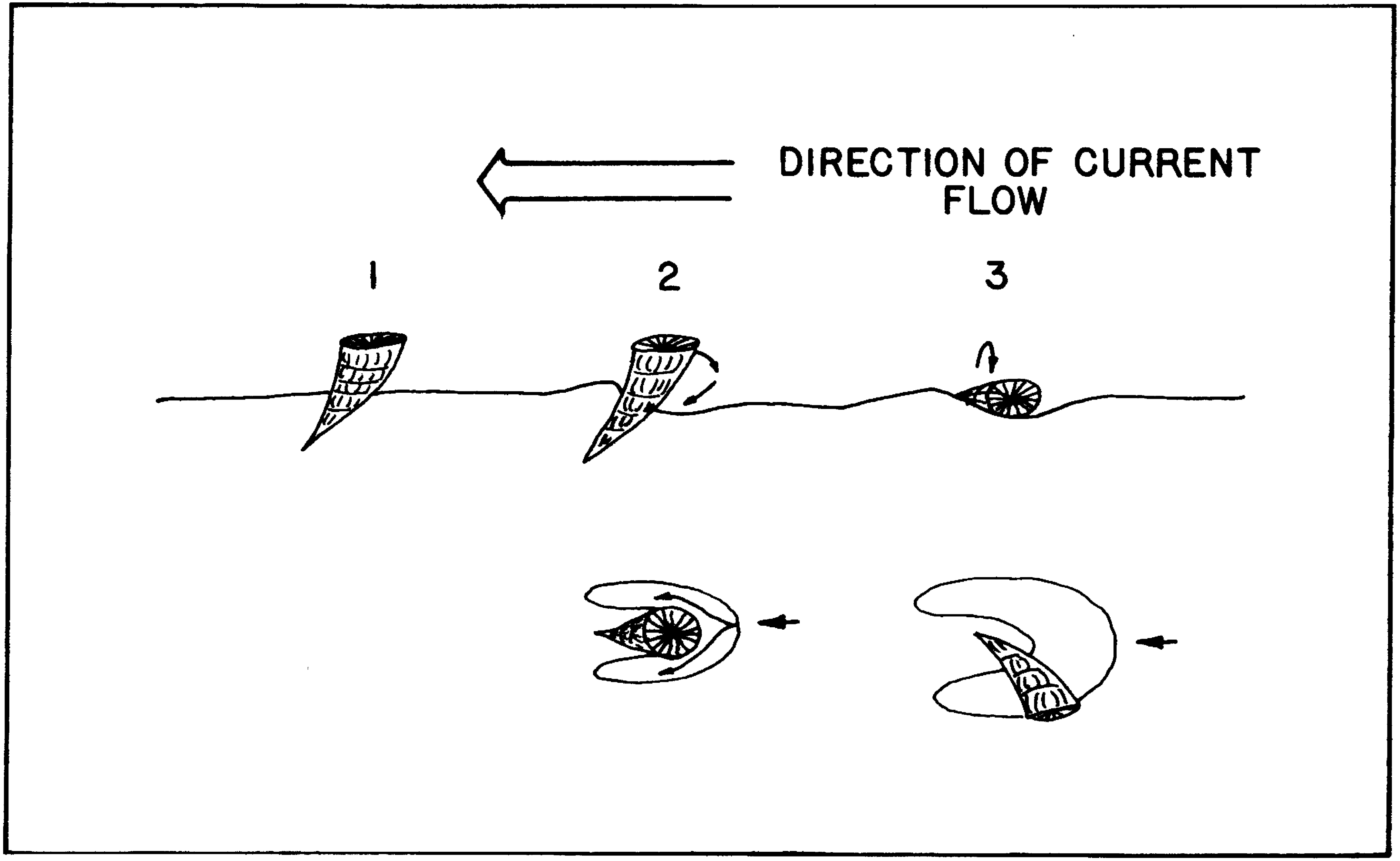


Figure 25. Current scouring of substrate and rotational toppling of the corallum.

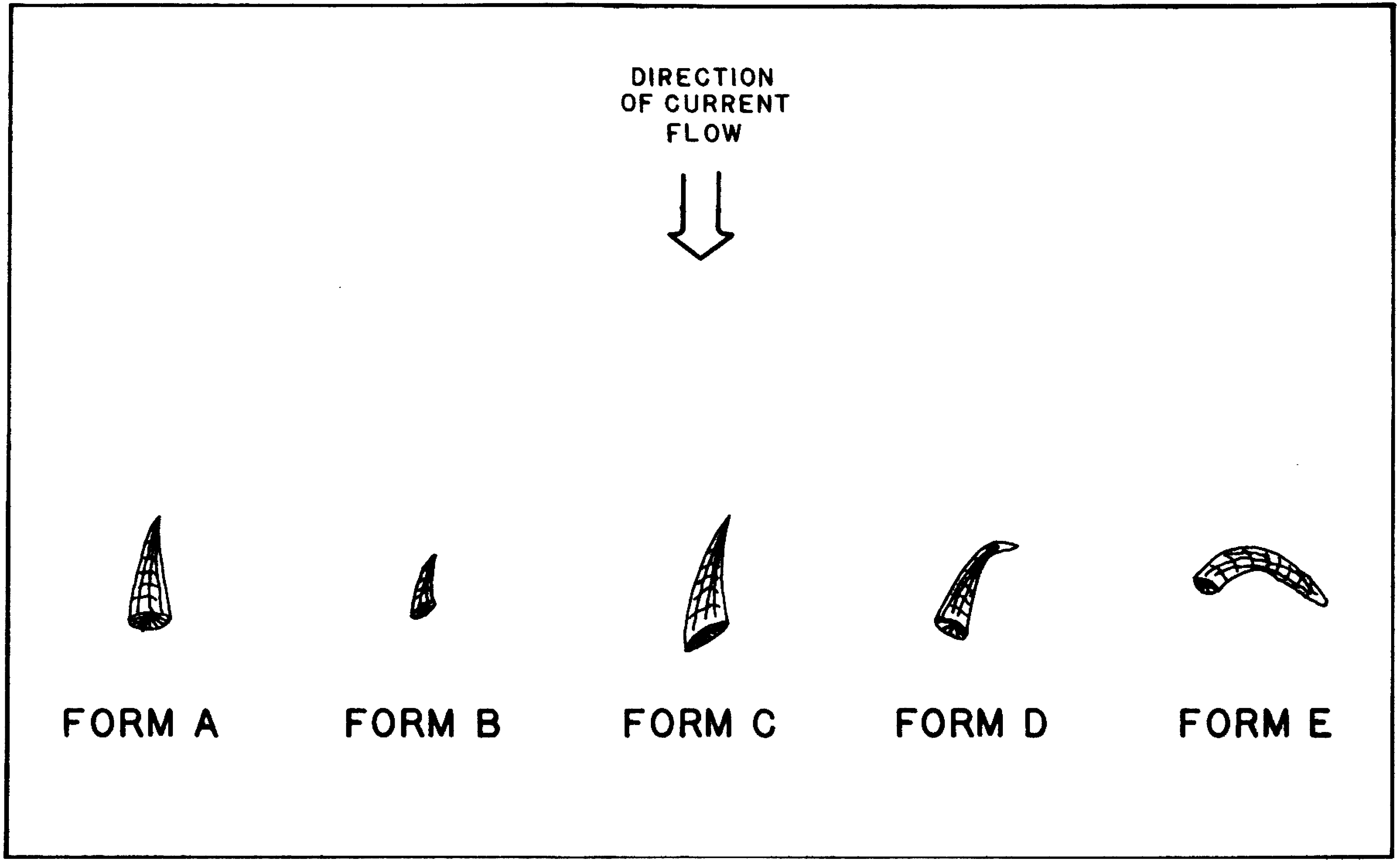


Figure 26. Stable orientations on a hard substrate under moderate current velocities.

conditions of substrate, original orientation, coral form is altered and then subjected to the current.

On runs with the models starting in the life orientation, scouring of the substrate occurred upstream and on both sides of the model. The models toppled toward the current and down into the scour depression (see Figure 25). Once toppled, the models would commonly rotate either left or right until perpendicular to the current where they stabilized in the troughs of ripples and were subsequently buried. On runs starting from the toppled position in soft substrate the models would commonly rotate until perpendicular to the current. Stabilization and burial in the troughs of ripples followed.

The physical conditions of this study differ from the conditions found in the natural environment. Rugose corals are found in lithotopes of limestone, calcareous or silty shale or marl (Wells, 1957, p. 773). Forms B and C were modeled after a horn coral collected from a substrate which was a crinoidal limestone with a fine carbonate (micritic?) matrix. Form E was modeled after forms found in a fine carbonate mud (W. A. McClellan, 1974, written communication). In the natural environment more than one type of current and also waves are likely to affect the growth and orientation of corals.

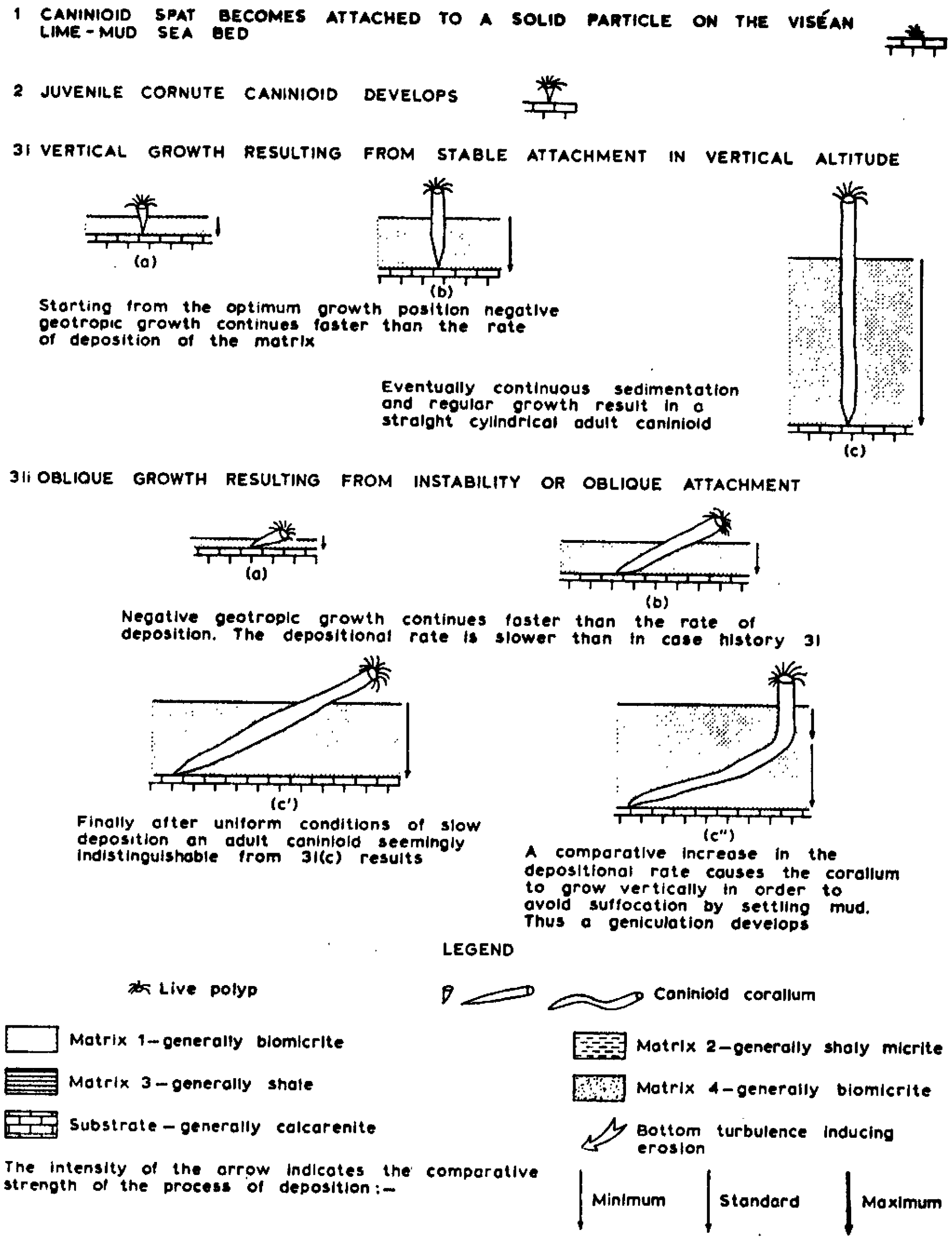
The environments inhabited by these coral forms would have been subjected to a variety of current directions instead of a strictly unidirectional current as used in the experiment. Wave action would have added to the forces applied to the corals and increased the amount of agitation. Consequently, the orientation of corals reflects the cumulative effects of the multi-directional currents, and this situation may mask the influence of any one particular current or wave direction. Furthermore, the current velocities used for this experiment exceed those generally encountered in a shallow shelf environment. The range of normal tidal currents is 50 to 100 cm/sec (Kirby-Smith, 1973, p. 16). However, large oceanic currents, the Gulf Stream for example, flow at a rate between 200 and 300 cm/sec (Ross, 1970, p. 217). Kissling (1965), p. 601) estimated current velocities of 4 knots (200 cm/sec) in the channel between Florida Bay and the Florida Straits produced by tidal exchange. Events such as hurricanes, tsunamies, and rip currents produce very high current velocities for short periods of time. In the experiment the higher velocities were used to shorten the duration of the experiment. The runs did not exceed 30 minutes a piece. The experiment permits some generalizations regarding the final position of Mississippian rugose coralla when subjected to currents.

Conclusions

From the results of this experiment, it was found that the models oriented as anticipated. The literature on experiment of the orientation of objects by currents revealed that elongated forms commonly orient perpendicular to the current. Twenhofel (1950, p. 205) stated that particles come to rest with their long axes perpendicular to the direction of the current. The reactions of the models during run 24 compare favorably with the orientation observed by Nagle (1967). Nagle observed in his study of the orientation of shells by waves and currents that the shells on a slate substrate in a flume oriented parallel to the direction of the current. According to Brenchly and Newell (1970, p. 185) most elongate objects take up a preferred, final orientation with the longest axes across the current. Orientations to the current conform with the results of scouring obtained by Abbott (1974, pp. 20-21) whose experiments illustrated the scouring, toppling, and rotation of the corals in troughs of ripples. Brenchly and Newell (1970, p. 218) stated that, "if fossil unidirectional orientations occur in transported assemblages, then a position with the center of gravity into the current is perhaps the most likely." In rugose corals the center of gravity presumably would be nearer to the apical end due to the hollow calyx and possible buoyance derived from the decaying tissue. The hydraulic stabilities of the various forms may be seen in the results of run 24 (Figure 26). The conical forms orient parallel to the current with the calice pointing downstream.

Corals prefer to maintain a life orientation where the length axis of the organism is vertical and the calice is propped above the substrate to avoid sediment clogging the feeding mechanisms. If anything should happen to alter this position, such as toppling, the organism redirects its growth with a combination phototropic response (growth directed towards a light source) and a negative geotropic response (growth directed away from the pull of gravity) to attain the original life orientation. Hubbard (1970, p. 203) suggested that the response to toppling is more a negative geotropic response than anything else. If the organism is successful, geniculation, a rapid change in the direction of growth, or curving, a gradual change in the direction of growth, will result. If the organism was not successful in the redirection of growth, the organism died (Figure 27).

As a result of observations on the reactions of the various forms to different current velocities, it is concluded that in assemblages dominated by any one of these forms, the dominant external morphology was probably the product of the current regime. The straight forms would have occupied areas of low current velocity where there was little toppling and relatively little movement of the substrate. Forms with apical geniculation would have occupied areas similar to the straight forms. Corals toppled as juveniles continued to grow. As the effect of the negative geotropic response, the corralum curves rapidly to grow upright. The early geniculation will appear at the apical end of a mature or older corallum. The flume study showed that forms with apical geniculations are more resistant to toppling by current action than the other forms. Apically geniculate forms may also have occupied areas of a more erratic current regime. Curved forms may have occupied areas of modest to high current where scouring resulted in a continuous rotation into the current, without toppling, and with continued growth. Forms with the geniculation midway along the length axis (Form E, Figure 24) probably also inhabited areas of high current velocities. Relief in the substrate protected the coral until growth exceeded the relief and exposed the coral to the current of the coral. Toppling ensued. The toppled coral was then protected from the current and would redirect growth perpendicular to the substrate (Hubbard, 1970, p. 205).



1 CANINIOID SPAT BECOMES ATTACHED TO A SOLID PARTICLE ON THE VISÉAN LIME-MUD SEA BED

2 JUVENILE CORNUTE CANINIOID DEVELOPS

3i VERTICAL GROWTH RESULTING FROM STABLE ATTACHMENT IN VERTICAL ALTITUDE

Starting from the optimum growth position negative geotropic growth continues faster than the rate of deposition of the matrix

Eventually continuous sedimentation and regular growth result in a straight cylindrical adult caninioid

3ii OBLIQUE GROWTH RESULTING FROM INSTABILITY OR OBLIQUE ATTACHMENT

Negative geotropic growth continues faster than the rate of deposition. The depositional rate is slower than in case history 3i

Finally after uniform conditions of slow deposition an adult caninioid seemingly indistinguishable from 3i(c) results

A comparative increase in the depositional rate causes the corallum to grow vertically in order to avoid suffocation by settling mud. Thus a geniculation develops

LEGEND

Live polyp

Caninioid corallum

Matrix 1—generally biomicrite

Matrix 2—generally shaly micrite

Matrix 3—generally shale

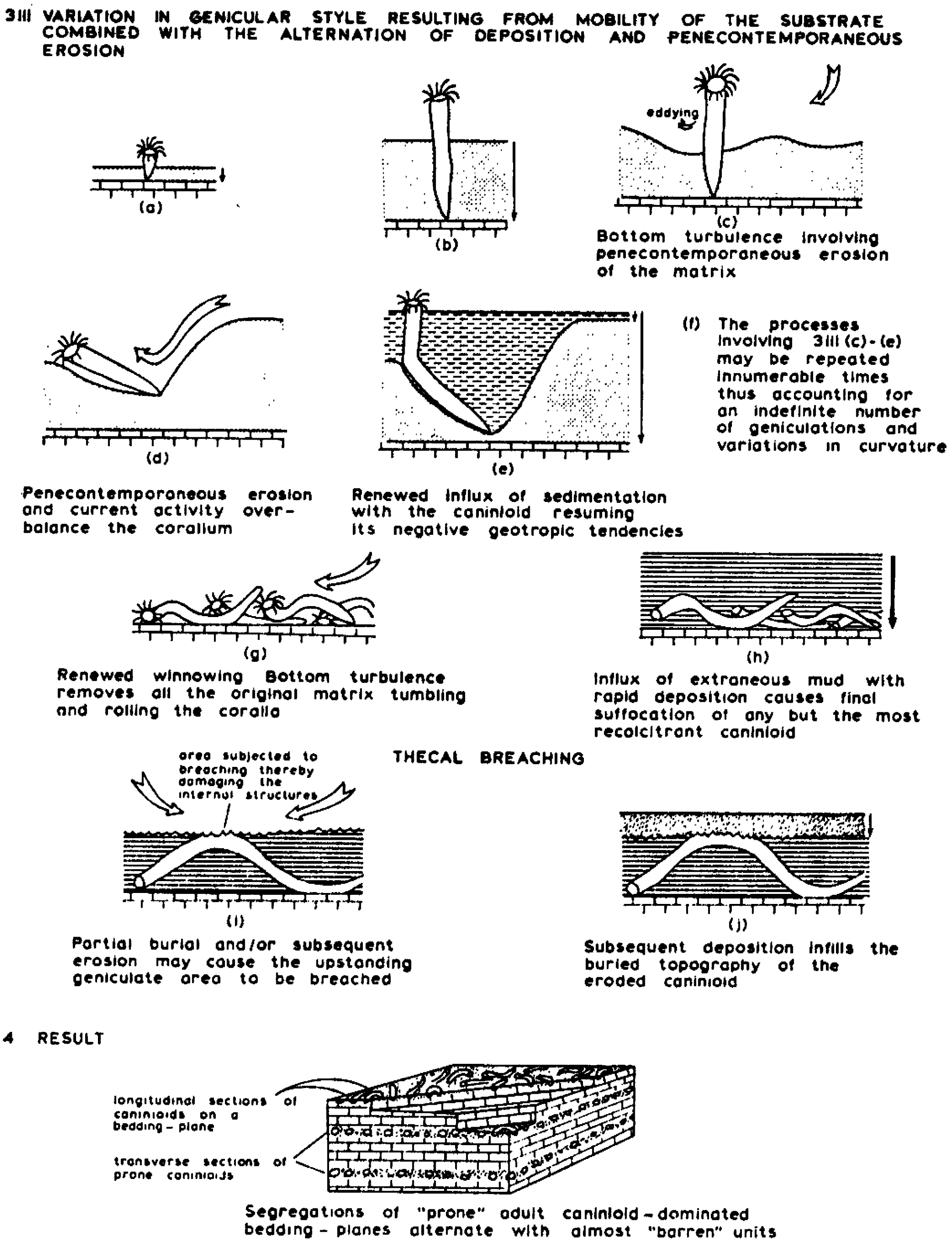
Matrix 4—generally biomicrite

Substrate—generally calcarenite

Bottom turbulence inducing erosion

The intensity of the arrow indicates the comparative strength of the process of deposition:—

Figure 27. Diagram showing the possible origins of the various caninioid growth forms (from Hubbard, 1970, pp. 206-207).



(c) Bottom turbulence involving penecontemporaneous erosion of the matrix

(d) Penecontemporaneous erosion and current activity over-balance the corallum

(e) Renewed influx of sedimentation with the caninioid resuming its negative geotropic tendencies

(f) The processes involving 3iii (c)-(e) may be repeated innumerable times thus accounting for an indefinite number of geniculations and variations in curvature

(g) Renewed winnowing Bottom turbulence removes all the original matrix tumbling and rolling the coralla

(h) Influx of extraneous mud with rapid deposition causes final suffocation of any but the most recalcitrant caninioid

(i) Partial burial and/or subsequent erosion may cause the upstanding geniculate area to be breached

(j) Subsequent deposition infills the buried topography of the eroded caninioid

Segregations of "prone" adult caninioid - dominated bedding - planes alternate with almost "barren" units

Figure 27. Continued.

Paleocurrent Analysis

Methods

Study of the orientations of late Mississippian rugose corals in the Great Blue suggests current action was present in the study area at the time of deposition. Data collected were used to reconstruct the current regime, and to interpret the predominant current direction, type and strength.

Orientations and size measurements of rugose corals were made in the field at four locations (Figure 1). The coral populations studied are all in the lower Great Blue near the top of the *Lithostrotion-Turbophyllum* Zone. Measurements of the orientations of the toppled coralla were made on bedding-plane surfaces at the four locations.

Coral-strewn bedding-surfaces (Figure 28) in the Pisgah Hills are well exposed as the result of a road cut for U. S. Highway 89-91 through the unit (Figure 2). The resulting exposed area is approximately 300 meters long and 30 meters high, and includes a stratigraphic succession of beds 15 meters thick. At this location the orientations and sizes of 2,032 toppled and 1,428 upright coralla were measured. At the Beirdneau Peak location the orientations and sizes of 41 toppled and 6 upright coralla were measured. At the Logan Peak location the orientations and sizes of 146 toppled and 35 upright coralla were measured. At the East Fork Canyon location the orientations and sizes of 89 toppled and 32 upright coralla were measured (Figure 1).

Figure 28. Coral-strewn bedding surface in the *Lithostrotion-Turbophyllum* Zone of the lower Great Blue Limestone in the roadcut of U. S. Highway 89-91 at Dry Lake.

Orientations were made with a hand compass. The direction of the orientation was that of the apical end of the corallum. When the rose diagrams were plotted on the base map, an adjustment was made for the magnetic declination. The degree of precision of the compass orientations was such that compensation for the angle of dip of the bedding-planes when measuring the orientations was not necessary. At a 45° azimuth, where the error would be greatest, the adjustment would have been less than 3°. The data was plotted in sectors of 10°.

If a preferred orientation is present, it may be determined from the mean vector, or modes if multi-tailed, of the coralla and from this the dominant current direction, can be inferred. The relation of the orientation pattern of each location to one another may show a larger pattern. The original pattern of the currents can become confused by differential rotation during tectonic activity. The pattern of orientations of the coralla at any sample site would not be affected by tectonic activity. The coralla would all be moved or rotated the same amount and in the same direction. Most forms of tectonic activity would not affect the larger pattern of orientations between the various sample sites. The only form of tectonic movement that would alter this larger pattern would be thrust faulting with horizontal rotation of the thrust sheet if one or more of the locations were not on the rotated block. If all of the locations were on the thrust sheet the relationships of the various locations and the individual coralla within the locations is unchanged, but the larger pattern is altered with respect to true north.

Solitary rugose corals of the genus *Turbophyllum* accounted for 99.5 percent of the total measurements. Measurements of the orientations were also taken on sections of articulated crinoid columnals and the coralla of the phaceloid rugose coral *Lithostrotion*. The low number of articulated crinoid columnals measured, 24 specimens, makes an analysis of the orientations difficult. The results of the measurements of orientations of the rugose corals were plotted on four rose diagrams, one for each location (Figures 29-32). The rose diagrams were divided into sectors of ten degrees and the total specimens were plotted as a linear function along the radius. The diagrams were tested for goodness of fit applied to circular data (Tables 3-6) and it was determined that the orientation patterns of three locations were not random (Tables 3, 4, and 6). The test of the rose diagram for the Logan Peak location indicates the distribution is random (Table 5). The observations were entered into a computer program which converts degrees into sine and cosine values and computes the vector sine, vector cosine, radial deviation, mean vector and modal vector (Table 7).

Interpretations

The rose diagrams and the computer results show that the rugose coralla at the locations in the Great Blue exhibit preferred orientations. Mean vectors range from 111° 20' to 170° 22'. Modal vectors range from 155° to 175° (Table 7). The visual evidence of the rose diagrams is reinforced by the mean and modal vector orientations. The rose diagrams of the Beirdneau Peak and Logan Peak locations exhibit bimodal distribution patterns with the stronger component in the southeast quadrant and the weaker component in the northwest quadrant.

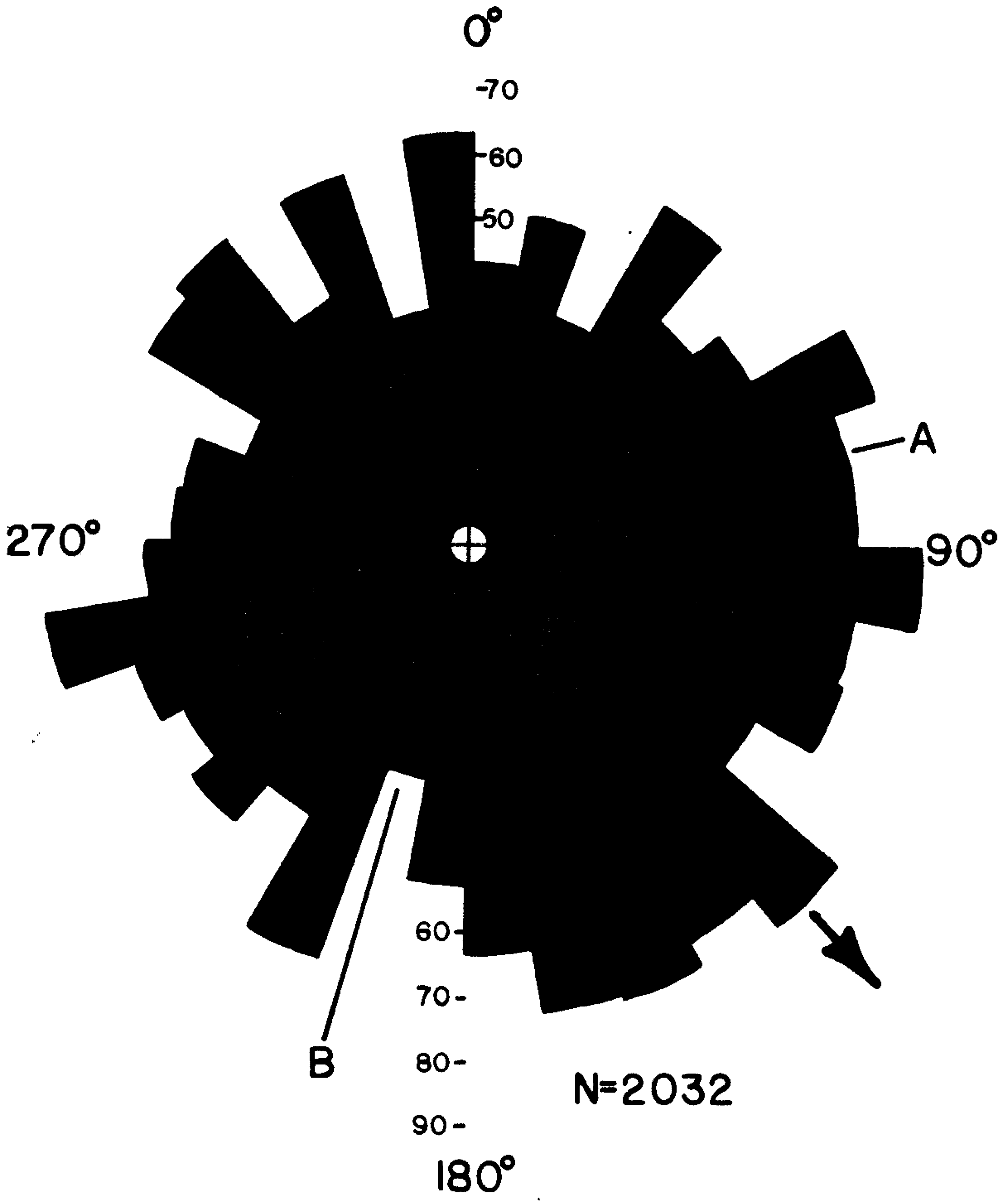


Figure 29. Rose diagram of the orientations of the apical ends of recumbent rugose coralla from the *Lithostrotion-Turbophyllum* Zone of the lower Great Blue at Dry Lake. The arrow indicates the direction of the mean vector, and A-B indicates the radial deviation. The numbers and associated tick marks indicate the radii of successive unit circles.

Table 3. Test for goodness of fit for data in a circle for the orientations of the apical ends of rugose coralla at the Dry Lake location

---

The test statistic is:

$$X^2 = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i$$

O is the observed frequency in a sector and E is the expected frequency in a sector, determined by the total observations divided by the number of sectors.

$$E = 2{,}032/8 = 254$$

Sector	
1	$(215-254)^2/254=5.988$
2	$(267-254)^2/254=0.665$
3	$(300-254)^2/254=8.331$
4	$(301-254)^2/254=8.697$
5	$(241-254)^2/254=0.665$
6	$(251-254)^2/254=0.035$
7	$(222-254)^2/254=4.031$
8	$(235-254)^2/254=1.421$
	29.833

For seven degrees of freedom (N-1) the critical X^2 value at α=.001 is 24.3221. Calculated value 29.833, is greater than 24.322 and the distribution is <u>not random</u>.

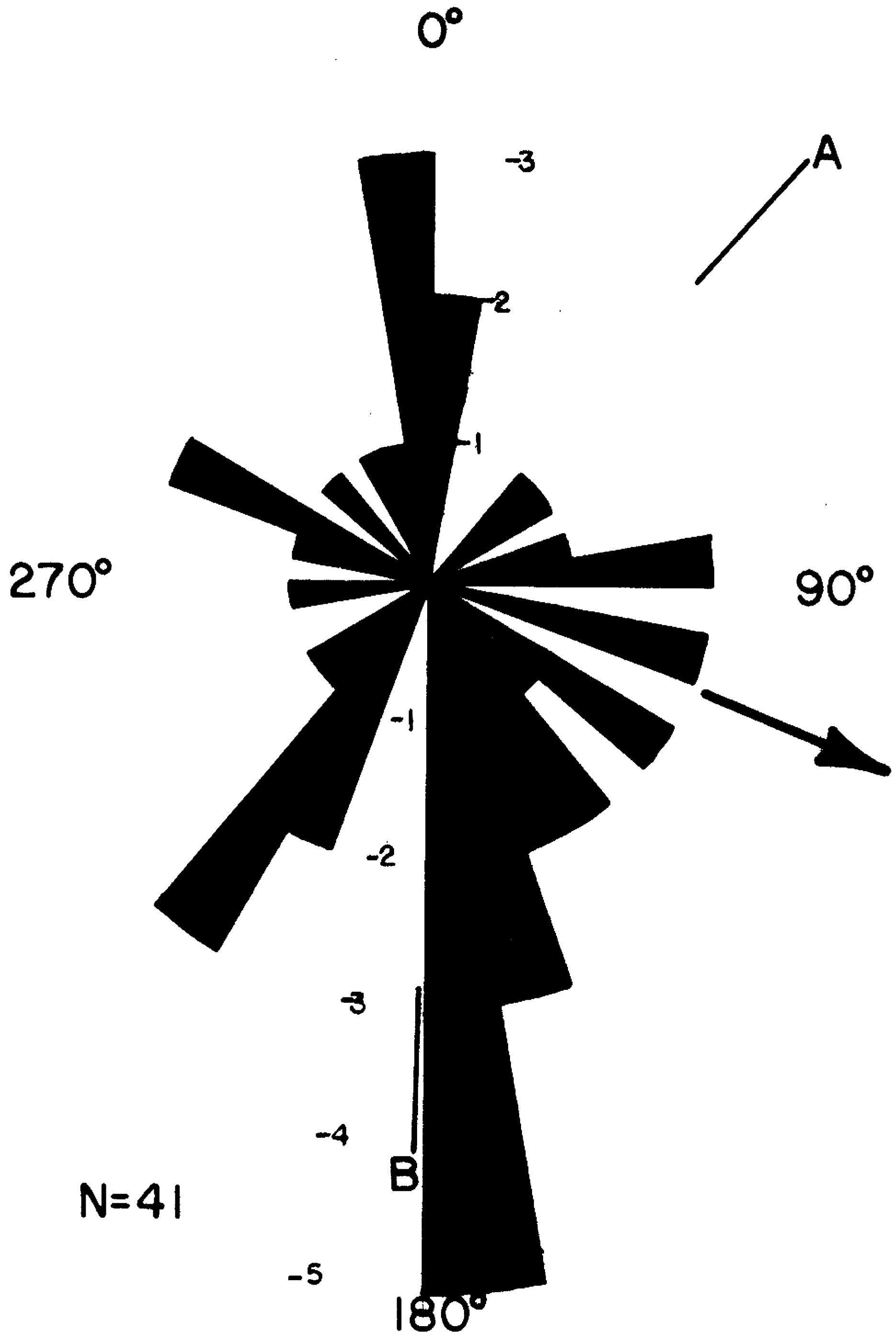


Figure 30. Rose diagram of the orientations of the apical ends of recumbent rugose coralla from the *Lithostrotion-Turbophyllum* Zone of the lower Great Blue at the Beirdneau Peak location. The arrow indicates the direction of the mean vector, and A-B indicates the radial deviation. The numbers and associated tick marks indicate the radii of successive unit circles.

Table 4. Test for goodness of fit for data in a circle for the orientations of the apical ends of rugose coralla at the Beirdneau Peak location

The test statistic is:

$$X^2 = \sum_{i=1}^{k} (O_i - E_i)^2/E_i$$

O is the observed frequency in a sector and E is the expected frequency in a sector, determined by the total observations divided by the number of sectors.

$$E = 41/6 = 6.8$$

Sector	
1	(4-6.8) /6.8=1.153
2	(5-6.8) /6.8=0.476
3	(5-6.8) /6.8=0.888
4	(7-6.8) /6.8=0.006
5	(4-6.8) /6.8=1.153
6	(6-6.8) /6.8=0.094
	12.770

For six degrees of freedom (N-1) the critical X^2 value at $\alpha = .05$ is 11.070. Calculated value, 12.770, is greater than 11.070 and the distribution is not random.

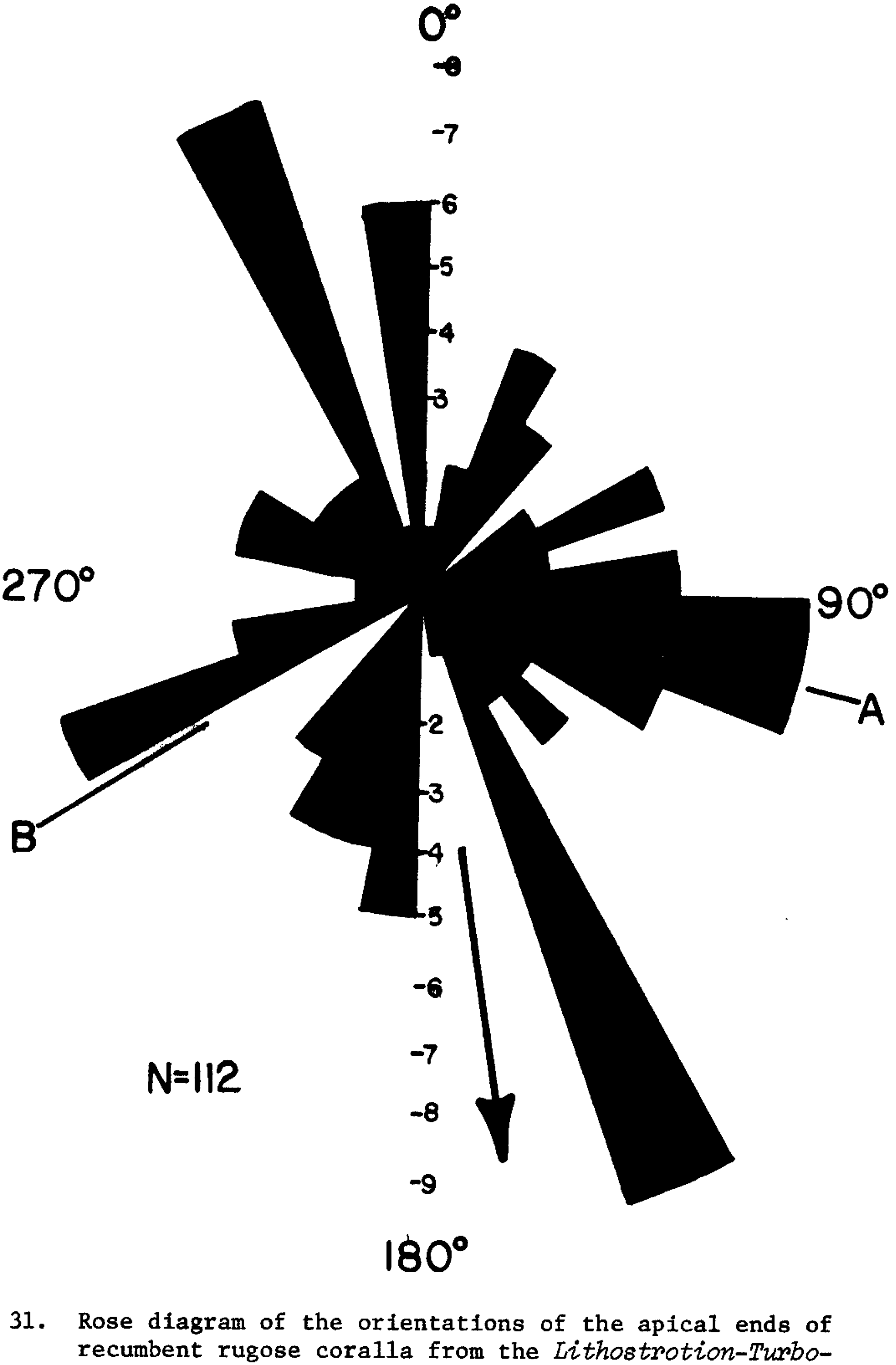


Figure 31. Rose diagram of the orientations of the apical ends of recumbent rugose coralla from the *Lithostrotion-Turbophyllum* Zone of the lower Great Blue at the Logan Peak location. The arrow indicates the direction of the mean vector, and A-B indicates the radial deviation. The numbers and associated tick marks indicate the radii of successive unit circles.

Table 5. Test for goodness of fit for data in a circle for the orientations of the apical ends of rugose coralla at the Logan Peak location

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The test statistic is:

$$X^2 = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i$$

O is the observed frequency in a sector and E is the expected frequency in a sector, determined by the total observations divided by the number of sectors.

$$E = 112/6 = 18.7$$

Sector	
1	(12-18.7) /18.7=2.400
2	(28-18.7) /18.7=4.625
3	(18-18.7) /18.7=0.026
4	(16-18.7) /18.7=0.389
5	(17-18.7) /18.7=0.154
6	(21-18.7) /18.7=0.283
	7.877

For six degrees of freedom (N-1) the critical X^2 value at $\alpha = .05$ is 11.070. Calculated value, 7.877, is less than 11.070 and the distribution is <u>random</u>.

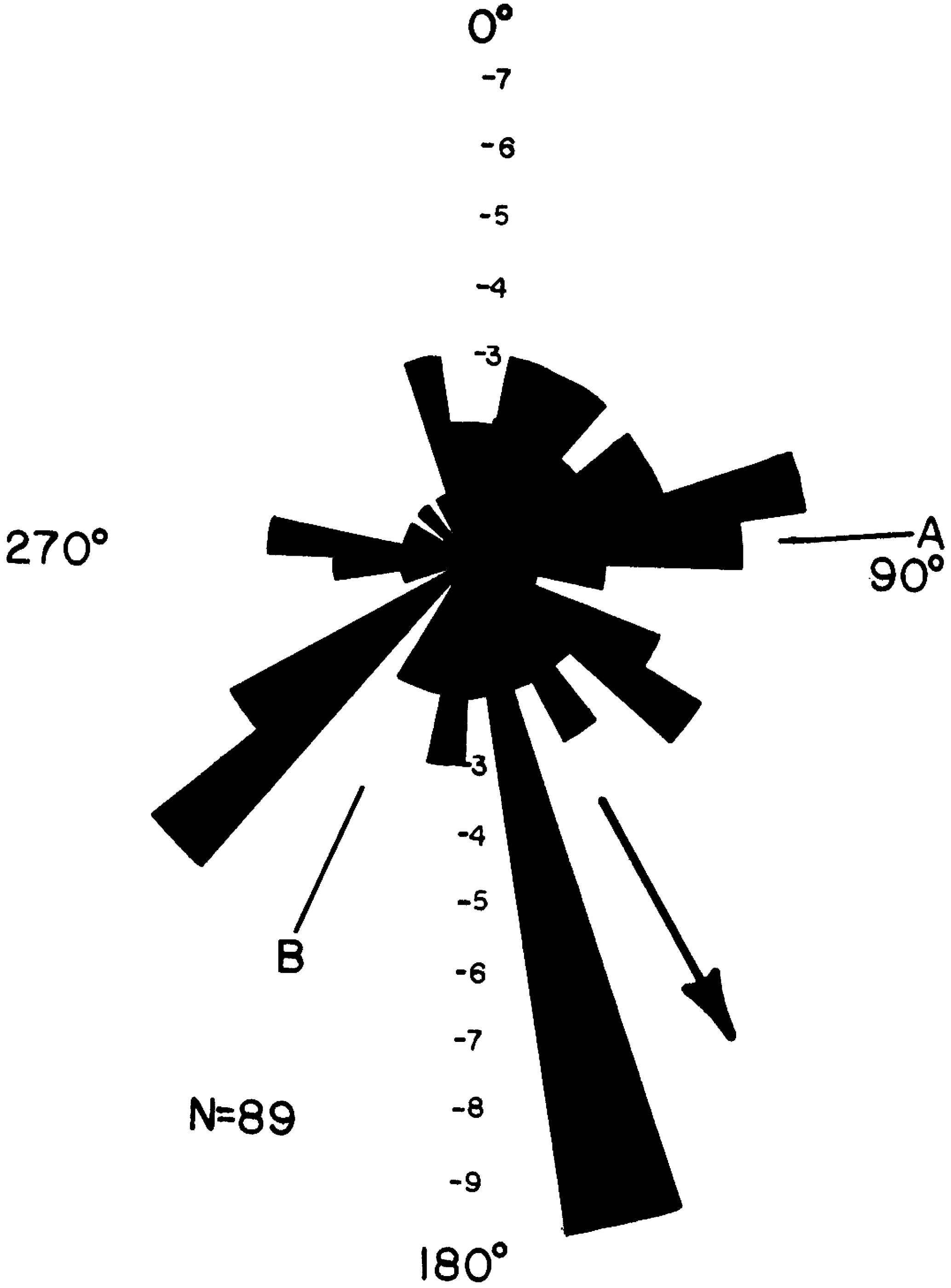

Figure 32. Rose diagram of the orientations of the apical ends of recumbent rugose coralla from the *Lithostrotion-Turbophyllum* Zone of the lower Great Blue at the East Fork Canyon location. The arrow indicates the direction of the mean vector, and A-B indicates the radial deviation. The numbers and associated tick marks indicate the radii of successive unit circles.

Table 6. Test for goodness of fit for data in a circle for the orientations of the apical ends of rugose coralla at the East Fork Canyon location

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The test statistic is:

$$X^2 = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i$$

O is the observed frequency in a sector and E is the expected frequency in a sector, determined by the total observations divided by the number of sectors.

$$E = 88/6 = 14.8$$

Sector	
1	(16-14.8) /14.8=0.097
2	(18-14.8) /14.8=0.692
3	(23-14.8) /14.8=4.543
4	(17-14.8) /14.8=0.327
5	(8-14.8) /14.8=3.124
6	(7-14.8) /14.8=4.111
	12.894

For six degrees of freedom (N-1) the critical X^2 value at $\alpha = .05$ is 11.070. Calculated value, 12.894, is greater than 11.070 and the distribution is not random.

Table 7. Results of the orientations of the apical ends of rugose corals in the *Lithostrotion-Turbophyllum* Zone at the four locations in the study area

Location	Vector sine	Vector cosine	Vector length	Radial deviation	Mean vector	Mode vector
Dry Lake	0.7184161	-0.6956110	0.0448279	1.0504486	135° 55'	160°
Logan Peak	0.9859422	-0.1670879	0.0307435	1.1769143	170° 22'	155°
East Canyon	0.8602665	-0.5098446	0.0546890	0.9159555	149° 20'	165°
Bierdneau Peak	0.3635706	-0.9315666	0.0259375	1.2170658	111° 20'	175°
Average	0.7320588	-0.5760272	0.0390494	1.0990960	141° 45'	164°

Rose diagrams (Figures 29-32) show a definite preferred orientation of the apical end of the coralla in the direction that is now southeast. When compared to the position of the continental plates with respect to the Equator in late Mississippian time, the pattern of orientations established by the rose diagrams of the locations would be shifted so that the mean and mode vectors point south instead of southeast (Figure 33).

The rose diagrams, mean vectors, mode vectors, and the results of the flume experiment suggest that the strongest current was directed from the south to the north in the late Mississippian.

The preferred orientation of the coralla, indicated by the mean and modal vectors, suggests that they were produced by a unidirectional current. This assumption is not always valid as shown by Kissling and Lineback (1967, p. 173; see Figure 34). In their study, four different current regimes were proposed to produce the same pattern of orientations.

The bimodal patterns of preferred orientations at two locations and the moderate unimodal pattern of the Dry Lake location suggest tidal-type activity. The distributional pattern with the mode directed to the south suggests that the ebb current of the tides, that is the stronger component (Klein, 1970), flowed from south to north in the late Mississippian.

The patterns of the preferred orientations suggest that the area was not under the influence of a wind-driven oceanic circulation system. The epicontinental sea is restricted to the west by stratigraphic reefs and the Antlers orogenic belt (Rose, 1976). Stong currents may have

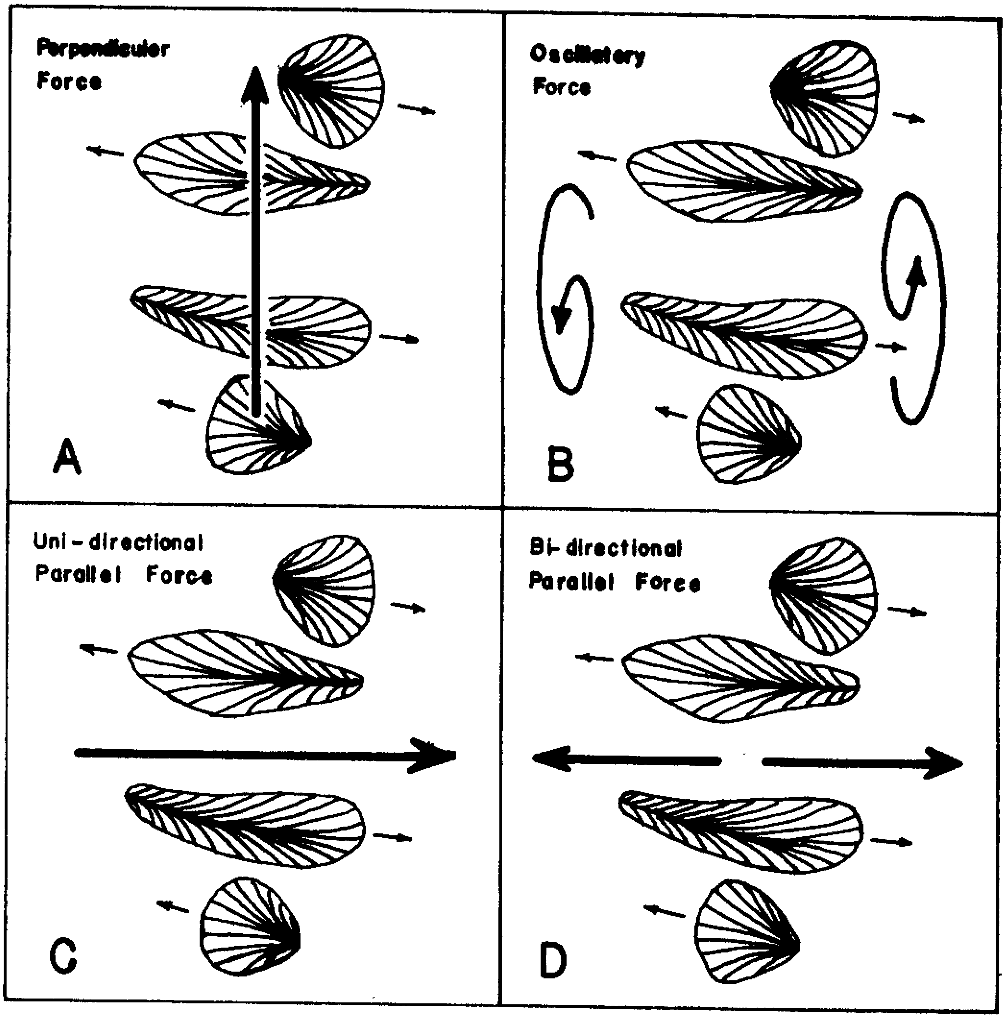


Figure 33. Four interpretations of the forces causing preferred orientation of coral colonies. Small arrows indicate the prevalent orientations of the distal ends of colonies (from Kissling and Lineback, 1967, p. 172).

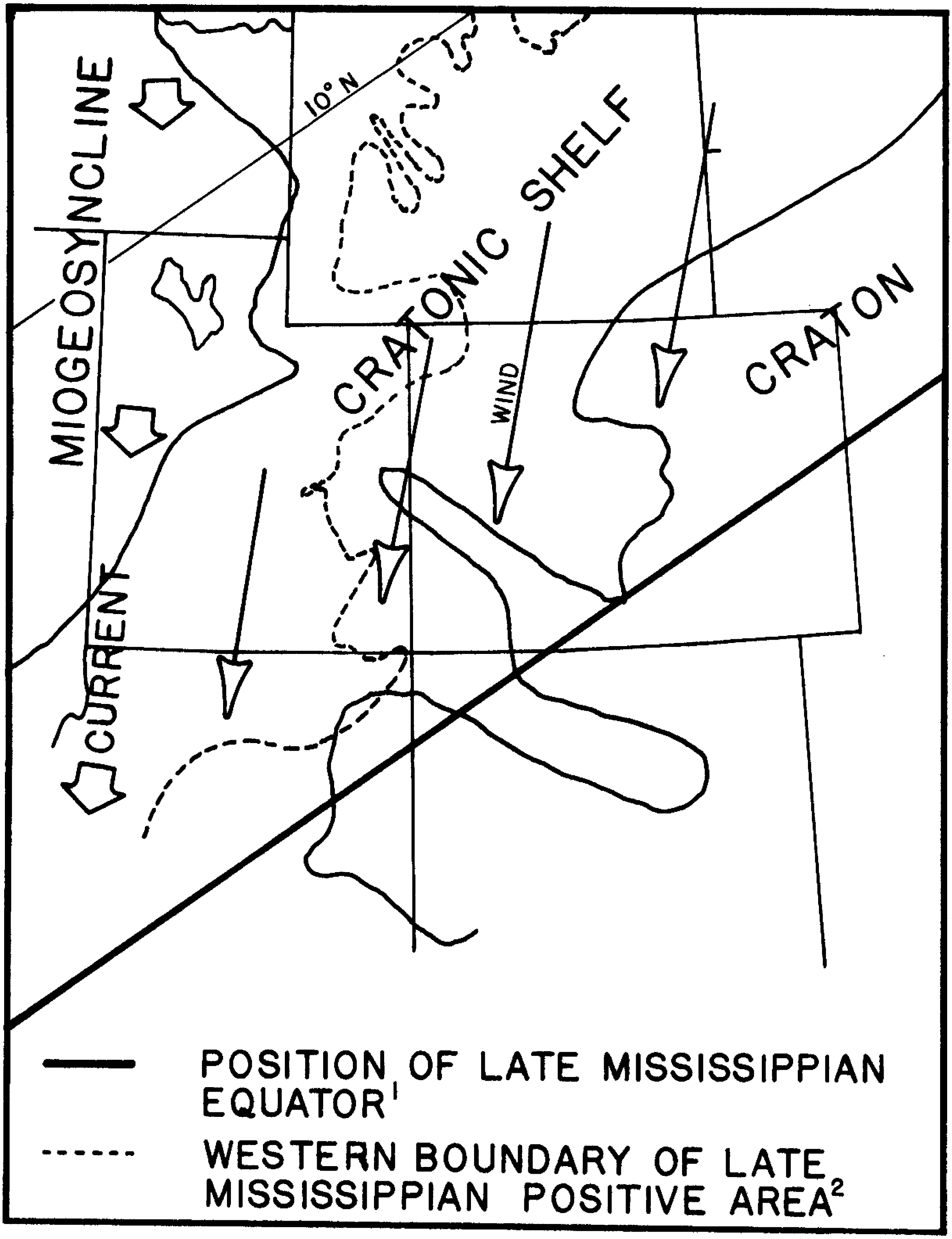


Figure 34. Late Mississippian paleogeography in the Cordilleran region. (1. Seyfert and Sirkin, 1973, p. 260; 2. Sando, 1967, p. 30.)

flowed from north to south in the miogeosyncline between the Antlers orogenic belt and the reefs. Some of the energy of these currents may have extended onto the shelf but did not effect the environment to a great extent. The proposed tidal currents were probably of modest to low intensity. The coralla have been toppled and reoriented to preferred, non-random orientations indicating current activity. Low current velocities are suggested by the absence of current induced structures. The micro-crystalline lithology of the rock suggests low agitation. Visible evidence of abrasion resulting from transport is not present. The populations do not appear to have been winnowed by current activity, with the possible exception of the population in which smaller sized specimens are scarce.

Mean and modal vectors of the orientations at the locations are all in the same quadrant of the rose diagrams and appear to be related. Application of the "Bartlett Test" for the homogeneity of variance (radial deviation of the orientations), with three degrees of freedom, revealed a significant variance in the radial deviations between the locations (Table 8). Significant variance of the radial deviations suggests that the overall circulation pattern was being modified at each locality.

Rheotropic responses by the colonial corals and negative geotropic responses by the rugose corals, as a result of toppling, are found at the various locations. At Dry Lake, straight and moderately curved forms of rugose corals and spherical or equant forms of colonial corals are present (Figure 35). Less than 25 percent of the rugose corallum

Table 8. Bartlett's test for homogeneity of variance in the orientations of the apical ends of rugose coralla at the locations within the study area

Origin of samples	Sum of squares $n_i s_i^2$	Degrees of freedom n_i	Mean squares s_i^2	$\log s_i^2$	$n_i \log s_i^2$	$1/n_i$
Beirdneau Peak	59.24999	40	1.4812491	0.17	6.80	0.016877
Dry Lake	2241.0907	2031	1.1034420	0.04	81.24	0.000446
Logan Peak	153.7492	111	1.3851286	0.14	15.54	0.006504
East Fork Canyon	108.7463	120	0.9062192	-0.04	-4.80	0.009195
	2562.8361	2308			98.78	0.033022

$s^2 = \Sigma n_i s_i / n_i = 2562.8361/2308 = 1.1104142$ s^2 is the variance for all of the samples

$(\Sigma n_i) \log s^2 = (2308)\ (.045463) = 104.921$

$M = (2.3026)\ [(\Sigma n_i) \log s^2 - n_i \log s_i^2]$ $M = (2.3026)\ (104.921-98.78) = 14.141832$

$E = 1 + \frac{1}{3(k-1)} (\Sigma 1/n_i - 1/\Sigma n_i)$ $E = 1 + \frac{1}{3(3)} [.033022-(1/2308)] = 1.0036209$

E is a correction factor

$X^2 = M/E = 14.141832/1.0036209 = 14.09081$

The calculated value, 14.09081, exceeds the critical X^2 value, 7.815, at $\alpha = .05$ at three degrees of freedom. Reject the null hypothesis. The variance between the locations is significant.

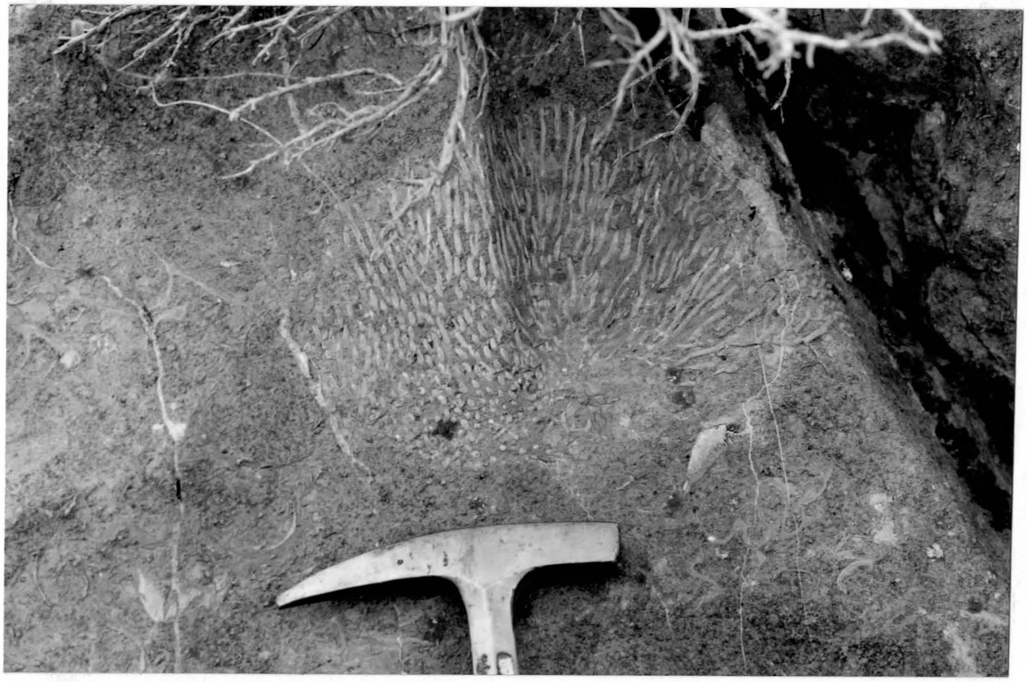


Figure 35. Cross-section of hemispherical *Syringopora* colony from the lower Great Blue at Dry Lake.

exhibit a curve of more than 45 degrees. Hubbard (1970, p. 207) suggested that straight forms are indicative of lower energy environments. Curved forms could result from rotation of the corallite into the scours created by current action, with subsequent growth compensating for the rotation (Figure 36). The curved morphology would be the result of moderate, unidirectional current activity.

Lithostrotion at the Logan Peak location exhibits a definite rheotropic response in the direction which is now north (Figure 37). The rugose-coral assemblage at this location has the largest fraction of geniculate individuals, approximately 12 percent. A geniculate form of rugose coral has undergone a radical and rapid change in orientation (toppling) that resulted in a negative geotropic response in an effort to regain the life orientation (Figure 38).

Figure 36. Curving morphology of the rugose coral *Turbophyllum*. Specimens were collected at sample site 15 at Dry Lake.

Figure 37. Preserved rheotropic response of a *Lithostrotion* colony in the lower Great Blue at Logan Peak.

Figure 38. Geniculate morphology of a rugose coral, slab 5-10. The slab was collected at sample site 5 at Dry Lake location.

POPULATION DYNAMICS

General Statement

Size-frequency histograms of populations of marine invertebrates are useful in understanding the long and short-term changes in the populations of the communities. Hallam (1972) reviewed the interpretation of size-frequency distributions of life assemblage and of death assemblages. Size-frequency histograms may be used, along with other evidence, to determine if a sample population represents a life assemblage (biocoenosis) in which all phases and forms of a living population are present in the fossil record, or a death assemblage (thanatocoenosis) in which only the phases and forms which were buried and not diagenetically obliterated are present in the fossil record. A death assemblage often represents a part of a population transported after death.

If a life assemblage is present, a size-frequency histogram may be useful in determining recruitment, growth, variation in growth rate, mortality rate and cessation of growth (maturity) (Craig and Oertel, 1966). In a death assemblage conclusions made from interpretation of the shape and position of the size-frequency histogram must be accompanied by other supporting evidence to be valid.

Size Frequency Distribution of Rugose Corals

In order to reconstruct population dynamics within the *Lithostrotion-Turbophyllum* Zone of the lower Great Blue limestone and to compare the populations of corals at each of the four locations, size-frequency distributions of the lengths of the rugose corals were plotted on graphs (Figure 39). Of the four samples, three were platykurtic (.810) or very platykurtic (.737) and one was very leptokurtic (1.64) (Table 4). For normal curves, $K_G = 1.00$; leptokurtic curves have K_G values greater than 100; and platykurtic curves have K_G values less than 1.00 (Folk, 1974, p. 48). All four graphs show curves that are normal (+.10-0-.10), to slightly positively (.20 and .33), or negatively (-.33) skewed (Table 9). A student's t-test of the four populations shows significant different between the mean-length values of compared populations in the four areas (Table 9).

The means of the Dry Lake and East Fork Canyon locations when compared with the mean of the Beirdneau Peak location show no significant differences. Similarity of the means in these comparisons may be an artifact of the small sample size (N = 10) of the Beirdneau Peak population. The Beirdneau Peak population exhibits the greatest deviation from the other locations in terms of skewness and kurtosis. The deviation may also be the result of the relatively small sample size (N = 10). The histogram of the East Fork Canyon population is very platykurtic and normally distributed. The histogram of the Logan Peak population is platykurtic with a slight positive skew. The less peaked aspect of the histogram of the Logan Peak population and the

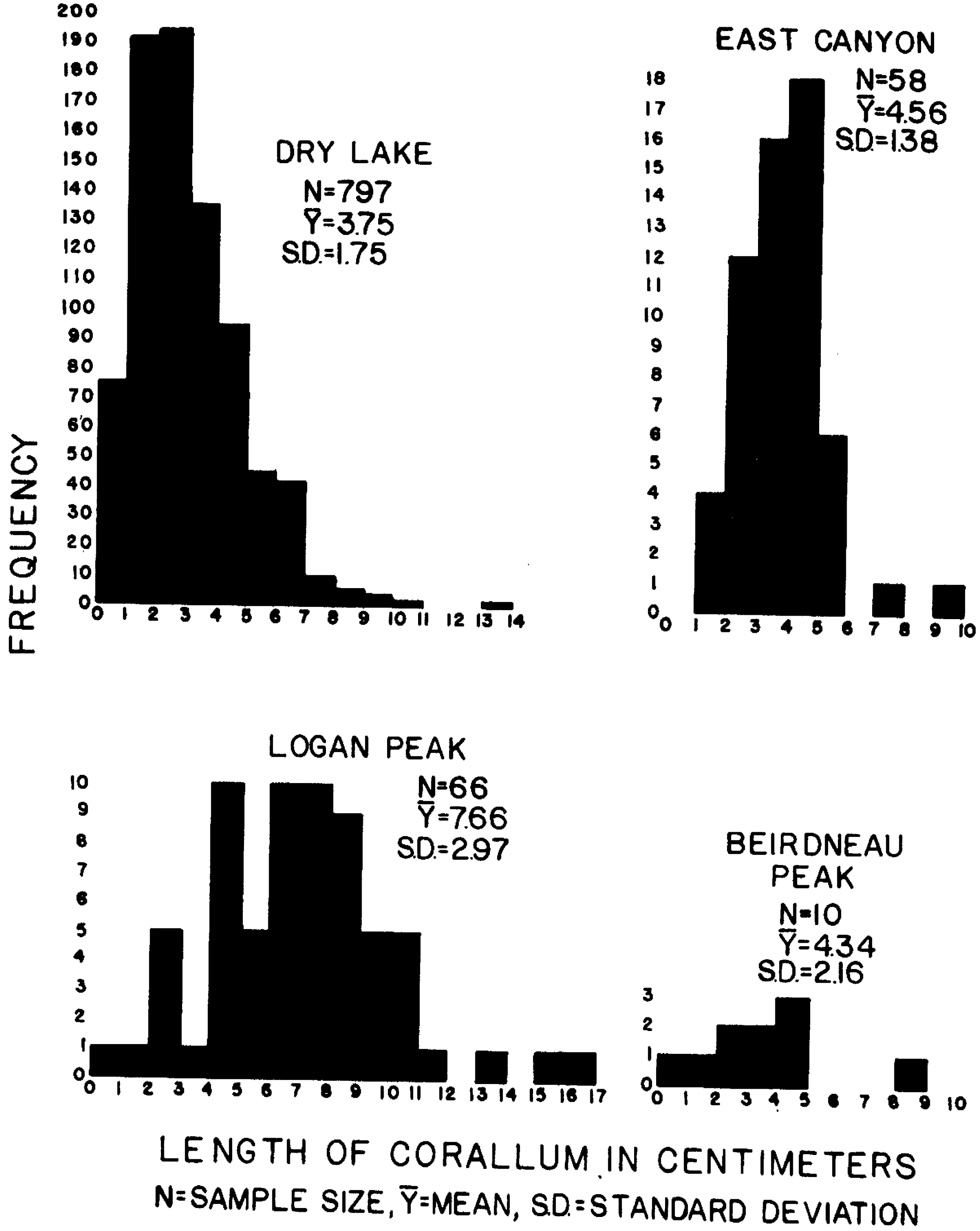


Figure 39. Size-frequency histograms of four populations of rugose corals.

Table 9. Statistical data for the size-frequency histograms of rugose coral populations in the study area

	Dry Lake	Beirdneau Peak	Logan Peak	East Fork Canyon
Sample size	797	10	66	58
Kurtosis	0.82	1.64	0.74	0.82
Skewness	0.33	0.33	0.20	0.00
Sorting	1.58	1.29	1.34	1.29
Mean	3.75	4.34	7.66	4.56
Standard deviation	1.75	2.16	2.97	1.38

T-test comparing the means of each population against each other sample

	Dry Lake	Beirdneau Peak	Logan Peak	East Fork Canyon
Dry Lake	-	1.04	[16.28	[3.48]
Beirdneau Peak		-	[3.42]	0.46
Logan Peak			-	[7.29]
East Fork Canyon				-

The numbers in brackets indicate a significant difference in the means.

larger mean when compared to those of the Dry Lake and East Fork Canyon suggest that the smaller individuals are not as abundant. The juveniles may have been removed by some physical process, such as current winnowing, or this size stage was rapidly passed through by maturing individuals. Because of the small sample size from the Beirdneau Peak population, the negatively skewed, leptokurtic histogram may not be representative of the population.

Size-Frequency Distribution of *Rugosochonetes loganensis*

The brachiopod *Rugosochonetes loganensis* is abundant in three separate faunal zones and three different lithologies within the Great Blue Limestone. The size-frequency distributions of the hinge length of the three populations of *Rugosochonetes loganensis* were plotted on graphs (Figure 40) to aid in the reconstruction of the population dynamics of this taxon, to assist in a comparison of the three populations, and to evaluate the effect, if any, of the type of substrate on the fauna.

Population A was sampled from the upper part of the Long Trail Shale (sample sites 1, 3, and 8), a lithology with insoluble residue in excess of 90 percent. Population A is mesokurtic (1.06) with a slight, positive skewness (+0.25). Population B was sampled from the *Rugosochonetes-Orthotetes* Zone, a shale unit of the upper Great Blue with the insoluble residue in excess of 90 percent. Population B is platykurtic (0.75) with a moderate positive skewness (+0.43). Population C was sampled from the *Rugosochonetes-Paladin* Zone (sample sites 10, 12, and 16), a packed biomicrite unit in the upper

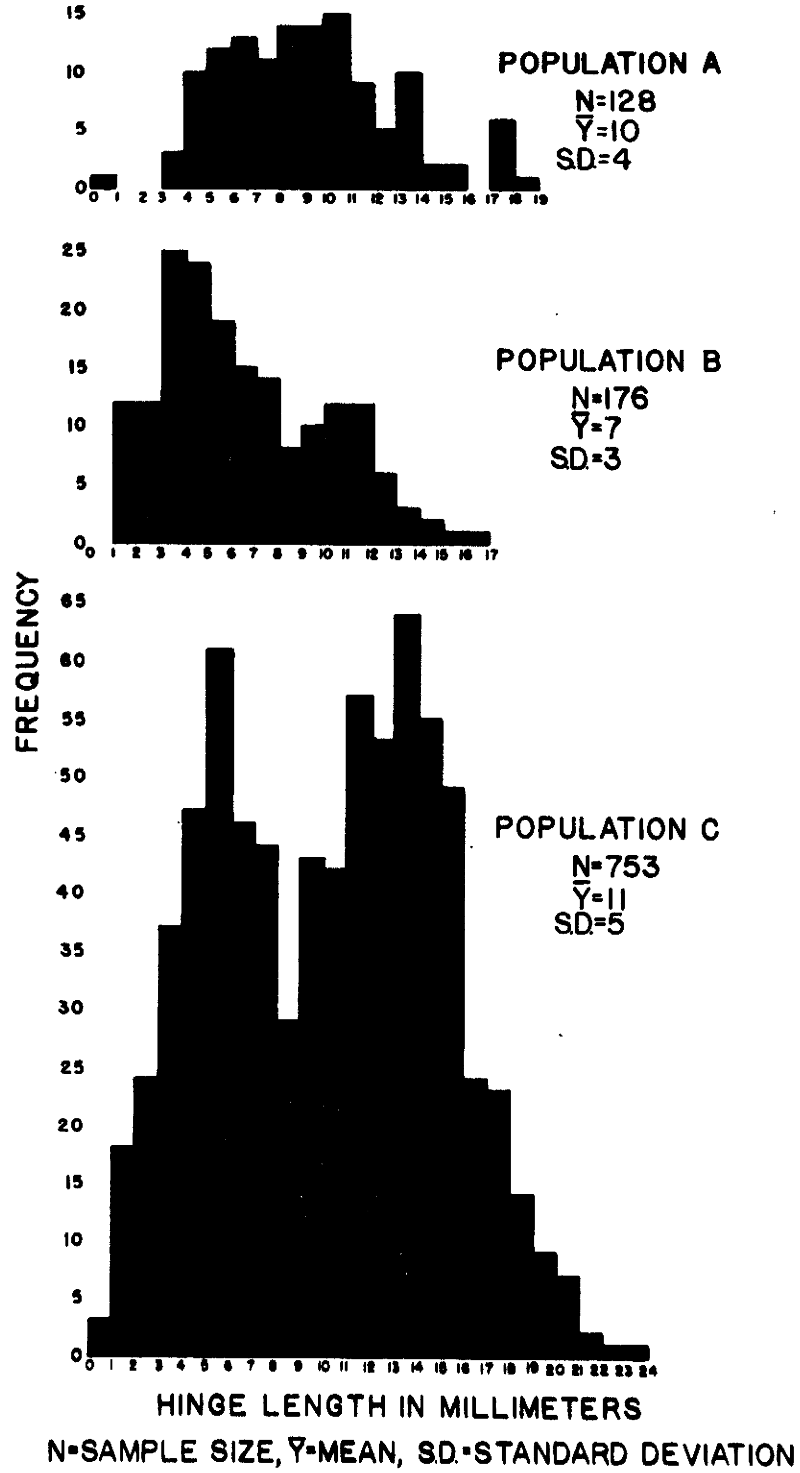


Figure 40. Size-frequency histograms of three populations of the brachiopod *Rugosochonetes loganensis*. Population A is from the Brachiopod-Pelecypod Zone, Population B is from the *Rugosochonetes-Orthotetes* Zone and Population C is from the *Rugosochonetes-Paladin* Zone.

Great Blue with the insoluble residue less than 50 percent. Population C is platykurtic (0.77) with a slight, negative skewness (-0.09). A population is considered to have normal distribution if the skewness is between +0.1 and -0.1 (Folk, 1974).

A Student's t-test of the three populations (Table 10) shows a significant difference in the means, except the comparison of the means of Populations A and C that are similar. The histogram of Population B shows possible bimodality and the histogram of Population C shows definite bimodality. The bimodality is probably the result of seasonal deaths between successive age (size) classes. Thayer (1975b, p. 141) suggested that, if variations in the growth rate are random, polymodal distributions record multiple episodes of recruitment.

Populations A and B are positively skewed while Population C is normally distributed. Percival (1944) suggested that the high numbers of juvenile individuals present in a life assemblage resulted from the high number of young produced and high juvenile mortality rates. Consequently, the size-frequency distribution of an unwinnowed life assemblage of brachiopods should be expected to be platykurtic, positively skewed, and concave. Size-frequency histograms of populations that show a normal distribution have not necessarily been winnowed as discussed by Boucot (1953) and Fagerstrom (1964, p. 1,201). A normal distribution may reflect an unwinnowed population, characterized by rapid growth of the immature individuals (Surlyk, 1972; Thayer, 1975b). Irregular recruitment, increasing mortality rate, and patchy distributions can result in life assemblages with normally distributed size-

Table 10. Statistical data for the size-frequency histograms of populations of *Rugosochonetes loganensis* in the study area

	Population A (shale)	Population B (shale)	Population C Carbonate)
Sample size	128	175	753
Kurtosis	1.06	0.74	0.77
Skewness	0.25	0.43	-0.09
Sorting	1.31	1.58	1.52
Mean	10.0 mm	7.0 mm	11.0 mm
Standard deviation	4.0 mm	3.0 mm	5.0 mm

T-test comparing the means of each population against other samples

	Population A	Population B	Population C
Population A	-	[6.47]	2.21
Population B		-	[9.55]
Population C			-

The numbers in brackets indicate a significant difference in the means.

frequency curves. Craig and Hallam (1963) also suggested that normal distributions may reflect unwinnowed life assemblages. Mortality rates among preservable young may be lower than expected. Selective preservation of larger individuals as opposed to the smaller forms, or simple overlooking the juvenile individuals when sampling the population may also account for normal distributions.

The skewness of Populations A and B suggest that high juvenile mortality took place in the terrigenous mud habitat. The high mortality rate may be due to increased sedimentation rate burying the juveniles, increased agitation overturning the smaller forms, or burial by the shifting substrate.

The differences in the means of Populations A and B and the similarity of Populations A and C are perplexing in consideration of the fact that both Population A and B occupied very similar lithologies, namely terrigenous muds. In the terrigenous muds death of most of the individuals resulted from increased sedimentation rate, increased substrate mobility (shifting substrate), and/or the inability of the larger individuals to resume life position after being overturned by current activity. Vulnerability to the high stresses throughout the life time of the brachiopod may have been responsible for the limiting of the size attained by most individuals of *Rugosochonetes loganesis* in Population B which has the smallest value for mean lengths (Table 10). In the population that inhabited the calcilutite (C) rapid growth would have been advantageous in the stabilization and support of the organism on a more fluid substrate. The juvenile stage, in which the individuals would have been most susceptible to foundering in the fluid substrate, was rapidly passed through during ontogeny. The result is the attainment of a larger mean size and, in association with a low juvenile mortality rate, a non-skewed to slightly negative skewed size-frequency distribution (Table 10). Surlyk (1972) noted that free-lying small brachiopods associated with Cretaceous chalks displayed negatively skewed size-frequency distributions. He attributed the histogram shape to rapid juvenile growth rate during the stage of life most vulnerable to being fouled in the ooze.

The mesokurtic histogram of Population A may indicate current winnowing of the juveniles from this population that is associated with pelecypods and may be a nearshore assemblage. The platykurtic histograms of Populations B and C suggest that these populations were subjected to some post-mortem sorting.

SUCCESSION OF COMMUNITIES

Allogenic succession or succession controlled by physical changes in the environment (Walker and Alberstadt, 1975, p. 238) is exhibited by the faunal zones present in the Great Blue Limestone. The physical factor which triggered the succession is the change in the nature of the substrate from detritus-free limestone to shale and vice versa. The influx of terrigenous detritus suggests increased proximity to the source area and a shallower environment with increased agitation and turbidity. Many factors affect the change in the nature of the substrate. The composition of the source area, the climate, and relief in the source area, the distance from the source area to the site of deposition, and transport all affect the nature of the material to be deposited. At the site of deposition, temperature, pH, Eh, agitation and organic activity act to determine the nature of the substrate. Many of the factors which govern the nature of the substrate vary uniformly or predictably with the depth of the site of deposition.

Commonly, a nearshore shallow environment is closer to the source of terrigenous influx and is often subjected to higher energy levels than an offshore deep environment. Proximity to the source area generally results in more terrigenous material of larger clast size being deposited. Increased agitation may result in increased turbidity as the smaller particles are kept in suspension. However, fossil communities described as nearshore or offshore do not necessarily correspond to proximity to the shore (Taylor and Sheehan, 1968). The terms are more closely related to the relative depth of the environment in which the assemblage aggregated (Bretsky, 1968). Nearshore assemblages inhabited areas relatively shallower than the offshore assemblages, and were characteristic of an environment close to shore as opposed to those farther from shore. However, nearshore communities may be found on reefs at great distances from the shore, whereas offshore communities may be found on steep sea floors relatively close to the shore.

If depth had some influence on the nature of the substrate, transgressions and regressions of the late Mississippian seas could produce the changes in the substrate and the allogenic succession of the communities in the Great Blue. Paleozoic marine invertebrate communities also may have been depth-dependent in that their distribution is restricted to environments characteristic of certain depths (Calef and Hancock, 1974; Ziegler, Cocks, and Bambach, 1968). Faunal communities often paralleled the nearshore-offshore profile (Anderson, 1971), and persisted within narrow bathymetric zonations (Broadhurts and Simpson, 1973).

Changes in the depth due to transgressions or regressions would cause a migration of the various communities to maintain their environmental tolerances. Therefore, community succession or cycles of community succession may be seen in sequential beds of the stratigraphic section at any one locality. The cyclical nature of the lithologies in the Great Blue can be explained with the model presented by Rose (1976, p. 452), as the result of repeated submergent-emergent cycles of deposition. "The thick upper depositional succession appears to consist of several thick carbonate cycles rather than the simple transgressive-regressive couplet of its lower counterpart" (Rose, 1976, p. 464). Sando (1976, p. 321) suggested that depositional cycles included a complex of marine transgressions and regressions. The faunal zones observed in the Great Blue are probably not the result of succession within a stable environment but of migration of communities in resonance with migrations of their preferred environments. These environmental shifts across a shallow marine late Mississippian shelf were controlled by transgressions and regressions.

The faunal zones of the Great Blue and the change from one zone to another are closely related to the lithology. The *Turbophyllum* Zone and the *Lithostrotion-Turbophyllum* Zone are present in the fine to medium-crystalline limestone of the lower Great Blue. The Brachiopod-Pelecypod Zone is in the Long Trail Shale, near the top of the unit. The lower part of the finely-crystalline, dark-gray limestone of the upper Great Blue contains the Coral-Cephalopod Zone. The upper part of the upper Great Blue contains the *Caninia* Zone. The shale layer in the upper Great Blue contains the *Rugosochonetes-Orthotetes* Zone. Above the shale layer is the *Rugosochonetes-Paladin* Zone in a fine-crystalline, gray limestone. Above this is a dark-gray, crinoidal limestone which includes the Crinoid-Bryozoan Zone. The various lithologies and the associated faunal zones may be correlated to the relative depth and degree of agitation experienced by the community and substrate at the time of deposition.

Faunal reassemblages within the Great Blue tend to support the assumption of a shallow, normal marine, low to moderate energy, current-swept environment proposed in the paleocurrent section. The *Turbophyllum, Lithostrotion-Turbophyllum, Caninia* and *Rugosochonetes-Paladin* Zones reflect relatively deeper offshore communities at or near effective wave base. Certain brachiopods, namely species of spiriferids, orthids and strophomenids, which are found in these assemblage zones, tended to colonize the slightly deeper offshore areas (Bretsky, 1969; Watkins, 1975).

Gradual physical fluctuations of the environment commonly caused a community to revert to the previous stage of succession. Rapid changes in the environment may cause the community to revert, at once, to some primary stage of the succession or may open the area to an entirely new stage of succession (Walker and Alberstadt, 1975).

Succession of the communities begins with the faunal assemblage in the *Turbophyllum* Zone which has low diversity (Table 11). Colonial and solitary corals, crinoids, and a few brachiopods are present. The epifaunal trophic levels are occupied, whereas infaunal niches are vacant. Rugose corals appear to be the dominant and most abundant fauna. The zone appears to be a late pioneer community or an early intermediate community.

The faunal assemblage in the *Lithostrotion-Turbophyllum* Zone exhibits approximately the same diversity as the fauna in the *Turbophyllum* Zone. However, the dominance and abundance of the rugose corals suggest an initial exploitation of an environment which has undergone a

Table 11. Diversity, dominance and niches occupied in the faunal zones of the Great Blue Limestone

Mega-faunal zone	Diversity (−ΣP(n log P))	% dominance	Niches occupied ID	ED	ILF	ELF	EHF	NC
Crinoid-Bryozoan	0.550	75					X	
Rugosochonetes-Paladin	0.690	81	X	X		X	X	
Rugosochonetes-Orthotetes	1.304	52	X			X	?	
Caninia	1.520	56		X		X	X	X
Coral-Cephalopod		90					X	X
Brachiopod-Pelecypod	1.546	30	X	X	X	X	X	X
Lithostrotion-Turbophyllum	1.170	61		X		X	X	
Turbophyllum		90					X	

ID = infaunal deposit feeder; ED = epifaunal deposit feeder; ILF = infaunal low filter feeder; ELF = epifaunal low filter feeder; EHF = epifaunal high filter feeder; NC = nektonic carnivore.

P = percentage of individuals belonging to each species.

change. The situation is probably similar to the opening of a completely new successional stage rather than a reversion to a pioneer community as suggested by Walker and Alberstadt (1974, p. 256).

The faunal assemblage in the Brachiopod-Pelecypod Zone shows an increase in the infaunal and low-level filter-feeders and the relative exclusion of the higher level filter-feeders. The increase is probably due to the influx of terrigenous detritus. Within this zone diversity is high, with most of the trophic levels occupied, and the dominance is low, compared to the underlying zones. Densities in the Brachiopod-Pelecypod Zone are very high. *Rugosochonetes loganensis* is recognized as an opportunistic species (R. R. Alexander, personal communication) and is found in varying abundances throughout the Great Blue. The proliferation of an opportunistic species is triggered by an environmental perturbation which allows exploitation of the new environment. In the case of *Rugosochonetes loganensis* in the Great Blue the perturbation is believed to be terrigenous influx. Sheldon (1974) suggested that *Rugosochonetes* flourished at times of quartz influx which he correlated to the rainy seasons.

The perturbation either opens a new stage of succession or causes regression of the community to a previous stage of succession. The previous stages of succession may not be observable in the geologic record due to the nature of the perturbations which cause the change.

The abrupt change in the lithology from the Long Trail Shale to the upper Great Blue and the sparse fauna found in the Coral-Cephelopod Zone suggest a drastic change in the environment which resulted in a habitat inimical to colonization by sessile benthos, with the exception of the corals. The patchy distribution of the faunas in the *Caninia* Zone suggests a stage in succession similar to stage 5 of Walker and Alberstadt (1975, p. 247) although the faunas are different. The spiriferid brachiopods are dominant in this zone, and only the epifaunal trophic levels are occupied.

In the *Rugosochonetes-Orthotetes* Zone the high filter-feeders are absent whereas the infaunal and low filter-feeder forms are abundant. Diversity is lower and dominance is increased. The influx of terrigenous detritus may have been the environmental perturbation which caused the increase in the abundance of *Rugosochonetes loganensis*. In the *Rugosochonetes-Paladin* Zone the opportunistic species *Rugosochonetes loganensis* is present and abundant. Although the percent of dominance is high and the diversity is low (Table 11) most of the trophic levels are occupied. The environmental stress created by a fluid substrate precluded inhabitation by many bulky sessile filter-feeding benthos which would have sunk in the ooze and been fouled while feeding. In the *Rugosochonetes-Paladin* Zone there is a significant percent of insoluble residue (45 to 50 percent) which suggests a lithotope intermediate between the terrigenous muds and the lime muds. This lime-mud substrate was not particularly suitable for occupation by either corals or many suspension-feeding pelecypods, although pectenoids are occasionally found in this zone. The Crinoid-Bryozoan Zone is dominated by crinoids. The diversity is low, and only the very-high and high filter-feeder trophic levels are occupied. Again, this zone may represent an entirely new stage in the allogenic succession brought on by changes in the environment.

TROPHIC-LEVEL ZONATIONS

Trophic-level reconstructions at sample sites within the Great Blue Limestone and within the faunal zones correspond well with the model of Walker (1972) although they are not identical to his examples. Walker's model applied the work of Turpaeva (1957), who described trophic groups, namely, swallowers (infaunal deposit-feeders), collectors (epifaunal deposit-feeders), filterer-A (low-level suspension-feeders), filterer-B (high-level suspension-feeders), and awaiters (passive suspension-feeders?). Turpaeva also proposed the following relationships (from Walker, 1972, p. 83):

1. A community is usually dominated by one trophic group.
2. If the most dominant species (in terms of biomass) in the community belongs to one particular trophic group, the next most dominant species belongs to a different group. Often, the third most dominant species belongs to still a third group. Thus, to quote Turpaeva (1957, p. 144), "the dominant group of species in a biocoenosis consists of representatives of different food groups."
3. Among the various species of a community which belong to a given trophic group, a single species commonly dominates the group in terms of biomass.
4. Thus, the several most dominant species in the benthic community use the available food resources more fully than if they fed at a single level, and feeding competition is minimized.

In most cases, within populations at sample sites, one taxon is dominant and the second most abundant taxon is assigned to a different trophic level. At only four sample sites are the first and second most abundant taxa assigned to the same trophic level. In these cases the percentage of the second most abundant taxon is considerably less than that of the most abundant taxon.

The *Turbophyllum* Zone contains a sparse population of rugose corals (Figure 41) which are high-level filter-feeders. No infaunal forms were recorded in this zone. Samples from the *Lithostrotion-Turbophyllum* Zone (Figure 42, Tables 12-15) contain populations in which the high suspension-feeders are dominant and the very-high suspension-feeders are secondary. No infaunal deposit-feeding forms are present in this zone. Samples from the Brachiopod-Pelecypod Zone (Figure 43, Tables 16-20) contain a population representing all trophic levels. The low suspension-feeders are dominant with the deep-infaunal deposit-feeders secondary. The Coral-Cephalopod Zone contains a sparse faunal assemblage. Widely scattered rugose corals and the rare presence of a cephalopod comprise the fossil populations (Figure 44). Samples from the *Caninia Zone* (Figure 45, Table 21) contain a preserved community in which the low suspension-feeders are dominant and the high suspension-feeders are secondary. The *Caninia* Zone is similar to the *Lithostrotion-Turbophyllum* Zone in that no infaunal forms are present. The dominant fauna within the *Rugosochonetes-Orthotetes* Zone (Figure 46, Tables 22 and 23) are the low suspension-feeders. The deep-infaunal deposit-feeders are secondary. The positions of the dominant and secondary trophic levels are the same as in the Brachiopod-Pelecypod Zone. Assemblages within the samples from the *Rugosochonetes-Paladin* Zone (Figure 47, Tables 24 and 25) exhibit dominance of the low

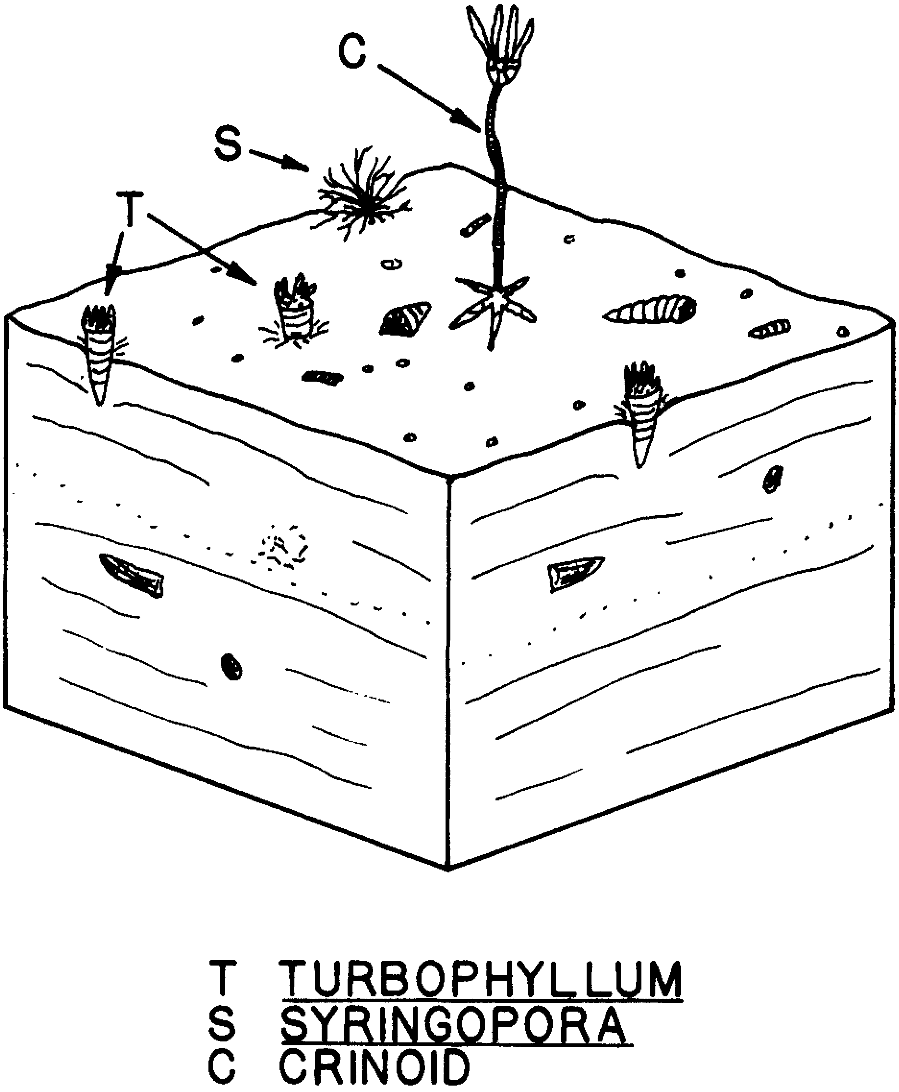


Figure 41. Block diagram of the *Turbophyllum* Zone.

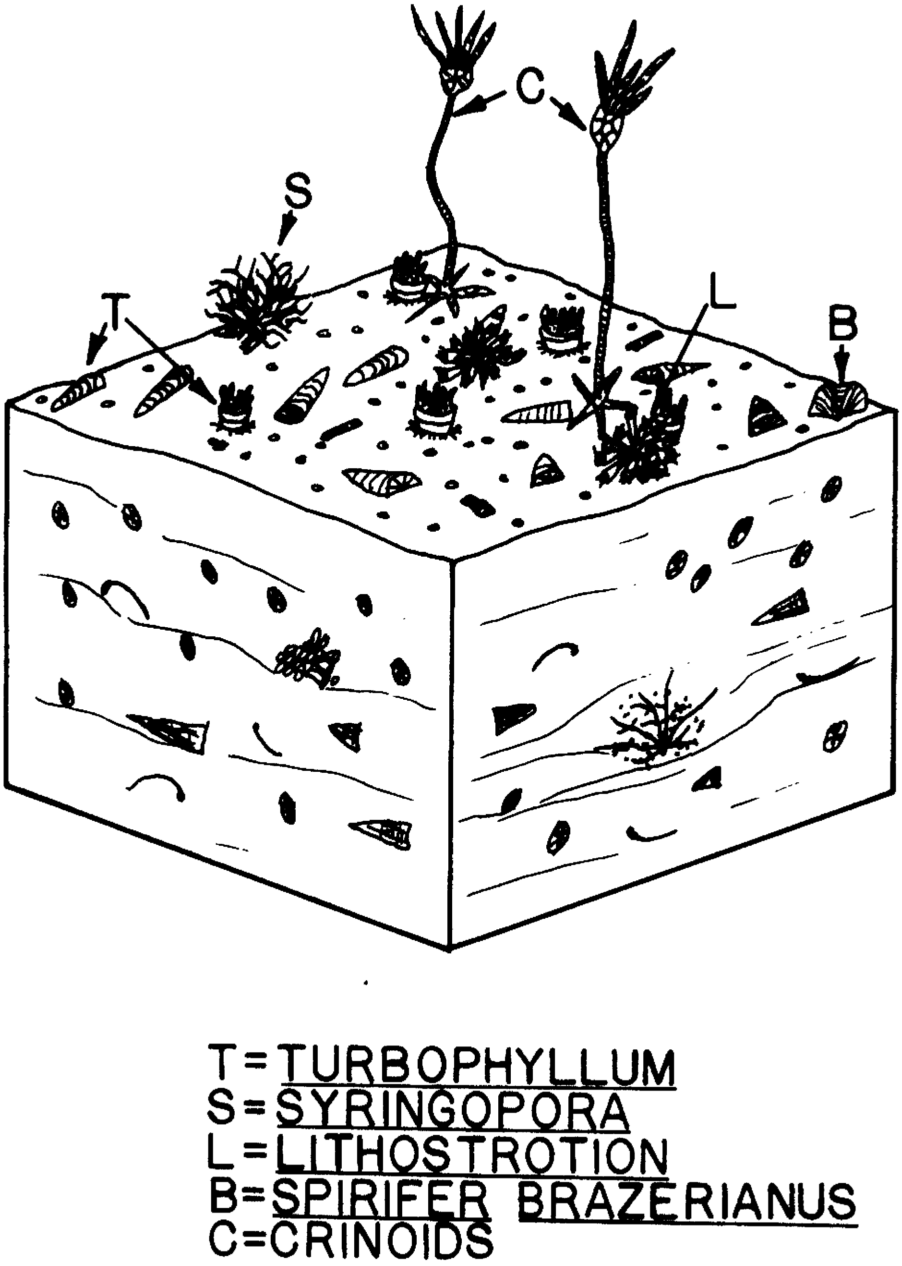


Figure 42. Block diagram of the *Lithostrotion-Turbophyllum* Zone.

Table 12. Trophic levels and abundances of fauna at sample site 15

UNIT #1 Site #15 *Lithostrotion-Turbophyllum* Zone Dry Lake

Taxon	Trophic level	Number	Percent
Turbophyllum	HF	31	57
Orthotetes kaskaskiensis	LF-HF[a]	7	13
Crinoids	VHF	5(?)	9
Byrozoans	HF	5(?)	9
Syringopora	HF	2	4
Rugosochonetes loganensis	LF	2	4
Gastropod	MED	1	2
Linoproductus tenuicostus	LF	1	2
Echinoids	HF	1(?)	2
		54	102

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

[a] Juvenile-young adult stages cemented and occupied HF trophic level. Older adults detached, free-lying and occupied LF trophic level.

Table 13. Trophic levels and abundances of fauna at sample site 17

UNIT #1 Site #17 *Lithostrotion-Turbophyllum* Zone Beirdneau Peak

Taxon	Trophic level	Number	Percent
Turbophyllum	HF	12	54
Crinoids	VHF	8(?)	36
Lithostrotion	HF	1	5
Syringiopora	HF	1	5
		22	100

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

Table 14. Trophic levels and abundances of fauna at sample site 18

UNIT #1 Site #18 *Lithostrotion-Turbophyllum* Zone Logan Peak

Taxon	Trophic level	Number	Percent
Turbophyllum	HF	34	72
Crinoids	VHF	5(?)	11
Lithostrotion	HF	4	9
Syringiopora	HF	2	4
Straparollus	MED	1	2
Spirifer brazerianus	LF	1	2
		47	100

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

Table 15. Trophic levels and abundances of fauna at sample site 19

UNIT #1 Site #19 *Lithostrotion-Turbophyllum* Zone East Fork Canyon

Taxon	Trophic level	Number	Percent
Turbophyllum	HF	15	52
Crinoids	VHF	4(?)	14
Cleiothyridina hirsuta	LF	4	14
Bryozoans	HF	2(?)	7
Ostracods	NBC	2	7
Echinoids	VHF	1(?)	3
Spirifer	LF	1	3
		29	100

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

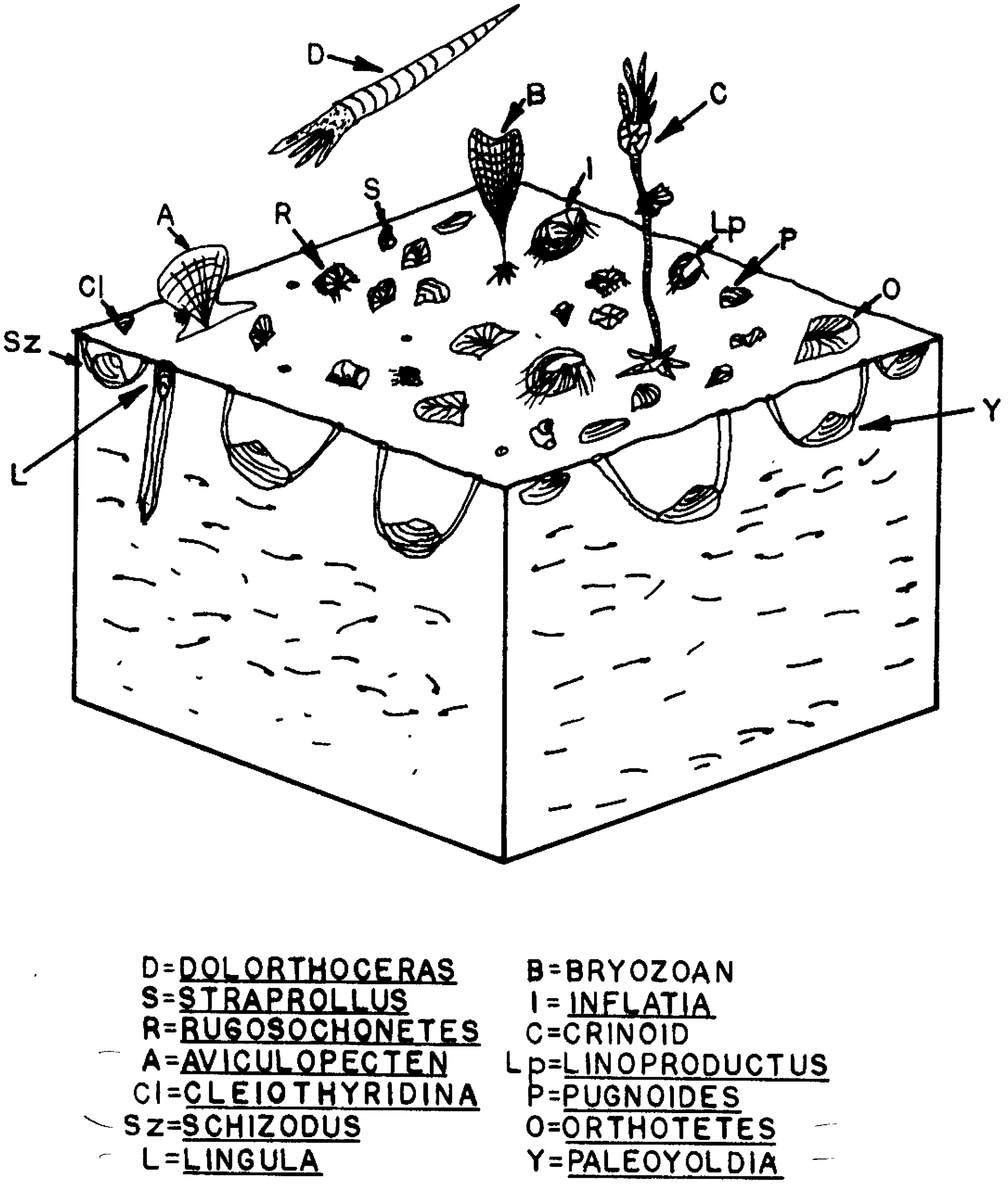


Figure 43. Block diagram of the Brachiopod-Pelecypod Zone.

Table 16. Trophic levels and abundances of fauna at sample site 1

UNIT #2 Site #1 Brachiopod-Pelecypod Zone Dry Lake

Taxon	Trophic level	Number	Percent
Rugosochonetes loganensis	LF	124	51
Pugnoides ottumwa	LF	29	12
Bryozoan	HF	24	10
Linoproductus tenuicostus	LF(?) HF(?)[b]	16	6
Crinoids	VHF	10(?)	4
Echinoconchus alternatus	LF	8	3
Inflatia inflatus	LF	8	3
Orthotetes kaskaskiensis	LF-HF[a]	5	2
Schellwienella	LF-HF[a]	5	2
Cleiothyridina hirsuta	LF	4	2
Spirifer brazerianus	LF	3	1
Rhipidomella	VLF	2	1
Schuchertella	LF-HF[a]	1	.5
Composita sulcata	LF	1	.5
Paleoyoldia	DID	1	.5
		241	98.5

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal low filter-feeder
LF = Low filter-feeder
HF = High filter feeder
VHF = Verh-high filter-feeder
NBC = Nektobenthic carnivore
NC = Nektonic carnivore

[a] Juvenile-young adult stages cemented and occupied HF trophic level. Older adults detached, free=lying and occupied LF trophic level.

[b] Juvenile-young adult attached by spines to host and occupied VHF trophic level. Older adults detached, free-lying and occupied LF trophic level (see Grant, 1963).

Table 17. Trophic levels and abundances of fauna at sample site 3

UNIT #2 Site #3 Brachiopod-Pelecypod Zone Dry Lake

Taxon	Trophic level	Number	Percent
Cleiothyridina hirsuta	LF	129	22
Paleoyoldia	DID	117	20
Pugnoides ottumwa	LF	49	8
Inflatia inflatus	LF	40	7
Linoproductus tenuicostus	LF-HF[b]	40	7
Punctospirifer	LF	39	6
Aviculopecten	LF	32	5
Rugosochonetes loganensis	LF	24	4
Orthotetes kaskaskiensis	LF-HF[a]	24	4
Myalina	LF	21	4
Schizodus	SID	18	3
Martinia	LF	15	3
Schuchertella	LF-HF[a]	9	2
Deltopecten	LF	5	1
Composita sulcata	LF	4	.7
Cypricardinia	ILF	3	.5
Rhipidomella	LF	2	.3
Eumetria	LF	2	.3
Centronella	LF	2	.3
Allorisma	SID	1	.2
Girtyella	LF	1	.2
Pelecypod (?)	ID	1	.2
Echinoid	VHF	1	.2
Caneyella	LF	1	.2
		579	99.1

DID = Deep-infaunal deposit-feeder
SID = Shallow infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

[a] Juvenile-young adult stages cemented and occupied HF trophic level. Older adults detached, free-lying and occupied LF trophic level.

[b] Juvenile-young adult attached by spines to host and occupied VHF trophic level. Older adults detached, free-lying and occupied LF trophic level (see Grant, 1963).

Table 18. Trophic levels and abundances of fauna at sample site 7

UNIT #2 Site #7 Brachiopod-Pelecypod Zone Dry Lake

Taxon	Trophic level	Number	Percent
Cleiothyridina hirsuta	LF	170	56
Aviculopecten	LF	30	10
Paleoyoldia	DID	19	6
Allorisma	SID	15	5
Deltopecten	LF	13	4
Inflatia inflatus	LF	12	4
Schuchertella	LF-HF[a]	12	4
Composita sulcata	LF	10	3
Pugnoides ottumwa	LF	6	2
Schizodus	SID	5	1.5
Orthotetes kaskaskiensis	LF-HF[a]	5	1.5
Lingula	ILF	3	1
Myalina	LF	2	.5
Streptacis	MED	1	.5
		303	99

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal-low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

[a] Juvenile-young adult stages cemented and occupied HF trophic level. Older adults detached, free-lying and occupied LF trophic level.

Table 19. Trophic levels and abundances of fauna at sample site 8

UNIT #2 Site #8 Brachiopod-Pelecypod Zone Dry Lake

Taxon	Trophic level	Number	Percent
Cleiothyridina hirsuta	LF	89	41
Rugosochonetes loganensis	LF(?)	57	26
Orthotetes kaskaskiensis	LF-HF[a]	19	9
Schizodus	SID	17	8
Martinia	LF	7	3
Paleoyoldia	DID	5	3
Crinoids	VHF	4(?)	2
Aviculopecten	LF	4	2
Inflatia inflatus	LF	4	2
Pugnoides ottumwa	LF	3	1
Composita sulcata	LF	2	1
Blastoids	VHF	2	1
Lingula	ILF	2	1
Deltopecten	LF	1	.5
Punctospirifer	LF	1	.5
Allorisma	SID	1	.5
		218	101.5

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal-low filter-feered
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

[a] Juvenile-young adult stages cemented and occupied HF trophic level. Older adults detached, free-lying and occupied LF trophic level.

Table 20. Trophic levels and abundances of fauna at sample site 14

UNIT #2 Site #14 Brachiopod-Pelecypod Zone Dry Lake

Taxon	Trophic level	Number	Percent
Paleoyoldia	DID	261	50
Schuchertella	LF-HF[a]	57	11
Orthotetes kaskaskiensis	LF-HF[a]	47	9
Straprollus	SD	37	7
Dictyoclostus	LF	29	6
Streptacis	SD	13	2.5
Schizodus	SID	13	2.5
Aviculopecten	LF	13	2.5
Inflatia inflatus	LF	10	2
Deltopecten	LF	7	1
Parallelodon	LF	7	1
Streblopteria	LF	5	1
Martinia	LF	5	1
Dolorthoceras	NBC	4	.8
Composita sulcata	LF	3	.6
Pleurotomaria	MED	2	.4
Echinoconchus alternatus	LF	1	.2
Crinoid	VHF	1	.2
		515	98.7

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal-low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

[a] Juvenile-young adult stages cemented and occupied HF trophic level. Older adults detached, free-lying and occupied LF trophic level.

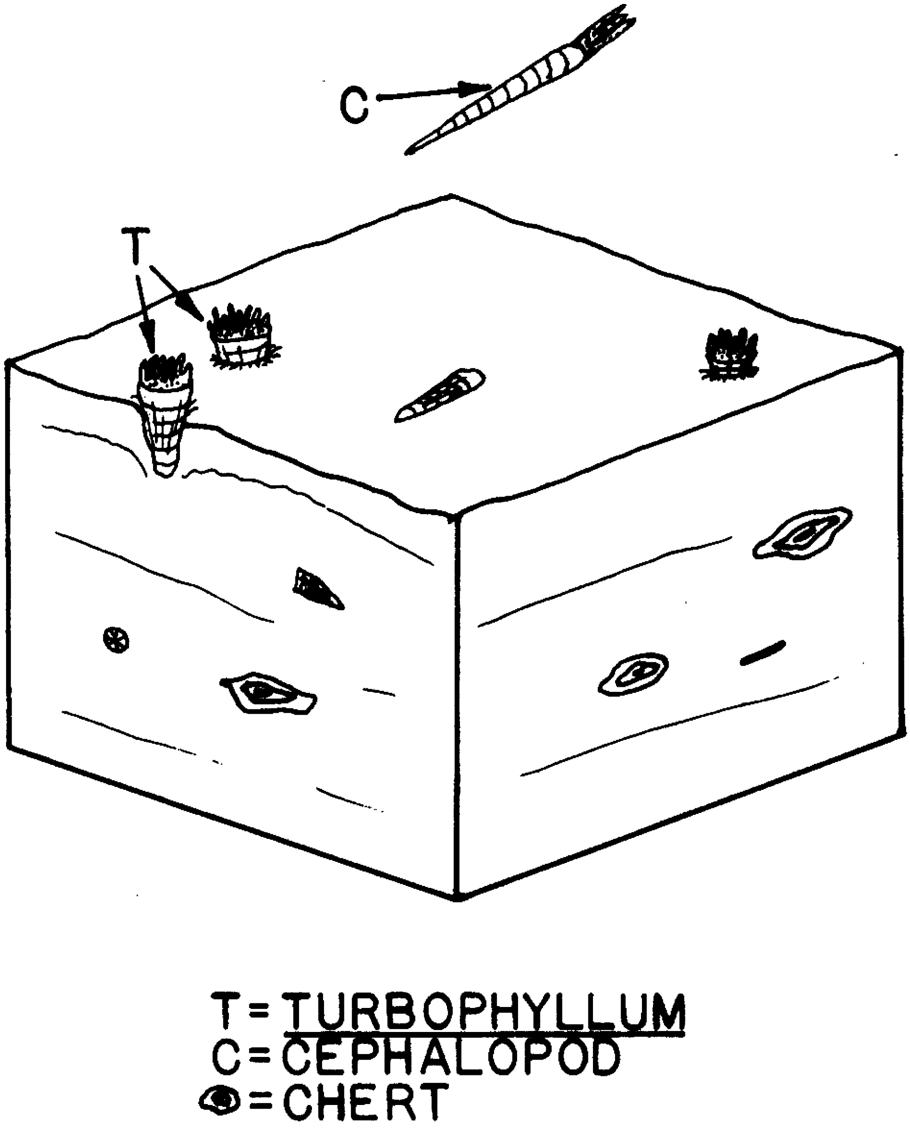


Figure 44. Block diagram of the Coral-Cephalopod Zone.

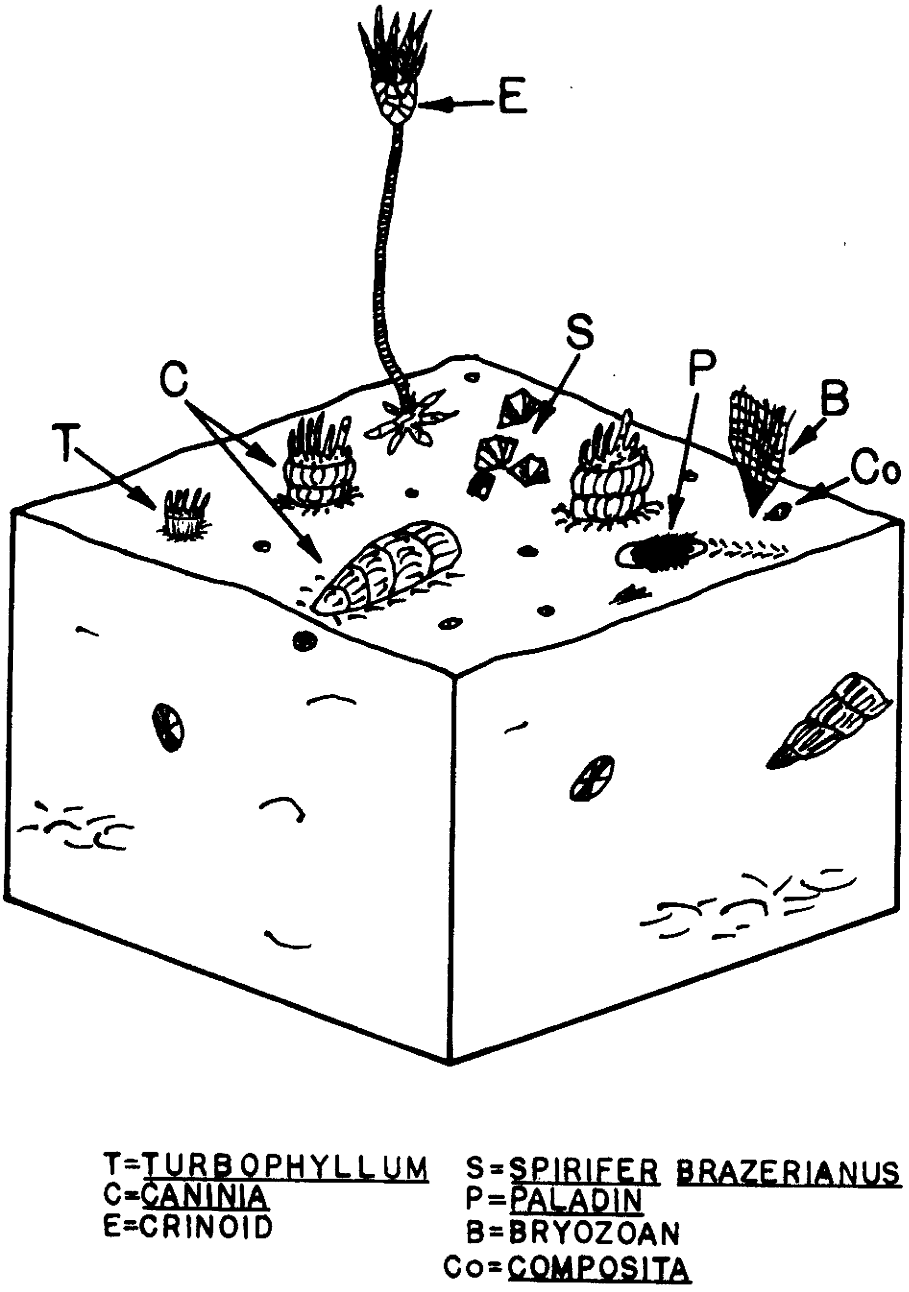


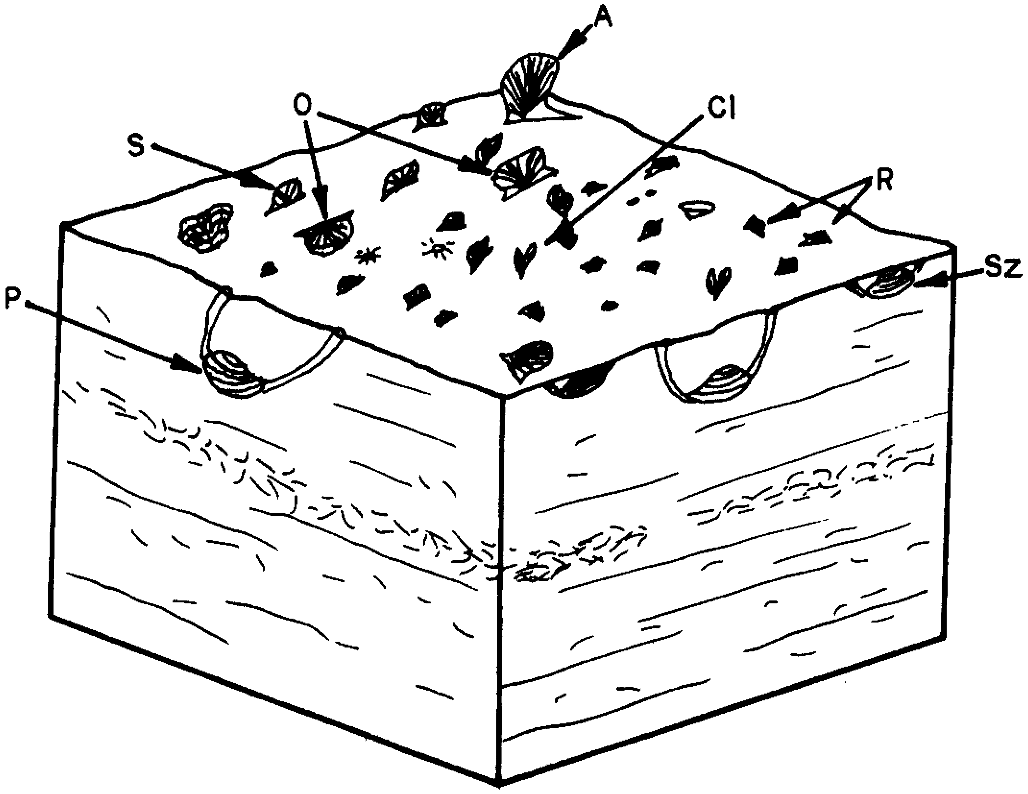
Figure 45. Block diagram of the *Caninia* Zone.

Table 21. Trophic levels and abundances of fauna at sample site 5

UNIT #3 Site #5 *Caninia* Zone Dry Lake

Taxon	Trophic level	Number	Percent
Spirifer brazerianus	LF	36	56
Turbophyllum	HF	8	12
Eumorphoceras	NBC	5	8
Crinoids	VHF	5(?)	8
Composita sulcata	LF	4	6
Caninia	HF	3	5
Bryozoans	HF	2	3
Paladin	SD	1	1.5
Shark	NC	1	1.5
		64	99

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal-low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore



R=*RUGOSOCHONETES LOGANENSIS*
O=*ORTHOTETES KASKASKIENSIS*
Cl=*CLEIOTHYRIDINA*
A=*AVICULOPECTEN*
S=*SCHUCHERTELLA*
P=*PALEOYOLDIA*
Sz=*SCHIZODUS*

Figure 46. Block diagram of the *Rugosochonetes-Orthotetes* Zone.

Table 22. Trophic levels and abundances of fauna at sample site 9

UNIT #3 Site #9 *Rugosochonetes-Orthotetes* Zone Dry Lake

Taxon	Trophic level	Number	Percent
Rugosochonetes loganensis	LF(?)	211	63
Orthotetes kaskaskiensis	LF-HF[a]	22	7
Eumetria	LF	17	5
Streptorhynchus	LF-HF[a]	16	5
Paleoyoldia	DID	13	4
Cleiothyridina hirsuta	LF	13	4
Leiorhynchus	LF	12	3.5
Aviculopecten	LF	6	2
Schuchertella	LF-HF[a]	6	2
Bellerophon	HF(?)	4	1
Leda	DID	3	1
Schizodus	SID	3	1
Leptodesma	LF	2	.6
Composita sulcata	LF	2	.6
Inflatia inflatus	LF	1	.3
Orbiculoidia	LF	1	.3
Dielasma	LF	1	.3
		333	100.6

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi-or endobenthonic deposit-feeder
ILF = Infaunal-low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

[a] Juvenile-young adult stages cemented and occupied HF trophic level. Older adults detached, free-lying and occupied LF trophic level.

Table 23. Trophic levels and abundances of fauna at sample site 12

UNIT #3 Site #12 *Rugosochonetes-Orthotetes* Zone Dry Lake

Taxon	Trophic level	Number	Percent
Schuchertella	LF-HF[a]	88	66
Rugosochonetes loganensis	LF(?)	33	25
Cleiothyridinia hirsuta	LF	4	3
Paleoyoldia	DID	3	2
Orbiculoidia	LF	2	1.5
Orthotetes kaskaskiensis	LF-HF[a]	1	.75
Streptorhynchus	LF-HF[a]	1	.75
		132	99

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal-low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

[a] Juvenile-young adult stages cemented and occupied HF trophic level. Older adults detached, free-lying and occupied LF trophic level.

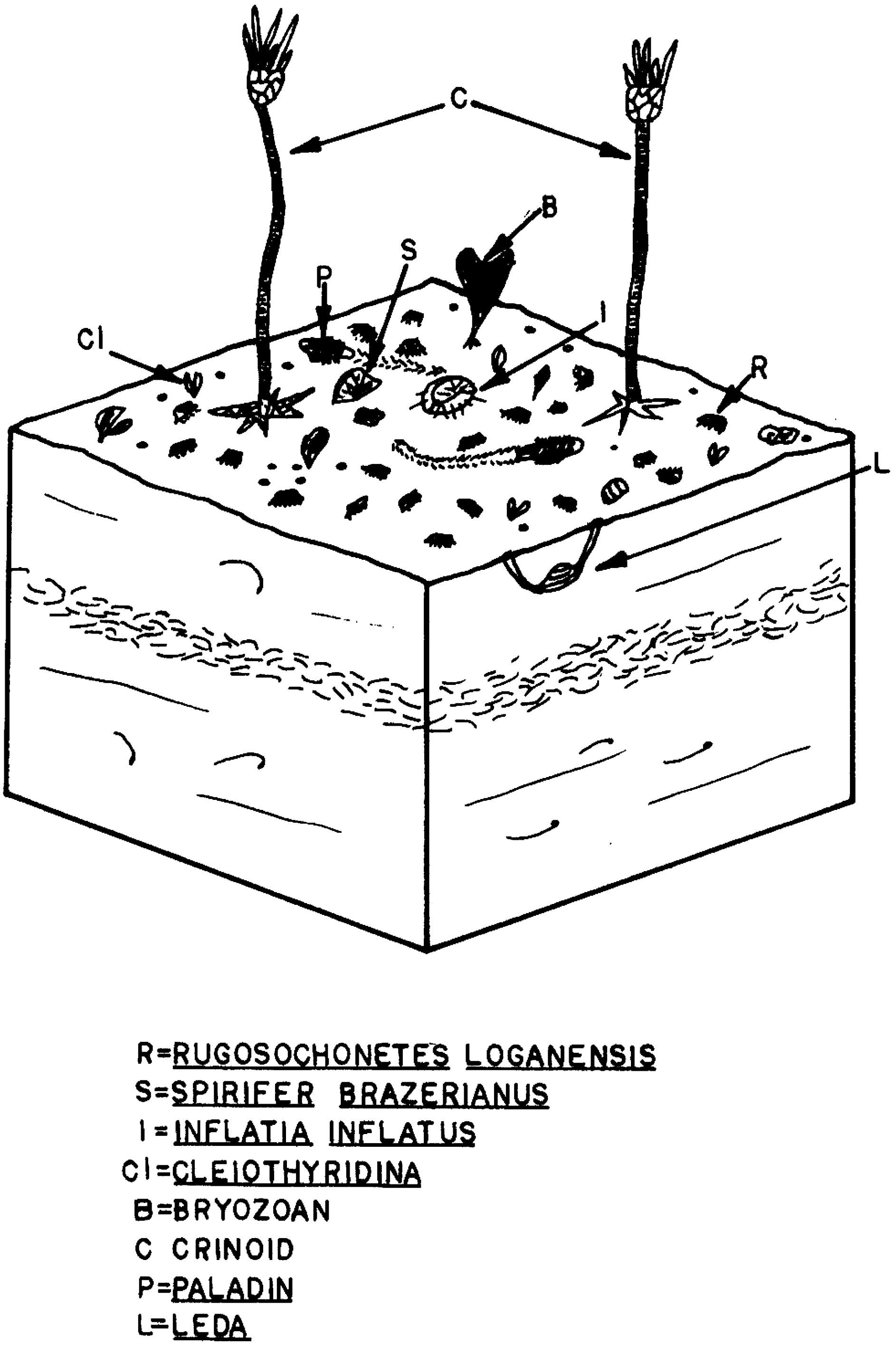


Figure 47. Block diagram of the *Rugosochonetes-Paladin* Zone.

Table 24. Trophic levels and abundances of fauna at sample site 11

UNIT #3 Site #11 *Rugosochonetes-Paladin* Zone Dry Lake

Taxon	Trophic level	Number	Percent
Rugosochonetes loganensis	LF(?)	331	84
Crinoids	VHF	20(?)	5
Inflatia inflatus	LF	13	3
Spirifer brazerianus	LF	12	3
Martinia	LF	6	1.5
Cleiothyridina hirsuta	LF	5	1.2
Bryozoan	HF	4	1
Straparollus	MED	1	.25
Echinoconchus alternatus	LF	1	.25
Blastoids	VHF	1	.25
Linoproductus tenuicostus	LF-HF[a]	1	.25
Rhipidomella	LF	1	.25
		396	99.95

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi- or endobenthonic deposit-feeder
ILF = Infaunal-low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnibore
NC = Nektonic carnivore

[a] Juvenile-young adult attached by spines to host and occupied VHF trophic level. Older adults detached, free-lying and occupied LF trophic level (see Grant, 1963).

Table 25. Trophic levels and abundances of fauna at sample site 16

UNIT #3 Site #16 *Rugosochonetes-Paladin* Zone Dry Lake

Taxon	Trophic level	Number	Percent
Rugosochonetes loganensis	LF(?)	205	77
Crinoids	VHF	20(?)	7.5
Paladin	SD	12	4.5
Inflatia inflatus	LF	9	3.5
Blastoids	VHF	8	3
Spirifer brazerianus	LF	4	1
Bryozoan	HF	3	.75
Cleiothyridina hirsuta	LF	3	.75
Leda	DID	1	.4
Colonial coral	HF	1	.4
Fern	--	1	.4
Leiorhynchus	LF	1	.4
		265	99.6

DID = Deep-infaunal deposit-feeder
SID = Shallow-infaunal deposit-feeder
MED = Mobile epi-or endobenthonic deposit-feeder
ILF = Infaunal-low filter-feeder
LF = Low filter-feeder
HF = High filter-feeder
VHF = Very-high filter-feeder
NBC = Nektobenthos carnivore
NC = Nektonic carnivore

suspension-feeders with the very-high suspension-feeders in the secondary position. The samples of the Crinoid-Bryozoan Zone contain crinoid and bryozoan debris (Figure 48). Both taxa are very high filter-feeders.

According to the trophic-level relationships listed by Walker (1972, p. 83), trophic relationships of partitioning or competition should be most apparent in faunal associations with an index of affinity of less than .30. In most cases the faunal associations within the proposed zone, especially in the associations containing the dominant taxon, are in close accord with the trophic-level separation proposed by Walker (1972).

There are some questions on the trophic levels of some taxa. Stratification of the low filter-feeder trophic-level may result from the life position assumed by the strophomenid brachiopods (free-lying, parallel to the substrate) as opposed to the other brachiopods (perpendicular to oblique to the substrate). Grant (1963, p. 134) suggested that juveniles and young adults of species of linoproductid brachiopods may have used spines to attach to crinoid stems, thereby becoming very high filter-feeders instead of low filter-feeders. Later in their ontogeny these linoproductids became detached from their host and assumed a semi-infaunal mode of life.

The faunal zones within the limestone units show a distinct absence of the infaunal trophic-level forms. A possible explanation my be a lack of organic material as a food source for the deposit-feeders.

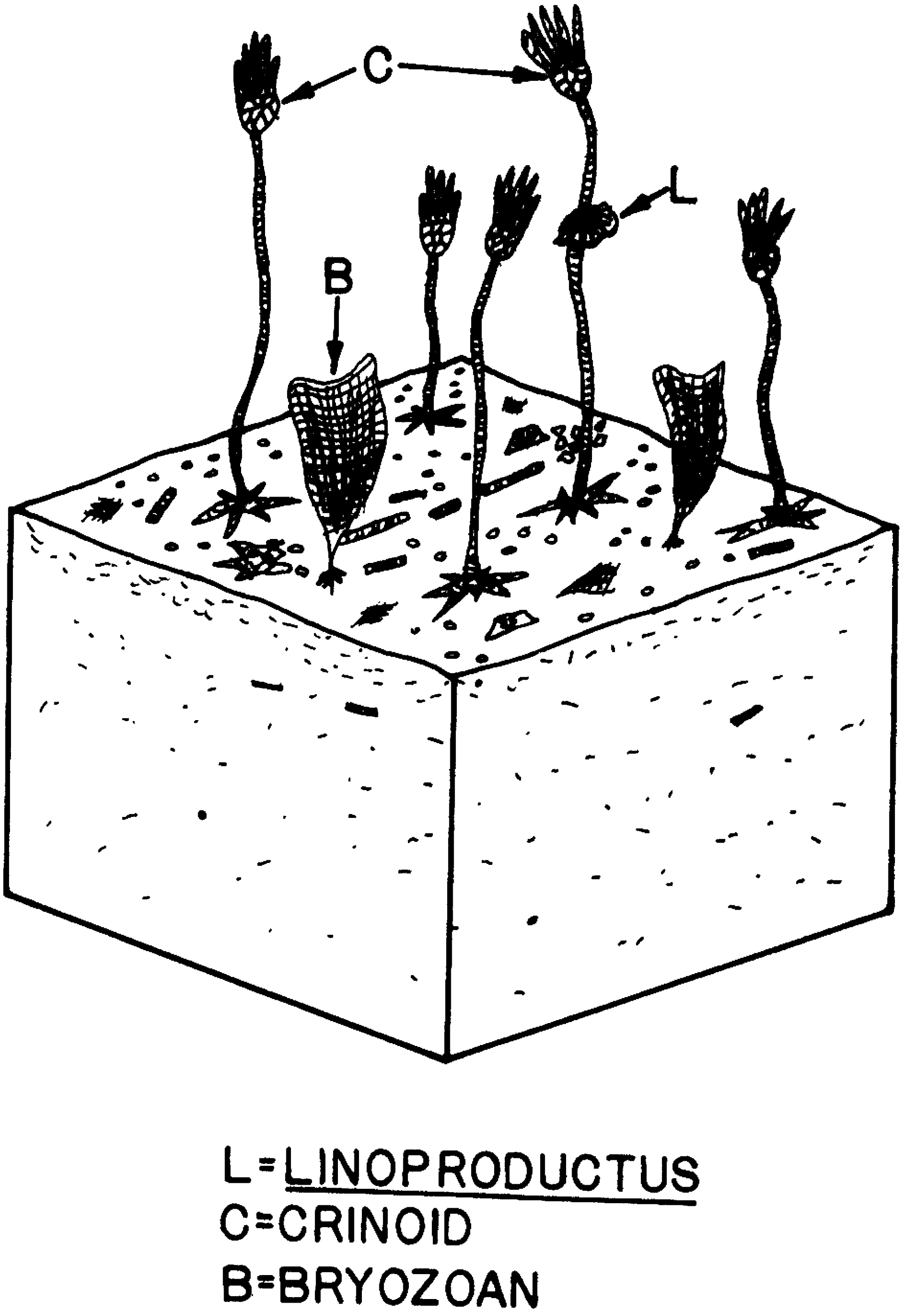


Figure 48. Block diagram of the Crinoid-Bryozoan Zone.

Also, the darkness of the limestones may indicate a reducing environment just below the sediment-water interface although no sulfides were indicated from the X-ray mineralogy (Table 1). The faunal zones within the shale units show a marked decrease in forms which feed above the sediment, whereas the infauna increased. This may be due to the increases in agitation, insedimentation rate, in turbidity, or in mobility of the substrate which the pelecypods are better able to cope with.

The density of the fauna in the proposed Coral-Cephalopod Zone is low. The sparse fauna is probably the result of increased environmental stress that rendered the habitat unsuitable for colonization by most epi- and endobenthic organisms. Such possible stresses include: increased turbidity, substrate fluidity, and lowered oxygen tension in and above the substrate.

PALEOECOLOGY

General Statement

The paleoecology of the Great Blue Limestone will be discussed for each of the faunal zones within the three units of the Great Blue. The factors considered will include: substrate, agitation, depth, turbidity, and sedimentation rate. Inferences concerning these factors for each faunal zone are presented in Table 26. The factors of light, temperature, and salinity did not vary significantly in the study area during the late Mississippian. The sediments accumulated in the photic zone as indicated by the preservation of corals inferred to have been hermatypic. Turbidity, resulting from the terrigenous influx and/or bioturbation, may have affected the amount of light which penetrated to the bottom. The temperature would have been warm as indicated by the equatorial position of the study area during the late Mississippian (Seyfert and Sirkin, 1973) and the proposed circulation pattern of the shelfal sea. An open-marine environment is indicated by the preserved presence of fauna with relatively narrow salinity tolerances (i.e. corals, crinoids, and brachiopods).

The inferred depth of the depositional environment in the study area during the late Mississippian fluctuated within the bathymetric zone below the intertidal and at, slightly below, or slightly above

Table 26. Paleoecology of the faunal zones of the Great Blue Limestone

Mega-faunal Zone	Substrate	Agitation	Dominant trophic level	Turbidity	Sedimentation rate	Depth
Crinoid-Bryozoan	Lime mud	Moderate	VHF	Clear	Low	Moderate
Rugosochonetes-Paladin	Lime mud	Low	LF	Cloudy	Low	Moderate
Rugosochonetes-Orthotetes	Terrig. mud	Low	LF	Cloudy	Mod	Shallow
Caninia	Lime mud	Moderate	HF	Low	Low	Moderate
Coral-Cephalopod	Lime mud	Low	HF	Low	Low	?
Brachiopod-Pelecypod	Terrig. mud	Moderate	LF-DID	Cloudy	Mod	Shallow
Lithostrotion-Turbophyllum	Lime mud	Moderate	HF	Clear	Low	Moderate
Turbophyllum	Lime and Terrig. mud	Low to Moderate	HF --	Clear to cloudy	Low to Mod	Moderate to Shallow

effective wave base. Evidence of agitated shallow water such as dunes, shrinkage cracks, rip-up clasts, oolites, pellets, oncolites, stromatolites, reefs or evaporites is not present in any part of the section. Data on post-mortem, recumbent coral orientation, presented later in this section, suggest the presence of currents of low energy. The increases in the insoluble residue content of the rocks reflect influxes of terrigenous material. Increased terrigenous influx suggests closer proximity to a source area as a consequence of changes in sea level or the shifting of distributaries that emptied into the shelfal sea.

Lower Great Blue

Turbophyllum Zone

The substrate of the *Turbophyllum* Zone varied between carbonate mud, indicated by the micrite lithology, and terrigenous mud, indicated by the high percent of insoluble residue (greater than 40 percent) including quartz, feldspars, and clay minerals. The sedimentation rate at the time of deposition was variable. Low sedimentation rates are indicated by the hemispherical morphology of the colonial corals *Lithostrotion* and *Syringopora* (Philcox, 1971). Moderate sedimentation rates are indicated by the sandy nature of part of the zone which suggests increased influx of terrigenous detritus. The absence of current-induced features and the low degree of visible abrasion on the coral specimens suggest low agitation. The inferred depth was probably at or just below effective wave base.

The degree of turbidity varied in relation to the deposition of lime mud or terrigenous mud. During the deposition of lime mud the sedimentation rate was low and the water generally clear. The presence of corals is evidence of low turbidity. Corals are and probably always were intolerant of turbid conditions and are not found in the intervals with higher percentages of insoluble residue. More turbid conditions resulting from the terrigenous influx probably created conditions inimical to colonization of the sandy substrate by corals.

Lithostrotion-Turbophyllum Zone

The substrate of the *Lithostrotion-Turbophyllum* Zone is inferred to have been a carbonate mud as evidenced by the micritic lithology and the low percent of insoluble residue (2-20 percent) present in the interval. Hubbard and Pocock (1972, p. 622) indicated solitary rugose corals preferred to inhabit finer grained sediments indicative of lower energy environments. The agitation is inferred to be low as indicated by a low degree of visible abrasion on the coralla and the segments of articulated crinoid columnals. However, the inferred agitation was sufficient to topple and reorient a majority of the coralla. The two to one ratio of toppled to upright (vertical) coralla at the four locations suggests that the current activity was low to moderate. The upright coralla were not scoured and toppled even after death. The generally platykurtic and positively skewed size-frequency distributions of the populations suggest an essentially unwinnowed population was preserved (Figure 39). The lack of evidence of winnowing also suggests a low energy environment. The hemispherical shape of the colonial corals suggests a low sedimentation rate and modest currents (Philcox, 1971). In the paleoecological analysis of the Middle Devonian Jeffersonville Limestone at the Falls of the Ohio River, Kentucky and Indiana, Kissling and Lineback (1967, p. 171) stated: "Gentle currents and low turbulence are suggested by the small number of overturned and recumbent corals, the high standard deviations of the mean azimuths, and the micrite nature of the sediment." Strong unidirectional currents should produce orientations of coralla along a mean vector with a low or small standard deviation of the mean azimuth. The strong current would reorient a majority of the coralla to the most hydraulically stable position. High or large standard deviations of the mean azimuth may be the result of gentle unidirectional currents which produced a preferred orientation, but could not reorient a substantial number of the coralla. A multiplicity of current directions with any degree of intensity would tend to cause an increase in the standard deviations. One current would alter the orientations produced by another current. The work of Kissling and Lineback (1967) included the possibility of a multiplicity of current directions. The radial deviations (standard deviation in radians) of the coralla at the four locations in the study area range from 1.21706 radians (69 degrees 36 minutes) to 0.95195 radians (54 degrees 36 minutes). The large radial deviations of the populations, the low ratio of toppled to upright coralla and the micrite nature of the substrate in the study area together indicate low to possibly moderate energy and variable currents.

Four well-preserved calyxes of *Cribroblastus cornutus* recently were found in the lower Great Blue (Luke and Moyle, 1976). These articulated calyxes support the inference of a low-energy environment. Wolfenden (1948, p. 884) indicated the crinoid-coral association is prominent in the shelf and back reef areas, where current activity is weak. Turbidity in this interval would have been low resulting from the low intensity currents clearing any suspended material from the area. Evidency of bioturbation, which could have kept the fines in suspension, is lacking. The sedimentation rate was probably low as indicated by the toppled coralla and the disarticulated brachiopods. If the sedimentation rate had been higher, a greater number of coralla probably would have been preserved in the life orientation and a greater percentage of the brachiopods would have been buried without disarticulation.

Long Trail Shale

Brachiopod-Pelecypod Zone

A substrate of terrigenous mud is inferred from the high percentage of insoluble residue (greater than 95 percent) containing quartz, feldspars, and clay minerals (Table 1). The agitation increased somewhat from the time of the deposition of the underlying *Lithostrotion-Turbophyllum* Zone as indicated by the presence of disarticulated pelecypods, sparse crinoid columnals and some abrasion on the valves of the pelecypods and brachiopods.

The zones with abundant mollusks are inferred to reflect environments of shallower water than those of the coral and brachiopod dominated zones. The zones dominated by the brachiopod *Rugosochonetes longanensis* are the exception to this inference. The mollusks are better adapted to the shallower areas with the accompanying increases in agitation, in turbidity, in terrigenous influx, and in substrate mobility. Exploitation of agitated, shoaled substrates by bivalved mollusks in comparison to brachiopods, is a consequence of superior anchorage to the substrate via a byssus (Stanley, 1972, p. 204) and mobility of the bivalved mollusks in shifting substrates (Purdy, 1964, p. 250). Thayer (1974, p. 121) stated: "An increase in the infauna is interpreted as adaptation to increased environmental stress." Bretsky (1968, p. 1232; 1969, p. 45) described a linguloid-molluscan association, similar in composition to the fauna in the Great Blue. He interpreted this association as a nearshore community. Levinton and Bambach (1974, p. 97) noted the presence of *Yoldia,* a deep infaunal deposit feeding pelecypod, in a shallow and turbulent channel community. *Paleoyoldia,* a distant relative with a similar mode of life is quite prevalent in the Long Trail Shale. Bowen, Rhodes and McAlester (1974, p. 100) indicated that mollusks dominated the nearshore *Bellerophon* community of the Upper Devonian, Sonyea Group in New York. Yochelson (1969, p. 445) suggested that pelecypods of the Redwall Limestone were most abundant in shallow-water environments. Watkins (1975, p. 125) indicated that pectenoid bivalves, which are common in the Brachiopod-Pelecypod Zone of this study, dominated nearshore habitats.

Pediculate, articulated brachiopods are among the most resistant of the bivalved organisms to disarticulation (Middlemass, 1962, p. 254). Thayer (1975a) indicated a distinct inability of the values of dead articulated brachiopod to gape due to the muscle arrangement. Brachiopods under the influence of weak currents should retain a high percentage of articulated valves, whereas, a high-energy environment would abrade and disarticulate the valves. Shell destruction is 150 to 1,000 times more rapid in the surf than in sublittoral environments (Driscoll, 1970, p. 905). Populations of brachiopods with a high percentage of disarticulated valves which show little visible abrasion, as is the case with the brachiopods in this zone, suggest an environment where the brachiopods were not buried immediately upon death, but remained uncovered for a time. The time between death and burial would allow the soft parts to decay. Moderate agitation would winnow the juveniles from the assemblage and disarticulate the valves of the remaining individuals without significant abrasion. Burial would then follow. However, Brookfield (1973, p. 245) expected exposed valves to become bored or encrusted. Borings or encrustations are not present on the fossils found in the Great Blue.

The relative abundance of echinoderm debris is considerably lower in the shale units than in the carbonate units. The low amount of debris in the shale units may indicate a relative increase in the agitation which increased the disarticulation and winnowing of crinoid calyxes and columnals. The paucity of crinoid debris may also indicate a substrate inimical to colonization by crinoids. Increased agitation is suggested by the influx of terrigenous material and the presence of disarticulated pelecypods and brachiopods. If crinoids and blastoids did exist in sizable numbers in the shale units they may have been disarticulated and transported away from the area by currents.

The water probably was cloudy as the result of the terrigenous influx and the increased agitation. The sedimentation rate was probably increase as the result of the increased terrigenous influx. However, the preservation of disarticulated brachiopods suggests that sedimentation rates did not rapidly bury these organisms upon their death. The disarticulation may be the result of the increased agitation.

Upper Great Blue

Coral-Cephalopod Zone

The microcrystalline nature of the rock is evidence of a former carbonate-mud substrate. The dark gray color of the rock and the sparse fauna with the absence of infaunal forms suggest that the Eh=0 line was near the sediment-water interface. The presence of corals and the small size of the population suggest the possibility of an Eh=0 line which fluctuated above and below the sediment-water interface. A small number of coral polyps may have been able to colonize this zone when the Eh=0 line was below the sediment-water interface. When the Eh=0 line rose above the substrate the corals were killed. The proposed lack of current activity may have resulted in the small number of polyps which were able to invade the area.

Quiet water is suggested by the micritic nature of the substrate. The inferred depth of this zone is relatively deeper than that of the other zones with the bottom below the effective wave base. Another explanation is that the depth remained the same as the other zones but with stagnant conditions prevailing. This situation would have been similar to that of a restricted lagoon with no current activity.

Caninia Zone

The microcrystalline nature of the rock and the low percentage of insoluble residue (10-30 percent) suggest a carbonate-mud substrate. The low degree of abrasion of the coralla and the micritic lithology suggest a low-energy environment of deposition. Hubbard and Pocock (1972, p. 622) indicated solitary rugose corals preferred finer grained sediments indicative of lower energy environments. The depth of this zone is inferred to be similar to the depth of the *Lithostrotion-Turbophyllum* Zone. The low degree of abrasion, nature of the substrate, and the types of fauna, specifically rugose corals and spiriferid brachiopods, suggest an offshore environment with the bottom at or below effective wave base. Comparatively low turbidity characterized the water immediately above the substrate occupied by corals which were intolerant of turbid water.

Rugosochonetes-Orthotetes Zone

A substrate of terrigenous mud is suggested by the high percentage of insoluble residue (greater than 90 percent) containing quartz, feldspars, and clay minerals (Table 1). The preserved faunal assemblage and the terrigenous influx suggest increased agitation and associated turbidity.

Rugosochonetes loganensis is a slightly concavo-convex strophomenid with a semi-infaunal life orientation. The expected ratio of concave-up to convex-up valves in a quiet-water environment for shells of this organism should be quite high. Populations of the same organism in a high-energy environment should have a low ratio of concve-up to convex-up valves because the valves would be overturned to the more hydrodynamically stable convex-up orientation (Emery, 1968; Clifton, 1971). The ratio of concave-up to convex-up valves of *Rugosochonetes loganensis* in the study area is approximately one. This ratio suggests moderate currents of sufficient energy to overturn approximately one-half of the valves. Bioturbation or some form of predation could have produced the observed results but no evidence (trace fossils) of such activity was observed. The abundance of pelecypods, a predominantly nearshore inhabitant, and the associated terrigenous influx, suggest a shallower environment.

Rugosochonetes-Paladin Zone

An argillaceous, carbonate-mud substrate is inferred from the intermediate percentage of insoluble residue (50 percent). Minimal abrasion and the low frequency of disarticulated brachiopod valves suggest a low degree of agitation. The amount of insoluble residue, and the low degree of abrasion on the brachiopod specimens, as evidenced by the spines preserved on the productid and chonetid brachiopods, suggest the depth of the environment was intermediate between the zones of shale deposition (*Rugosochonetes-Orthotetes* Zone) and the deeper zone of limestone deposition (*Caninia* Zone). Turbid conditions may have existed immediately above the substrate. Grazing trilobites may have churned up the sediment and the low intensity currents would not have removed the suspended material.

Crinoid-Bryozoan Zone

The low amount of insoluble residue, the microcrystalline nature of the rock, and the fauna of crinoids and bryozoans suggest a carbonate-mud substrate. Disarticulated crinoid and bryozoan debris indicate the presence of some agitation. However, very little agitation is necessary to disarticulate crinoids and bryozoans. Schwarzacher (1963, p. 584) stated that the competent velocities for moving crinoid debris are between 2 and 10 centimeters per second. A small number of sections of articulated crinoid columnals were found on slabs distributed throughout the Great Blue (Figure 49). The presence of segments of articulated crinoid columnals and blastoid brachioles (Figure 40) suggests a lower-energy environment, than the underlying, *Rugosochonetes-Paladin* Zone. The lithologies are similar to the crinoidal limestone characterized and illustrated by Lane (1971, p. 1,403) as a crinoidal deposit which accumulated under conditions of low sedimentation rates and weak currents (Figure 41). The nature of the substrate and the fauna present suggest a clear-water environment. Crinoids apparently grew best in shallow, rather clear, well aerated, and warm water (Manten, 1970, p. 171).

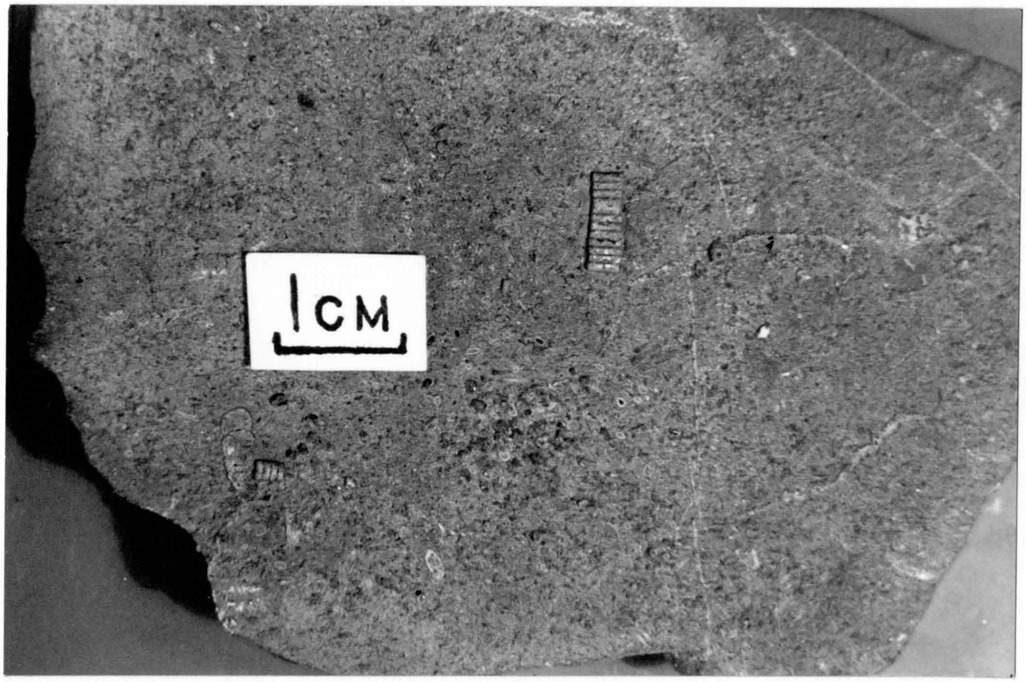


Figure 49. Section of articulated crinoid columnals, slab 15-10. The slab was collected at Dry Lake sample site 15.

Figure 50. Blastoid brachiol, slab 14-11. The slab was collected at Dry Lake sample site 14.

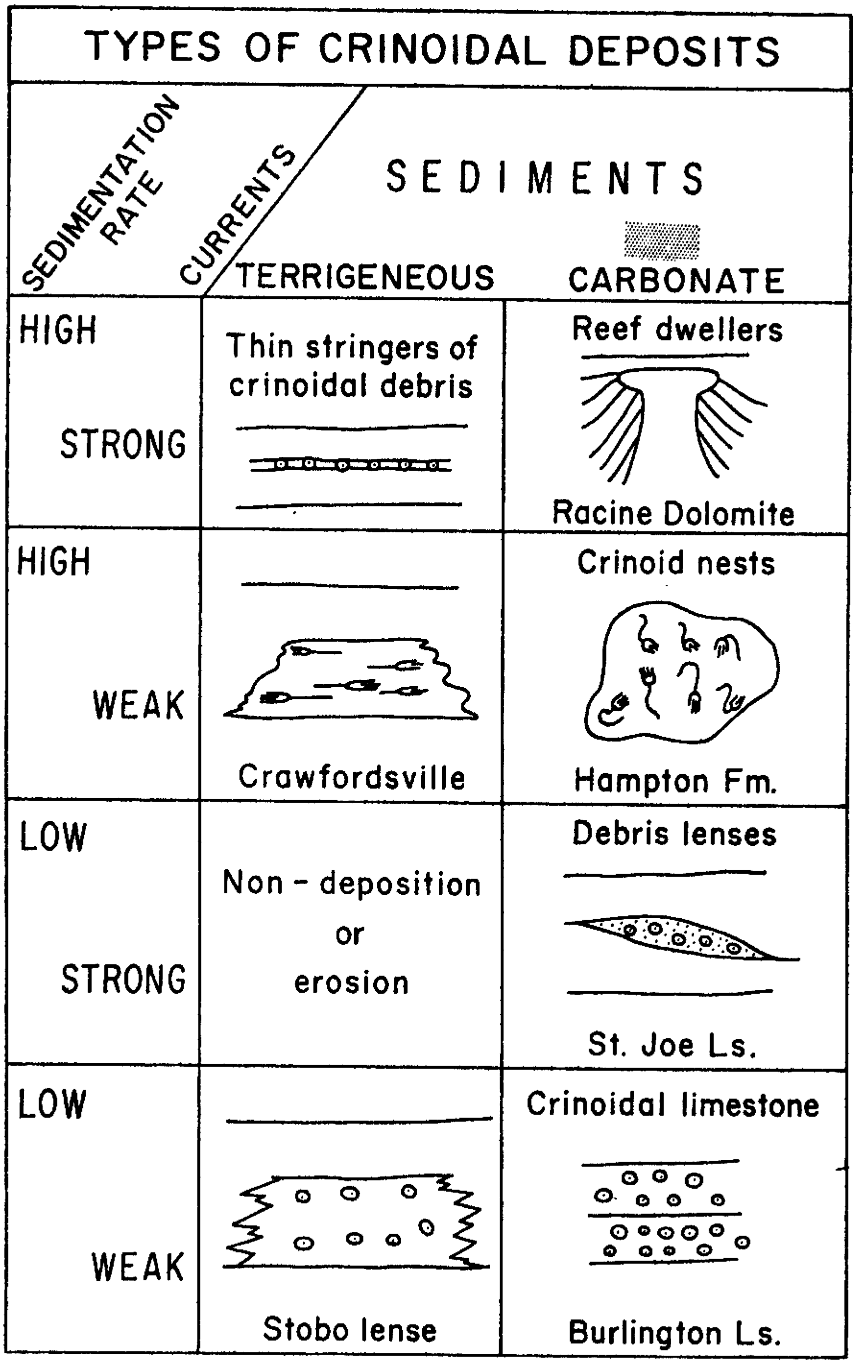


Figure 51. Generalized model of different types of sedimentary deposits rich in crinoids (from Lane, 1969, p. 1439).

LITERATURE CITED

Abbott, B. M. 1974. Flume studies on the stability of model corals as an aid to quantitative paleoecology. Palaeogeog., Palaeoclimat., Palaeoecol. 15:1-27.

Anderson, E. J. 1917. Environmental models for Paleozoic communities. Lethaia 4:287-302.

Beus, S. S. 1968. Paleozoic stratigraphy of Samaria Mountain, Idaho-Utah. Am. Assoc. Petroleum Geologists Bull. 52:782-808.

Beus, S. S. 1958. Geology of the northern part of Wellsville Mountain, Northern Wasatch Range, Utah. MS thesis, Utah State University, Logan, Utah.

Boucot, A. J. 1953. Life and death assemblages among fossils. American Jour. Science 251:25-40.

Bowen, Z. P., D. C. Rhodes, A. McAlester. 1974. Marine benthonic communities in the upper Devonian of New York. Lethaia 7:93-192.

Brenchley, P. J. and G. Newell. 1970. Flume experiments on the orientation and transport of models and shell valves. Palaeogeol., Palaeoclimat., Palaeoecol. 7:185-220.

Bretsky, P. W. 1969. Evolution of Paleozoic benthic marine invertebrate communities. Palaeogeog., Palaeoclimat., Palaeoecol. 6:45-59.

Bretsky, P. W. 1968. Evolution of Paleozoic benthic marine invertebrate communities. Science 159:1231-1233.

Broadhurst, F. M. and I. M. Simson. 1973. Bathymetry on a carboniferous reef. Lethaia 6:367-381.

Brookfield, M. E. 1973. Life and death of *Torquirhynchia inconstans* (Brachiopoda, upper Jurassic). Palaeogeog., Palaeoclimat., Palaeoecol. 13:241-259.

Calef, C. E. and N. J. Hancock. 1974. Wenlock and Ludlow marine communities in Wales and the Welsh borderland. Palaeontology 17:779-810.

Carr, W. J. and D. E. Trimble. 1961. Upper Paleozoic rock in the Deep Creek Mountains, Idaho. U. S. Dept. Int. Geol. Survey Prof. Paper 424-C, pp. 181-184.

Clifton, H. E. 1971. Orientation of empty pelecypod shells and shell fragments in quiet water. Jour. Sed. Petrology 41:671-682.

Craig, G. Y. and A. Hallam. 1963. Size frequency and growth-ring analysis of *Mytilus edulis* and *Cardium edule,* and their palaeoecological significance. Palaentology 6:731-750.

Craig, G. Y. and G. Oertel. 1966. Deterministic models of living and fossil populations of animals. Q. Jl. Geol. Soc. Lond. 122:315-355.

Crittenden, M. D., Jr. 1959. Mississippian stratigraphy of the central Wasatch and western Uinta Mountains, Utah. Intermountain Assoc. Petroleum Geologists Guidebook, 10th Ann. Field Conf., pp. 67-74.

Driscoll, E. G. 1970. Selective bivalve disarticulation in marine environments: a field study. Jour. Sed. Petrology 40:898-905.

Dutro, J. T., Jr. and W. J. Sando. 1963a. Age of certain post-Madison rocks in southwestern Montana and western Wyoming. U. S. Dept. Int. Geol. Survey Prof. Paper 475-B, pp. B-93-B-97.

Dutro, J. T., Jr. and W. J. Sando. 1963b. New Mississippian formations and faunal zones in the Chesterfield Range, Portneuf Quadrangle, S. E. Idaho. Am. Assoc. Petroleum Geologists Bull. 47:1963-1986.

Eardley, A. J. 1944. Geology of the north-central Wasatch Mountains, Utah. Geol. Soc. America Bull. 55:819-894.

Emery, K. O. 1968. Positions of empty pelecypod valves on the continental shelf. Jour. Sed. Petrology 38:1264-1269.

Fager, E. W. and J. A. McGowan. 1963. Zooplankton species groups in the North Pacific. Science 149:453-460.

Fagerstrom, J. A. 1964. Fossil communities in paleoecology: their recognition and significance. Geol. Soc. America Bull. 75:1197-1216.

Folk, R. L. 1974. Petrology of sedimentary rocks. Hemphill Publishing Co. 182 p.

Glenett, R. H. 1958. Geology of the southern part of Wellsville Mountain, Wasatch Range, Utah. MS thesis, Utah State University, Logan, Utah.

Gilluly, J. 1932. Geology and ore deposits of the Stockton and Fairfield Quadrangles, Utah. U. S. Dept. Int. Geol. Survey Prof. Paper 173.

Grant, R. E. 1963. Unusual attachment of a Permian Linoproductid brachiopod. Jour. Paleontology 37:134-140.

Hallam, A. 1972. Models involving population dynamics. pp. 62-81. In T. J. M. Schopf (Ed.), Models in Paleobiology. Freeman, Cooper and Co. 250 p.

Holland, F. D., Jr. 1952. Stratigraphic details of lower Mississippian rocks of northeastern Utah and southwestern Montana. Am. Assoc. Petroleum Geologists Bull. 36:1697-1734.

Hubbard, J. A. E. B. 1970. Sedimentological factors affecting the distribution and growth of Visean caninioid corals in northwest Ireland. Palaeontology 13:191-209.

Hubbard, J. A. E. B. and Y. P. Pocock. 1972. Sediment rejection by recent Scleractinian corals: a key to palaeo-environmental reconstruction. Sonderdruck aus der Geologischen Rundschau Band 61:589-626.

Kirby-Smith, W. W. 1972. Growth of the bay scallop: the influence of experimental water currents. J. Exp. Mar. Bio. Ecol. 8:7-18.

Kissling, D. L. 1965. Coral distribution on a shoal in Spanish Harbor, Florida Keys. Bull. Mar. Sci. Gulf and Caribbean 15:599-611.

Kissling, D. L. and J. A. Lineback. 1967. Paleoecological analysis of corals and stromatoporoids in a Devonian biostrome, Falls of the Ohio, Kentucky-Indiana. Geol. Soc. America Bull. 78:157-174.

Klein, G. D. 1970. Depositional and dispersal dynamics of intertidal sand bars. Jour. Sed. Petrology 40:1095-1127.

Lane, N. G. 1971. Crinoids and reefs. North Am. Paleont. Convention, Chicago, 1969, Proc., J:1430-1443.

Levinton, J. S. and R. K. Bambach. 1975. A comparative study of Silurian and Recent deposit-feeding bivalve communities. Paleobiology 1:97-124.

Luke, K. J. and R. W. Moyle. 1976. A new occurrence of *Cribroblastus cornutus* from the Brazer Formation, upper Mississippian of northern Utah. Geol. Soc. America, Abstracts With Programs 8:604.

Mansfield, G. R. 1927. Geography, geology, and mineral resources of part of southeastern Idaho. U. S. Dept. Int. Geol. Survey Prof. Paper 152, pp. 63-71 and pp. 182-183.

Manten, A. A. 1970. Palaeoecology of Silurian crinoids of Gotland (Sweden). Palaeogeog., Palaeoclimat., Palaeoecol. 7:171-184.

Menard, H. W. and A. J. Boucot. 1951. Experiments on the movement of shells by water. American Jour. Science 249:131-151.

Middlemass, F. A. 1962. Brachiopod ecology and lower Greensand paleogeography. Palaeontology 5:253-267.

Mullens, M. E. and G. A. Izzett. 1964. Geology of the Paradise Quadrangle, Cache County, Utah. U. S. Dept. Int. Geol. Survey Bull. 1181-S, 32 p.

Nagle, J. S. 1967. Wave and current orientation of shells. Jour. Sed. Petrology 37:1124-1138.

Olson, R. H. 1956. Geology of the Promontory Range: Geology of parts of northwestern Utah. Utah Geol. Soc. Guidebook 11:41-75.

Parks, J. M. 1951. Corals from the Brazer Formation (Mississippian) of northern Utah. Jour. Paleontology 25:171-186.

Percival, E. 1944. A contribution to the life-history of the brachiopod *Terebratella inconspicua* Sow. Trans. Royal Soc. New Zealand 74:1-23.

Philcox, M. E. 1971. Growth forms and role of colonial coelenterates in reefs of the Gower Formation (Silurian), Iowa. Jour. Paleontology 45:338-346.

Purdy, E. G. 1964. Sediments as substrates. pp. 238-271. In J. Imbrie and N. Newell (Eds.), Approaches to Paleoecology. John Wiley and Sons, Inc. 432 p.

Reyment, R. A. 1971. Introduction to Quantitative Paleoecology. Elsevier Publishing Company. 226 p.

Richardson, G. B. 1913. The Paleozoic section in northern Utah. American Jour. Science, 4th series 36:406-416.

Rose, P. R. 1976. Mississippian carbonate shelf margins, western United States. U. S. Dept. Int. Geol. Survey Jour. Res. 4:449-466.

Ross, D. A. 1970. Introduction to Oceanography. Appleton-Century-Crofts. 384 p.

Sadlick, W. 1954. The Mississippian-Pennsylvanian boundry in northeastern Utah. MS thesis, University of Utah, Salt Lake City, Utah.

Sando, Wm. J. 1967. Mississippian depositional provinces in the northern Cordilleran region. U. S. Dept. Int. Geol. Survey Prof. Paper 575-D, pp. D29-D38.

Sando, Wm. J. and J. T. Dutro Jr. 1960. Stratigraphy and coral zonations of the Madison Group and Brazer Dolomite in northeastern Utah, western Wyoming, and southwestern Montana. Wyoming Geol. Assoc. Guidebook, 15th Ann. Field Conf., pp. 117-126.

Sando, W. J., J. T. Dutro Jr. and W. C. Gere. 1959. Brazer Dolomite (Mississippian) Randolph Quadrangle, N. E. Utah. Am. Assoc. Petroleum Geologists 43:2741-2769.

Sando, W. J. B. L. Mamet and J. T. Dutro, Jr. 1969. Carboniferous megafaunal and microfaunal zonation in the northern Cordillera of the United States. U. S. Dept. Int. Geol. Survey Prof. Paper 613-E, 29 p.

Schwarzacher, W. 1963. Orientation of crinoids by current activity. Jour. Sed. Petrology 33:580-586.

Seyfert, C. K. and L. A. Sirkin. 1973. Earth History and Plate Tectonics: an Introduction to Historical Geology. Harper and Row, Publishers. 504 p.

Sheldon, R. W. 1974. Climatic control of brachiopods in the lower Namurian. Lethaia 7:257-263.

Sokal, R. R. and P. H. A. Sneath. 1963. Principles of Numerical Taxonomy. W. H. Freeman and Co. 359 p.

Spurr, J. E. 1895. Economic geology of the Mercur Mining District, Utah. U. S. Dept. Int. Geol. Survey 16th Ann. Report Pt. 2, pp. 343-355.

Stanley, S. M. 1972. Functional morphology and evolution of byssally attached bivalve mollusks. Jour. Palentology 46:165-212.

Steele-Petrovic, H. M. 1975. An explanation for the tolerance of brachiopods and relative intolerance of filter feeding bivalves for soft muddy bottoms. Jour. Paleontology 49:552-556.

Strikland, J. W. 1956. Mississippian stratigraphy, western Wyoming. Wyoming Geol. Assoc. Guidebook, 11th Ann. Field Conf., pp. 51-57.

Surlyk, F. 1972. Morphological adaptations and population structures of the Danish Chalk brachiopods (Maastrichtian, upper Cretaceous). Det K. Dan. Vidensk. Selsk. Biol. Skr. 19:1-57.

Taylor, M. and P. M. Sheehan. 1968. Evolution of fossil invertebrate communities: additional factors. Science 161:491.

Thayer, C. W. 1975a. Diductor muscles of brachiopods: active or passive. Paleobiology 1:44-47.

Thayer, C. W. 1975b. Size-frequency and population structure of brachiopods. Palaeogeog., Palaeoclimat., Palaeoecol. 17:139-148.

Thayer, C. W. 1974. Marine paleoecology in the upper Devonian of New York. Lethaia 7:121-155.

Turpaeva, E. P. 1957. Food interrelationships of dominant species in marine benthic biocoenoses. In B. N. Nikitin (Ed.), Transa Inst. Oceanol., Mar. Biol. USSR Acad. Sci. Press 20. (Published in U. S. by Amer. Inst. Biol. Sci., Wash., D. C.).

Twenhofel, W. J. 1950. Principles of Sedimentation. McGraw-Hill Book Co., New York. 250 p.

Walker, K. R. 1972. Trophic analysis: a method for studying the function of ancient communities. Jour. Paleontology 46:82-93.

Walker, K. R. and L. P. Alberstadt. 1975. Ecological succession as an aspect of structure in fossil communities. Paleobiology 1:238-257.

✓ Watkins, R. 1975. Paleoecology of some Carboniferous Pectinacea. Lethaia 8:125-131.

Wells, J. W. 1957. Corals. pp. 1087-1104. In J. W. Hedgpeth (Ed.), Treatise on Marine Ecology and Paleoecology. Geol. Soc. America Mem. 67 v. 1. 1296 p.

Williams, J. S. 1958. Geologic atlas of Utah, Cache County. Utah Geol. Mineralog. Survey Bull. 64. 104 p.

Williams, J. S. 1948. Paleozoic rocks-Logan Quadrangle, Utah. Geol. Soc. America Bull. 59:1121-1163.

Williams, J. S. 1943. Carboniferous formations of the Uinta and northern Wasatch Mountains, Utah. Geol. Soc. America Bull. 54:591-624.

Williams, J. S. and J. S. Yolton. 1945. Brazer (Mississippian) and lower Wells (Pennsylvanian) section at Dry Lake, Logan Quadrangle, Utah. Am. Assoc. Petroleum Geologists 29:1143-1155.

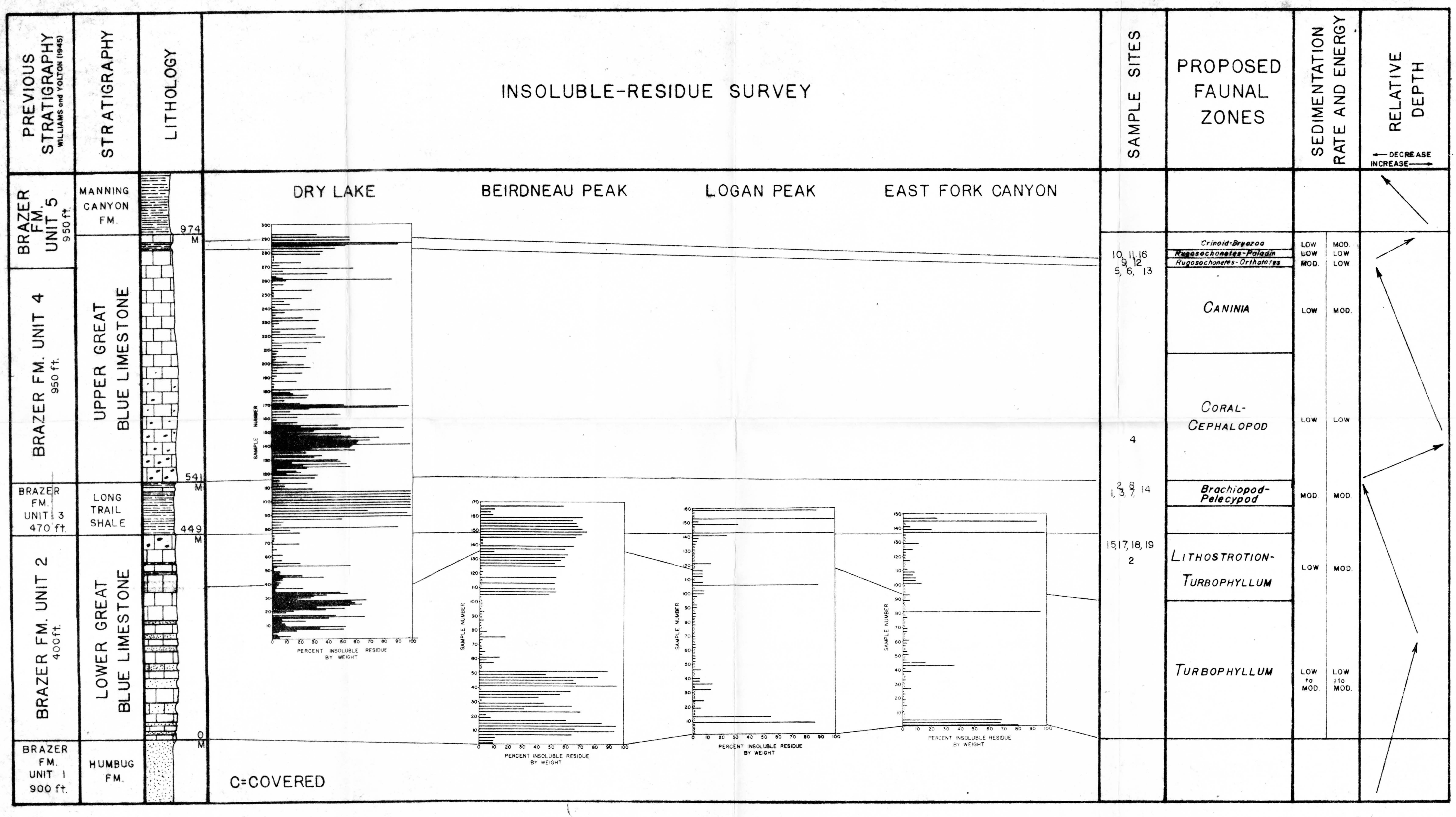
Wolfenden, E. B. 1958. Paleoecology of the Carboniferous reef complex and shelf limestones in northwest Derbyshire, England. Geol. Soc. America Bull. 69:871-898.

Yochelson, E. L. 1969. Gastropods and pelecypods. pp. 445-447. In E. D. Mckee and R. C. Gutshick (Eds.), History of the Redwall Limestone. Geol. Soc. America Mem. 114. 726 p.

Yolton, J. S. 1943. The Dry Lake section of the Brazer Formation. MS thesis, Utah State University, Logan, Utah.

Ziegler, A. M., L. R. M. Cocks and R. K. Bambach. 1968. The Composition and structure of lower Silurian marine communities. Lethaia 1:1-27.

PLATE I



LITHOSTRATIGRAPHIC CORRELATIONS AND ASSOCIATED FAUNAL ZONES OF FOUR SECTIONS OF THE GREAT BLUE LIMESTONE, NORTH-CENTRAL UTAH