GROWTH-FORM ANALYSIS AND PALEOECOLOGY OF THE CORALS OF THE LATE ORDOVICIAN THROUGH MID-SILURIAN FISH HAVEN AND LAKETOWN FORMATIONS, BEAR RIVER RANGE, NORTH-CENTRAL UTAH

by

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in

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Thomas B. Rich
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ABSTRACT

Growth-Form Analysis and Paleoecology of the Corals of the Late Ordovician through Mid-Silurian Fish Haven and Laketown Formations, Bear River Range, North-Central Utah

by

Thomas B. Rich, Master of Science
Utah State University, 1981

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

Morphology of corals of the Late Ordovician through mid-Silurian Fish Haven and Laketown Formations were analyzed to document adaptations to inferred environmental conditions, i.e., (bathymetry, illumination, sedimentation, currents, and energy), under which their enclosing sediment was deposited. Specimens and data were collected from six sites. Insoluble-residue tests were performed on the corals' matrices.

Individual corallites of radial-lensoidal corals radiate in all directions. Vertical growth, however, was restricted in turbulent conditions. Umbrellic, radial-lensoidal corals feature downward facing corallites, considered to be an adaptation to a well-illuminated environment.

On tabular lensoidal corals, constituent corallites faces exclusively upward, an orientation needed under relatively poor illumination. Orientation of these coralla at oblique angles to bedding
planes and to other coralla signify soft-sediment slumping or edge-first sinking into a semi-fluid substrate.

Hemispherical coralla prevailed under moderately high energy condition and negligible sedimentation. Conic coralla, formed during prodigious sediment accumulation, are extreme modifications of hemispherical coralla. The lower the rate of sediment accumulation, the less acute the angle of the apex (budding center of the "cone").

Circumrotary corals, or those that are distinguished by corallites radiating in virtually all directions, are considered to have dwelled in heavy surf, by analogy to certain modern corals.

Composite corals, those that exhibit more than one morphotype or a repetition of the same morphotype, reflect a change in growth during the life of the colony.

Internal features of individual corallites were examined and measured. Most of the corals in this study feature corallites suggestive of low-sediment rejection capability. Corallite packing arrangements, as well as indicating cleansing ability, are interpreted as adaptations to different levels of hydraulic stress.

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Several explanations are given to explain the lack of correlation between corallite variability and external morphology. Genetic differences may have resulted in differing variabilities of calical widths of different species under comparable environmental conditions (as indicated by intramorphotypic analyses of variance).

Differences in variability of tabulae spacing between tabular and radial coralla are attributed to the preponderance of lateral budding in the former mrophotype. Frequent budding is considered to have been concurrent with slow upward growth, reflected by narrow tabulae spacings.

A high energy fauna is represented by the abundance of tabulate and compound rugose, radial-lensoidal, and circumrotary coralla. These corals and their associated organisms in the community seemingly dwelled on a carbonate bank.

A favositid-dominated community provides evidence of variable sedimentation rates by the presence of diverse morphologies. Hemispherical coralla predominate indicating generally high energy and low to negligible sedimentation rates.

Two of the sites were dominated faunally by hemispherical, halysitid corals featuring cone-shaped bases. They are considered reflective of moderate energy and moderate sediment accumulation.

Tabular halysitid and favositid corals whose basal dimensions are oriented obliquely to one another and/or bedding planes signify negligible sedimentation and placid, relatively deep water conditions. These corals dominated two collecting sites.
Based on the patchiness of the occurrence of the coral assemblages, the Late Ordovician and Silurian sea floor is considered to have been an uneven, heterogeneous surface. Shallow water shelf conditions are inferred. Fluctuations in sea level elicited the observed variability in coral morphology.

(210 pages)
INTRODUCTION

Objectives and Methods

The intent of this report is to document synchronization of coral morphology and depositional environments of the Late Ordovician through Middle Silurian (Tippecanoe transgression) strata of the Bear River Range in north-central Utah. The stratigraphic units involved are the Fish Haven and Laketown Formations.

Field work consisted of measuring coral size, shape, orientation, spacing, and fragmentation. Taxonomic identification and measurement of internal features were performed in the laboratory. As the physiographic character of the six collecting sites varied, so did the type and quantity of data attained. For example, the Card Canyon, Tony Grove Lake, and Blacksmith Fork sites consist of a vertical cliff, a bedding plane, and a talus slope, respectively. Consequently, data on temporal and spatial aspects could not be collected consistently among these sites.

Four general morphologic types, or morphotypes, have been identified. Additionally, corals consisting of more than one morphotype or a repetition of the same shape are described. Where possible, coral specimens were collected. Their internal features, i.e., septal length and density, tabulae spacing, and calical shape and relief, were measured. Transverse and longitudinal sections through the colonies were prepared in order to measure the above mentioned morphologic characters. Insoluble-residue-analyses of the associated
lithologies were also performed. Synecological considerations, such as reconstruction of trophic levels, diversity, density, and distributions of faunal constituents are assessed for paleoenvironmental settings.

Location and Accessibility

Fossils and data were collected from six separate sites. These sites are located in Green Canyon, the Tony Grove Lake area (two sites), Card Canyon, Blacksmith Fork, and Sharp Mountain. All but the latter are located in the Logan, Utah Quadrangle (1:125,000:1904). The Sharp Mountain site is located in the Sharp Mountain Quadrangle (1:24,000) to the south. All sites are located in the western portion of the Ogden, Utah topographic sheet (1:250,000).

The Sharp Mountain site is situated in the northeast quarter of the northwest quarter of Section 4, Township 8 North, Range 2 East of the Sharp Mountain Quadrangle (Figure 1). It is reached by turning east approximately one quarter mile south of Avon, Utah. A south turn is taken toward the Circle C Ranch slightly more than one mile from the last junction. This eastern road is followed as far as possible by vehicle. The rest of this two and a-half-mile stretch to Pole Creek must be made on foot. When the creek is reached, it is followed upstream and eastward through a mile-long canyon. Once the canyon is traversed, a southward turn is made. About one quarter mile further, Pole Creek (which also bends to the south) is crossed where an unimproved road is sighted. This road is followed for about another quarter mile until the first prominent northwest-southeast-trending, northwest-sloping ridge is reached. The crest of this
Figure 1. Index map of collecting sites.
ridge is followed for two miles eastward until the site is encountered (Figure 2). Midway through this stretch of the hike, a maintained logging road will be crossed. The hiker is referred to the Paradise, James Peak and Sharp Mountain Quadrangles. Azimuth compass bearings from the site to Hyrum, Utah, Sharp Mountain and James Peak are 318, 174, and 214 degrees, respectively.

The Blacksmith Fork collecting site (Figure 1) is located east of Hyrum, Utah about 800 feet east of the T-intersection of the Blacksmith Fork highway and the Left Hand Fork road. It is the first large talus slope on the north side of the Blacksmith Fork highway to the east of the intersection. The best fossils were collected from the lower portion of the talus slope (Figure 3).

The turnoff to the Green Canyon data site is reached by traveling east on 19th North in North Logan, Utah (Figure 1). One and one-half miles east of the mountain front a left-hand turnoff is taken toward an abandoned quartzite quarry in the Ordovician Swan Peak Formation. Immediately up-section is the dark gray dolomite of the Fish Haven Formation. Fragmented coral specimens were collected from this lithology for a distance of about a quarter mile northward, or about one-half the distance to the high bench trending perpendicular to strike and located north of the quarry (Figure 4).

The mapped bedding plane north of Tony Grove Lake (referred to as the Tony Grove Lake Bedding Plane (Figure 1)) is located 3,750 feet (map distance) on an azimuth heading of 348 degrees from Tony Grove Lake. To Mt. Magog from the bedding plane a bearing of 320 degrees would be followed for 3,500 feet (map distance) to the site. The
Figure 2. Sharp Mountain collecting site (where bench in foreground intercepts with mountain front in background, view east).
Figure 3. Draw in which Blacksmith Fork collecting locality lies (view north).
Figure 4. Green Canyon collecting site. (Note gray dolostone collecting site overlying light-colored Swan Peak Quartzite. View northeast).
bedding plane is seen in Figure 5. It is most easily reached by taking the left fork of the trail heading north from Tony Grove Lake until the contact of the Swan Peak Quartzite and the Fish Haven Dolostone is encountered. From this point, it is best to walk northward, roughly bisecting the up-section and northerly strike directions for about one-quarter mile. Stratigraphically, the site is situated 130 feet above the base of the Fish Haven Formation (Figure 5).

To get to the White Pine Lake collecting site, (Figure 1), proceed northward from the Tony Grove Lake site on foot for about 20 minutes. The shingled bedding planes comprising the site (Figure 6) overlook a vast glacial cirque in which White Pine Lake lies. The lake is viewed by walking to the top of the small knoll to the immediate west of the site. Mt. Magog is 1800 feet on an azimuth bearing 356 degrees.

The turnoff to the Card Canyon collecting site (Figure 1) is located six miles east of the mouth of Logan Canyon. The site is reached by taking the jeep trail southward for about one-third mile until the side canyon widens. The prominent outcrop appearing on the top of the high knoll to the east is the collecting site (Figure 7). Azimuth compass bearings from the site to Beirdneau and Logan Peaks are 315 degrees and 228 degrees, respectively.

Previous Investigations

The following investigations represent the more significant publications on the Fish Haven and Laketown Dolostones.
Figure 5. Tony Grove Lake bedding plane (view northeast).
Figure 6. White Pine Lake collecting site (view east-northeast).
Figure 7. Card Canyon collecting site (uppermost rocky outcrop, view northeast).
Hayden (1872) noted in 1871 a small halysitid coral, *Halysites catenularia*, which had been found in Box Elder Canyon, 25 miles north of Ogden, Utah. The specimen was considered to be Silurian in age. Bradley (1873) who discovered the fossil, thought it was closely related to fossils found in the Niagaran Group of the eastern United States.

King (1876) used the "Wasatch Mountains" section for descriptions of several formations in his separation of Great Basin strata. He indicated that the lowermost beds of his "Wasatch Limestone" might yield Silurian fossils. The overlying rocks in this unit were considered to be of Devonian and Carboniferous age.

Kindle (1908b), while working on the Devonian Jefferson Formation in north-central Utah, collected a brachiopod fauna indicative of a Silurian age. Kindle (1908a) confirmed previous suspicions concerning the presence of Silurian strata in the western United States. From Green Canyon near Logan, Utah, he identified *Favosites gothlandicus*, *Favosites niagrensis*, *Halysites catenularia*, *Zaphrentis* sp., and *Pentamerus oblongus*. Budge (1966) considered the geographic description of Kindle (1908b) to be in error; he suggested the proper location of the fauna to be Hyrum Canyon.

Blackwelder (1919) used the Paradise Limestone, named by F. B. Weeks (Tomlinson 1917) from the vicinity of Paradise, Utah, in describing Silurian strata discovered by Kindle (1908a). A type-section for the formation was lacking even though the description was based on exposures in the Wellsville Mountains west of Paradise. This was the first subdivision of King's (1876) "Wasatch Limestone."
No mention was made of an upper Ordovician carbonate unit. A quartzite unit (the upper Swan Peak Formation) was listed as being the highest Ordovician strata.

Richardson (1913) subdivided the Paleozoic section described by King (1876). He cited the strata in the Randolph Quadrangle, Utah as being well exposed and "...one of the most complete Paleozoic sections known in the entire Cordilleran region." He named the Fish Haven Dolomite for exposures in Fish Haven Canyon in southeastern Idaho, reported a stratigraphic thickness of 500 feet, and described the lithology as "... fine textured, medium bedded, dark gray to blue-black, locally cherty, dolomite." Richardson (1913) also cited Edwin Kirk as having identified specimens of *Calapoecia* cf *C. canadensis* Billings, *Streptelasma* sp., *Halysites catenulatus* var. *gracilis* Hall, *Rhynchothere* cf *R. capax* Conrad, and *Columnaria thomii* Hall. The fossils were said to "...represent a widespread Richmondian fauna."

Richardson (1913) designated the type section of the Laketown Formation to be the strata exposed in Laketown Canyon located approximately three and a half miles southeast of Laketown, Utah. He characterized the lithology as "...massive light gray to whitish dolomite, containing lenses of calcareous sandstone, having a total thickness of approximately 1000 feet." Evidence for a Silurian age included considerable quantities of *Pentamerus* cf *P. oblongus* Sowerby. Richardson believed specimens of *Halysites catenulatus* and *Cyathophyllum* sp., found in the lower part of the Laketown Formation to indicate a possible
Richmondian age. He subsequently proposed restriction of the term Laketown to rocks of Silurian age. Both the lower contact with the Fish Haven Formation and the upper contact with the Devonian System were interpreted as conformable.

Tomlinson (1917) measured 755 feet of Silurian strata in Blacksmith Fork, Utah. He extended the terminology of Laketown Canyon to the Logan Quadrangle. No disagreement on the interpretation of Richardson (1913) that the base of the Laketown resting conformably on the underlying Fish Haven Formation was indicated.

Mansfield (1927) described strata assigned to the Laketown Formation from an unnamed canyon southwest of St. Charles, Idaho, in the Montpelier Quadrangle. He too considered the Fish Haven and Laketown Dolostones to be in conformable contact. Above the Laketown, the contact with the overlying rocks was said to possibly represent a break in sedimentation. The Fish Haven and Laketown Dolostones were depicted as Richmondian and Niagaran in age, respectively.

Ross (1934, 1937) mapped numerous quadrangles in Idaho and described and measured several sections. He reported faunal constituents as well. Included in these sections are the Fish Haven and Laketown Formations.

Richardson (1941) studied the Randolph Quadrangle of north-central Utah. Because Early and Late Silurian fossils were not found, he believed that both the upper and lower contacts of the Laketown Formation were disconformable. The Laketown Formation was noted as resting on the type section of the Fish Haven Formation in a small
canyon one mile south of St. Charles, Idaho. Paucity of fossils was cited as making determination of stratigraphic boundaries difficult.

In a survey of the Logan Quadrangle, Williams (1948) recorded a thickness for the Fish Haven Formation of about 140 feet in Green Canyon, near Logan, Utah. He considered it to lie disconformably over the Swan Peak Formation. As evidence for a depositional and erosional gap, he contrasted the changing lithology and thickness of the Swan Peak Formation to the uniformity of character and thickness of the Fish Haven Formation. The Fish Haven Dolostone was reported as having virtually no variation in thickness throughout the quadrangle. It was described as Cincinnatian in age. In the same report, the Laketown Dolostone was listed as being 1,500 feet thick. Dolomitization was held accountable for the destruction of all faunal constituents, save corals. Williams (1948) asserted that considerable hiatuses must have occurred before and after deposition of the Laketown Formation. He subdivided the formation into four members on the basis of color and bedding characteristics. A Niagaran age was reported. This judgment was based on the presence of halysitid and favositid corals, stromatoporids, and pentamerid brachiopods.

Ross (1953) stated: "In places it (the Fish Haven Formation) overlies the Garden City Formation rather than the stratigraphically next lower Swan Peak Formation." He also reported a statement by Flower (1952) that suggested that the presumably Richmondian strata of the West might be of late Middle Ordovician age. Flower (1952) had correlated many cephalopod genera from western strata with late Trentonian units of the eastern United States.
Stokes (1955) reported that the Rocky Mountain geosyncline was occupied by a shallow and narrow embayment during the Silurian Period. He described the Laketown Formation as being light to dark gray in color, having a relatively massive appearance, and containing several cherty members. He believed the gross lithology to be indicative of a very shallow water origin in a slowly subsiding, north-south trending trough. Based on a sparse faunal assemblage, Stokes (1955) considered the formation to be of Silurian age.

Berdan and Duncan (1955) contradicted Richardson's (1941) interpretation regarding the age of strata mapped as Silurian in the Crawford Mountains in Wyoming along the Utah border. Apparently, Richardson (1941) had not observed any fossils in these rocks, and so assigned them to the Silurian System due to their stratigraphic position below Devonian strata. Berdan and Duncan (1955) considered the strata in question to be of Late Ordovician age due to the discovery of specimens of *Catenipora gracilis* Hall, *Paleophyllum* cf. *P. halysitoides* Troedson, *Calapoecia* sp., *Strptelasma* sp., *Holophragma* sp., *Favosit es* sp. and large gastropods resembling *Maclurites*.

MacFarlane (1955) thought the absence of pronounced unconformities at the upper and lower contacts of the Silurian System in the Great Basin to be indicative of the presence of Early and Late Silurian strata. He considered the system to have conformable contacts on both its upper and lower boundaries in north-central Utah. He also noted that local diastems and disconformities are present in Silurian strata of the region.
Beus (1958) distinguished three members of the Laketown Formation in his study of northern Wellsville Mountain, Utah. In stratigraphic succession these units consisted of a dark-gray crystalline dolostone, a light gray massive dolostone containing some chert, and a medium to dark dolostone, also locally cherty. Rugose corals and crinoid stems were found. In the same study, Beus (1958) measured 140 feet of Fish Haven Formation.

Gibbs (1960) found the Fish Haven Formation in central Idaho to be 1,150 feet thick and of a more heterogeneous lithology than is found in north-central Utah. The fauna identified from the Fish Haven was deemed upper Ordovician. A coral fauna collected from the Laketown Dolostone just above the Fish Haven contact was considered to be of Middle to Late Silurian age.

Hafen (1961), in a study of the Sharp Mountain area south of Avon, Utah, suggested that the scarcity of organic matter in the Laketown Formation reflected a diagenetic origin of the dolomite.

Beus (1963), while studying the Blue Springs Hills of northern Utah, placed the contact between the Fish Haven and Laketown Formations at the highest stratigraphic occurrence of dark-gray, cherty dolostone. A biostratigraphically significant discovery during his investigation was the uncovering of an Ordovician rugose coral, *Streptelasma*, 300 feet above the base of the Fish Haven Dolostone.

Budge (1966) divided the Laketown Formation into four members in his study of the unit between Bear Lake and Logan, Utah. The criterion for subdivision was primarily color, although grain size
and bedding differences were also used to distinguish members. These constituent members will be discussed in detail in the following section on lithology. Of biostratigraphic significance was his discovery of an Ordovician fauna consisting of *Lichenaria* sp., *Holophragma* sp., *Paleophyllum* sp., and several species of *Streptelasma*.

Budge and Sheehan (1969) identified the corals *Bighornia*, *Paleophyllum*, *Streptelasma*, *Lichenaria*, and *Poerstephyllum* in an assemblage in Budge's (1966) lower-most member (Member A). *Virgiana* assemblage was described from the next highest member as being middle Llandoverian in age, giving further credence to the placement of the Ordovician-Silurian boundary in the lower Laketown Formation. Thus, the boundary between the two systems appears to be time transgressive as it is considered to coincide with the Fish Haven-Laketown contact in central Idaho.

Budge (1969) made a regional evaluation of Late Ordovician and Silurian shelf dolomites in north-central Utah and eastern Nevada. He recognized three coral associations consisting of a rugose dominated association that inhabited a low energy environment, a tabulate-rugose association indicative of moderate energy, and a dominantly tabulate coral association inferred to have developed in relatively high energy conditions.

Sheehan (1970) divided the interval of Laketown deposition into five units based on brachiopod community distributions (as did Zieglar 1965, in Wales). He noted replacement of endemic late Ordovician, North American species by European species near the Ordovician-Silurian
time transition and a subsequent reversal back to provincialism in the Late Silurian.

According to Gibbs (1972), the Laketown Formation and its correlative units have a relatively smaller regional extent than do the Fish Haven and its correlative units.

Budge (1977) reported that regional tectonic implications of the vertical and horizontal distribution of two Late Ordovician shelf faunas from the western United States (which show two major coral biostratigraphic units) include the existence of a major erosional hiatus separating Ordovician strata from Silurian rocks in the eastern Great Basin. The magnitude of this stratigraphic interruption is reported to increase westward. Accordingly, the hiatus must have been of relatively short duration in what is now north-central Utah, if it existed at all.

Sheehan (1980) identified three marine communities from the Silurian carbonate shelf in Nevada and Utah. In northern Utah, three members of the Laketown Formation were correlated with three of these communities. The lowest unit, the Tony Grove Lake Member, is considered to have been deposited in shallow subtidal to intertidal environments. The community associated with this member is strongly dominated by *Virgiana* brachiopods. Clastic features, such as small-scale cross bedding and trough structures were reported to be present in this unit.

The High Lake Member (Sheehan 1980) was deposited in waters in which a dasyclad algae-dominated community prevailed. The depositional
environment was believed to be covered by shallow, clear, and placid water.

The lower two members of Sheehan's (1980) stratigraphic subdivision comprise about 4/5 of the thickness of the Laketown. The Portage Canyon Member makes up the upper fifth of the formation and corresponds with a community dominated by *Pentameroides* brachiopods and is considered to represent subtidal deposition in moderately calm water.

**Lithology**

The Fish Haven Formation is generally a massive, medium to thick-bedded, medium crystalline, dark-gray to bluish-black, dolostone (Figure 8). The uppermost 1/4 to 1/5 of the 140 foot thickness contains ubiquitous chert nodules. The majority of these nodules have a flattened ellipsoidal shape, although a few appear to be spherical. Several coral specimens are seen to be chertified. The nodules commonly display red to yellow-brown oxide staining.

The color of the Fish Haven Formation has been observed by the author to vary laterally throughout the Bear River Range. In Green Canyon, it is a bluish-black and releases a sulfurous odor when fractured. The dolostone displays a medium dark gray hue in the Tony Grove Lake area. The Fish Haven is distinguished from the Laketown Formation with difficulty in other areas, such as in the Sharp Mountain area (Rauzi, personal oral communication, 1979).

In addition to the corals to be discussed in this text, the Fish Haven Dolostone contains algal structures seen as parallel to mildly undulating, wavy laminae.
Figure 8. Stratigraphic section of the Fish Haven and Laketown formations at Tony Grove Lake (modified from Budge 1966).
Bedding planes weather to form rough, serrated surfaces. The bedding plane mapped in the Tony Grove Lake vicinity (Figure 5) displays this feature. Large bedding planes are seen infrequently in the Fish Haven Formation, however, and the unit is characteristically a ledge former.

The Laketown Formation has been subdivided historically into three or four members (Figure 8). Individual beds are distinct, ranging in thickness from thin to very thick. The lower boundary of the Laketown is the first occurrence of variegated beds. These alternating bands of grayish-black to medium light-gray dolostone characterize Member A of Budge's (1966) subdivision. The lighter colored bands generally increase in relative thickness up-section from the contact with the Fish Haven. Member A is very thick to thin bedded. Crystallinity is very fine to fine. The unit is 300 feet thick.

Member B is a medium dark to dark-gray dolostone (Figure 8). Crystal size ranges from very fine to moderately coarse. It is thin to thickly bedded. The unit contains beds of intraformational conglomerate near its base. In the middle and top of the member are non-contiguous lenses of chert. Small, randomly oriented seams of quartz were noted by Budge (1966) to appear in these upper beds of the member. He interpreted them as having developed diagenetically. Member B is 600 feet thick.

Member C (Figure 8) is comprised of medium-light gray, thick bedded dolostone of variable crystal size and distinctive crystallinity. It has a porous texture and an extensively weathered appearance. In
the upper half of the member are chert laminae interlayered with dolomite beds. Budge (1966) felt that the relative coarse crystallinity of the member reflected the comparatively large grain size of the original sediment. The author has noted ripple marked, sandy laminae in this part of the section. Member C is 360 feet thick.

Member D (Figure 8) is, for the most part, a medium-dark gray, massively bedded dolomite of fine to intermediate crystal size. Discontinuous chert lenses are distributed throughout the unit. The uppermost 1/10 has a light-gray to whitish coloration similar to the overlying Devonian Water Canyon Formation. Unlike that unit, however, massive bedding and a comparatively dense texture prevail. Member D is 215 feet thick.

Thus, the Laketown Formation generally variegates in color from dark to light-gray. This alteration can be attributed to varying amounts of organic matter in the enclosing rock.

The bedding of the Laketown Dolostone shows considerable variation but is generally thick to massive although thinner beds are found locally. Bedding planes are often indistinct. The formation erodes to form pinnacles and jagged cliffs. Bedding surfaces often display a "meringue" surface. In the more coarsely crystalline beds, dolomite crystals stand out in relief. McFarlane (1955) considered this to be the result of differential solution of smaller grains and/or small amounts of calcareous matrix.

Vertical Relationships

The conformable contact between the Fish Haven Dolostone and
the underlying Swan Peak Formation was demonstrated by Williams (1948) by comparing relative lithologic uniformities and consistencies of thickness. Further evidence for a sedimentation break was provided by Mecham (1973) who reported orthoquartzite pebbles (derived from the upper Swan Peak Formation) in the first few inches above the base of the Fish Haven Formation.

Based on paleontologic evidence, the Fish Haven-Laketown contact should now be considered to be conformable. Indeed, the two units could quite justifiably be regarded as one formation as they comprise one lithologic entity.

As no distinctive Late Silurian fossils have been found in north-central Utah, stratigraphic relationship of the Laketown Dolostone with the overlying Devonian Water Canyon Formation has been considered to be disconformable. The Water Canyon Formation, dated on the basis of its constituent fish scales, is a silty, thin-bedded, white-weathering dolomite. However, Late Silurian brachiopods have been found in western Utah in the Laketown Formation (Wiate, in Hintze 1973).

Regional Correlations

The Fish Haven Formation and several other stratigraphic units were deposited simultaneously (Figure 9). The time-correlative unit to the northeast in Montana and Wyoming is the Bighorn Dolostone. Darton (1904) portrayed this unit as consisting of a basal sandstone, a cliff-forming dolostone, and a thin-bedded dolostone grading into a dolomitic limestone at the top. In central Idaho, the Fish Haven
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Figure 9. Correlation chart of Late Ordovician through Early Devonian strata, Great Basin (after Berry and Boucot 1970).
grades laterally into the Saturday Mountain Formation, a shaley dolostone enclosing quartzite pebbles and black, carbonaceous material (Ross 1937). To the west, the Fish Haven Dolostone correlates with the Ely Springs Formation (Ross 1964), which is transitional in character between the Fish Haven Formation and the Hanson Creek Formation of central Nevada. The Hanson Creek Formation is a cherty limestone and dark gray siltstone at its exposure in the Toquima Range (McKee and Ross 1969). In the Carlin, Nevada region, it is reported to be a dark-gray dolostone, thick bedded at the base and grading into thinner beds at the top (Roberts et al. 1958).

Due to an erosional episode in the western United States during the latest Silurian and/or earliest Devonian, the Laketown Formation and its correlatives have a more geographically restricted distribution than the Fish Haven Formation and its correlatives (Figure 9). The Laketown Dolostone is present in central Idaho and eastern Nevada as well as northern and western Utah. The Lone Mountain Formation, Roberts Mountain Formation, and unnamed shales are encountered progressively westward. Lithologically, these formations are, from central Utah westward, massive dolostone, limestone, and shale. Sedimentary facies of Late Ordovician and Middle Silurian times are depicted in Figures 10 and 11.

Paleogeographic and Paleotectonic Setting

During the Ordovician and Silurian Periods, the cratonic-miogeosynclinal margin coincided with the easternmost extent of the
Figure 10. Upper Ordovician sedimentary facies (from Dott and Batten 1976).
Figure 11. Middle Silurian sedimentary facies (from Dott and Batten 1976).
exposures of the Laketown Formation. That is, the "shelf hinge line" passed through what is now north-central Utah southwestward to Las Vegas, Nevada and northward along the current Idaho-Wyoming border. The Cordilleran eugeosyncline lay further west in western Nevada, California, Oregon, and Washington, whereas the vast craton extended throughout the interior portion of North America. Figure 12 depicts the early Paleozoic structural setting. The north-south trending shelf-slope boundary apparently curved eastward from northern Nevada into northwestern Utah (Sheehan 1979). This feature is graphically depicted in Figure 13.

Of great importance to paleogeographic reconstructions of the western United States has been the discovery of early Paleozoic outliers in the northern Front and southern Laramie Ranges of Colorado and Wyoming (Chronic et al. 1969). These erosional remnants are located in areas previously mapped as Pre-Cambrian. They contain faunas indicative of a marine setting far removed from shore. From a southern Wyoming outlier, Chronic and Ferris (1963) identified an unquestionably Silurian fossil assemblage. The virtual absence of clastic material in the Late Ordovician and Silurian strata also attests to their sedimentary origin in areas far removed from terrigenous sources.

Thus, a paleogeographic outline of the western interior of the United States includes a widespread, shallow sea, deepening to the west, during Late Ordovician through Middle Silurian times.

The transcontinental arch, previously considered to have been positive during Silurian time, probably was inundated at the climax
Figure 12. Paleotectonic map of North America for the Cambrian, Ordovician, and Silurian (from A. J. Eardley 1951).
Figure 13. Reconstructed distribution of Silurian depositional environments in Nevada, Utah, and Idaho (from Sheehan 1980).
of this transgressive interval (the Tippecanoe Sequence). The appraisal of Hintze (1959) that Upper Ordovician sediments represent the most widespread of all marine encroachments across the western craton now seems outdated. Silurian seas very likely were equally, if not more extensive.

Generally continuous sedimentation is suggested by the massively bedded nature of the strata under consideration. Only minor sedimentation breaks, represented by bedding planes, seem to have taken place. Examination of paleogeographic maps (Figures 14 and 15) reveals that north-central Utah occupied a tropical to subtropical latitude in Late Ordovician through Middle Silurian times.

**Paleobiogeography**

The following overview of Late Ordovician through Silurian biogeography has been synthesized from articles by Boucot (1974) and the Russian, Leleshus (1976).

The interval from Late Ordovician through Late Silurian times includes the continuation of provincialism in the Late Ordovician from earlier biologic segregation during the Middle Ordovician. Late Ordovician faunas from the western United States bear a greater similarity to time-equivalent faunas from the North American arctic than to faunas from the eastern United States (Duncan 1956).

The biogeographic differentiation characteristic of the Late Ordovician disappeared in the Early Silurian. Essentially cosmopolitan faunas are found in North America and Eurasia. In the Middle Silurian, a return to provinciality transpired, although the degree of endemicism was not as pronounced as in the Late Ordovician.
Figure 14. Late Ordovician paleogeography (from Dott and Batten 1976).
Figure 15. Middle Silurian paleogeography (from Dott and Batten 1976).
Finally, faunal geographic segregation became pronounced again in the latest Silurian.
The chief difference between Paleozoic corals and modern scleractinian corals is habitat. Whereas the majority of the modern hermatypic corals live in high energy, framework reefs, Paleozoic corals encrusted soft substrates in calm water. The inability of Paleozoic corals to attach to solid objects, other than their initial points of larval fixation (Sando 1977), restricted them from inhabiting reefs (Wells 1957, p. 773).

Thayer (personal oral communication, December 1979) proposed that Paleozoic corals may have lived on softer substrates because of the relative scarcity of burrowers in early Paleozoic times. Stromotoparoids filled the framework reefal niche in mid-Paleozoic times. The backreef lagoonal niche of modern patch reefs is considered the most analogous modern setting to the environment in which Paleozoic corals lived (Wells 1957, p. 773).

As will be expounded upon later, these niche differences between modern and Paleozoic corals are reflected by inferred lesser sediment-rejection capability of the extinct tabulate and rugose corals. However, tabulate corals were more euryfacial organisms than their modern scleractinian counterparts (Sokolov 1971, p. 324). It will also be shown that some coral faunas found in the Paleozoic rocks of the Bear River Range occupied high energy environments.

Modern hermatypic, or reefal, corals incorporate unicellular dinoflagellate algae within their inner skin tissue (Wells 1957, p. 773).
By consuming carbon dioxide, the algae allow host corals to more easily secrete their carbonate skeletons (Goreau and Goreau 1959). The coral also benefits in this symbiosis through the utilization of oxygen liberated by the algae. The association may be an essential factor in attaining high metabolic rates (Manten 1971).

The presence of growth lines on tabulae of tabulate corals (Sorauf 1974) and on walls of rugose corals (Pickett 1975) have been cited as evidence that Paleozoic corals, too, maintained such a symbiotic relationship with algae. Copper and Morrison (1978) describing micrite linings on the inner calices of an Ordovician tabulate coral from northern Ontario. These linings were also considered to indicate algal symbiosis. An important consequence of this alliance in modern, hermatypic corals is to limit them to the photic zone (depths at which light penetration occurs). The late Ordovician and Silurian corals under scrutiny here are regarded to have experienced a similar bathymetric restriction. Depths at which Paleozoic corals dwelled, then, were ordinarily less than 50 meters (Wells 1957; Sokolov 1971).

Coates and Kauffman (1973) identified an ahermatypic Cretaceous coral thicket which occupied a depth estimated at 200 to 500 feet. Wells (1957) asserted that the minimum temperature at which Paleozoic corals could live was in the range of 16 degrees to 21 degrees C. Apparently, as today, Paleozoic corals preferred clear, warm waters. Sokolov (1971) considered tabulate corals to have been fairly tolerant of temperature variations.

In reference to salinity tolerance of Paleozoic corals, normal marine conditions (34-36 parts per thousand) are generally assumed.
Heckel (1972) suggested that the constituents of marine assemblages have been marine since the time of their first appearance. The ancestors of modern corals, then, must have lived in waters of normal marine salinities, although Floyd et al. (1972) described a hypersaline, tidal flat favositid. The great majority of modern hermatypic corals are stenohaline (restricted to a narrow range of salinity). Inferentially, slight decreases in salinity were probably lethal to Paleozoic corals (Sokolov 1971, p. 324).

Wells (1957, p. 774) reported that Paleozoic corals preferred well-oxygenated, agitated, and gently circulating waters. However, he also mentioned that as long as light penetration was not significantly diminished, sediment in suspension could be withstood. Modern hermatypic corals suffer reduced growth rates during intervals of substantial resuspension of bottom sediments (Dodge et al. 1974). However, Manten (1971) mentioned that several solitary rugose and halysitid corals in the Silurian rocks of Gotland, Sweden, are characteristic of marly lithofacies, which are suggestive of murky waters.

Being sessile benthic organisms, corals cannot tolerate, shifting substrates or move away from areas of rapid sedimentation. As will be discussed in detail, the corals of the Late Ordovician and Silurian strata of north-central Utah prevailed when the rate of sedimentation was low to nil. Excessive sedimentation is considered to have been deadly. Planula larvae require a firm substrate for initial attachment (Wells 1957, p. 774).
Sokolov (1971) considered tabulate corals to have required a solid substrate for habitation. He cited low encrusting profiles as adaptations to unfirm substrates. The bulk of some Paleozoic corals, such as large hemispherical favositid colonies, may have provided added stability (Kobluk et al. 1977).

Vaughan and Wells (1943, p. 59) considered coral polyps to be entirely carnivorous. Their food supply was said to be tiny planktonic (floating) and nektonic (swimming) animals. Prey ensnarement is achieved through tentacular activity. This method of nutrient intake is known as suspension feeding. By using the photosynthetic products of their algal symbionts, corals also function as herbivores (Muscatine and Porter 1977). They have also been known to act as deposit feeders, or substrate scavengers (Goreau et al. 1971). Stephens (1962) documented coral uptake of dissolved organic material from sea water. This method of feeding is known as saprotrophism. However, suspension feeding is considered to supply most of the nutrient requirements of corals.
CORAL INTERNAL FEATURES AND TAXONOMY

In this section of the report, the internal features of the individual corallites of the various genera will be discussed (see Figure 16). Tabulate and compound rugose corals are comprised of up to hundreds of corallites, each housing an individual organism, or polyp. The skeleton of solitary rugose corals is one corallite in which one polyp lives.

Tabulae are transverse partitions of corallites. They may be planar features, curve convexly or concavely downward, or bend upward toward one partition of the corallite wall and downward toward another. The calice of the corallite is the uppermost tabula and has been defined by Hill (1956, p. F246) as "... a mold of the base of the polyp." Corallites grow by upward movement of the polyp and secretion of successive calices.

Septa are, according to Hill (1956, p. F247), "radially disposed, longitudinal partitions of corallites ...." They extend from the inner wall of the corallite toward the center. They range in length from extremely short to those which continue from the calical wall to the center of the corallite. In the latter case, an axial structure, or columella, may be formed by vertical prolongation of the septa. The number of septa are greatest in mature corallites, that is, septa are progressively added to the corallite during the lifetime of the polyp.
INTERNAL CORALLITE STRUCTURES

Figure 16. Structures of Paleozoic corals.
The marginarium is the peripheral part of the interior of the corallite. It is comprised of dissepiments (small domed plates parallel to the corallite wall) and a stereozone (dense skeletal deposits). Either or both of these features may be absent (and generally are absent in tabulate corals). Coenosteum is the skeletal deposit formed between corallites. Almost all the corals in this study lack this feature. It is noted in specimens of *Calapoecia*.

Calical relief is the maximum height from the lowest point in the calice to the plane formed by the upper perimeter per the maximum calical diameter. This feature was recorded on several corallites from coralla of various genera (Table 1). Only corals with corallites that appeared not to be abraded or missing the uppermost tabulae (calice) were used. Thus, only several corallites from a few coralla were quantified. Mean and standard deviation for calical relief of each coral and species measured are listed in Table 2 and 3, respectively. Calical shapes (viewed in longitudinal cross section), septal density (number of septa per calice), length of longest septum in proportion to calical diameters, and tabulae spacing were also gauged on numerous corals. Means, standard deviations, and coefficients of variance were determined for these aspects (see Table 4).

Tabulate corals, as implied by name, are characterized by relative prominence of tabulae, as contrasted with rugose, scleractinian, and octocoralline corals. They also feature poorly developed septa or no septa at all. They lived an exclusively colonial mode of existence. The form of the corallum is determined structurally
Table 1. Measurements of Height and Width of Corallites of Various Coralla (in Centimeters)

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<th>Corala</th>
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<td></td>
</tr>
<tr>
<td>Height</td>
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<td>Width</td>
</tr>
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</tr>
<tr>
<td>USU 20 - <em>Cystihalysites brownsportensis</em></td>
<td></td>
<td></td>
</tr>
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<td>Width</td>
</tr>
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Table 1. (Continued)

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SPL3 - *Lichenaria major*

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WPL17 - *Cyathophylloides gothlandicus*

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SPL16 - *Lichenaria grandis*

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TGL1 - *Catenipora gracilis*
Table 2. (Height/Width) Ratio of Corallites of Various Coralla

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<th>Species</th>
<th>n</th>
<th>$\bar{x}$</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM5</td>
<td><em>Favosites gothlandicus</em></td>
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<td><em>Lichenaria grandis</em></td>
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<td>1.60</td>
<td>.08</td>
</tr>
<tr>
<td>USU2</td>
<td><em>Cystihalysites brownsportensis</em></td>
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<td>1.06</td>
<td>.07</td>
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<tr>
<td>GCl</td>
<td><em>Streptelasma sp</em></td>
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<tr>
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<td>1.93</td>
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Table 3. Mean of Mean Height/Width Ratios of Coralla of Various Species

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<th>s</th>
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</thead>
<tbody>
<tr>
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<td>.47</td>
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Table 4. Gross Morphology, Tabulae Spacing, and Calical Features of Collected Specimens (in Millimeters)

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<th>Species &amp; Sample</th>
<th>Gross Morphology</th>
<th>Tabulae Spacing s, x, s/x</th>
<th>Calical Width s, x, s/x</th>
<th>No. of Septa</th>
<th>Longest Septa Calical Width</th>
<th>Calical Shape</th>
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<td>.96, 2.60, .37</td>
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<td>Elongate Hemispherical</td>
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NA - Not applicable
ND - No data
by the shape and arrangement of constituent corallites. In the following paragraphs, the various Ordovician and Silurian corals from the Fish Haven and Laketown Formations are discussed.

**Tabulate Genera**

The structure of the genus *Lichenaria* is quite simple in that it lacks mural pores and septa. The prismatic corallites form massive cerioid coralla, and have essentially straight, horizontal tabulae. Two species of this Ordovician genus have been recognized, based on sizes of mature corallites. *Lichenaria grandis* Bassler 1932 is distinguished by larger corallites measuring from 1.3 mm to 1.7 mm, whereas *Lichenaria major* Bassler 1944 displays mature corallites over 3.0 mm in diameter. This taxonomic split may be in error, because a continuum of mature corallite diameters is discernable.

*Calapoecia anticostiensis* Billings 1865 features circular corallites separated by coenenchyme marked by costae (prolonged septa on outer side of corallite walls). The corallite walls are so porous that they appear as a mere lattice-work with pore space accounting for about 50% of the area of the wall. Although septa are prolonged outside the corallite, they extend for only an extremely short distance into the corallite interior. Tabulae are slightly irregular, although calices are essentially flat-floored. Calical relief for corallites of this species averaged 1.46 although this value varied somewhat (standard deviation = .47).

The genus *Syringopora* is characterized by closely to loosely set cylindrical corallites connected by transverse structures known
as stolons. Encasement in rock matrices prohibited the collection of specimens of this genus and precluded quantification of internal features and identification of species. Budge (1966) identified *S. verticillata* in the upper Laketown Formation. Miller (1977) reported a calical relief, in specimens of this genus from Mississippian strata of 1.0. The calice of *Syringopora* is flat-floored and "closely set, deeply depressed axially ..." (Hill 1956, p. F472).

The genus *Halysites* is represented by two subgenera and three species in this investigation. The cylindrical corallites are oval to round when viewed transversely and unite to form anastomosing ranks (commonly referred to as chains) that intersect with other ranks. Areas between ranks have been labeled lacunae (Buehler 1955). Tabulae are abundant, flat, and somewhat closely spaced. Septa (sensu strictu) are not actually present but are represented by slender spines, or septal spines. These features number twelve in all specimens observed regardless of species and extend from the corallite walls slightly more than halfway to the center of the calice. The complete shape of halysitid coralla are seldom preserved, undoubtedly due to their relatively fragile fasciculate structure. Most specimens collected allow only identification and lithologic correlation. This is particularly true for samples of the subgenus *Catenipora* from Green Canyon.

*Catenipora* is restricted to Ordovician strata. This is evidenced by its association with distinctively Ordovician assemblages (such as at the White Pine Lake collecting site). The subgenus is distinguished by the uniform size and relative rectangularity of corallites. Based
on average calical diameter, specimens collected for this report are referred to the species *Catenipora gracilis* Hall 1851.

The subgenera *Cystihalysites* and *Halysites* (sensu strictu) have two types of corallites. "Normal sized autocorallites form the apparent links in the ranks. Smaller mesocorallites, not apparent without very close examination by the naked eye, are intercalated between autocorallites along the length of ranks. The two subgenera differ in the nature of their tabulature within the mesocorallites. Tabulae within mesocorallites of *Cystihalysites* often are arched, intersecting one another. This is not true of the subgenus *Halysites* (sensu strictu) wherein they are flat and do not intertwine. Both subgenera feature ellipsoidal calical openings.

Two species of *Cystihalysites* are present in the Laketown Formation. They are differentiated by autocorallite size and the presence or absence of transverse growth lines on the outside of corallites. *C. magnitubis* Buehler 1955 displays these growth lines. Mean corallite size is greater than 2.5 mm. Corallites of *C. brownsportensis* Amsden 1949 lack growth lines and do not reach a width greater than 2.5 mm.

One specimen of *Foerstephyllum halli* Nicholson 1879 was collected from the White Pine Lake collecting site. Within the calices of this coral are 26 to 28 very short septa that are finely denticulated on their inner edge. Although tabulae have been obscured diagenetically, they are described by Bassler (1950) as being numerous and horizontal. Even though the corallites
cannot accurately be described as polygonal, their spatial configuration is best labeled cerioid.

*Favosites gothlandicus* Lamarck 1816 is noted for its thin walled, prismatic, aseptate corallites. Calical widths of mature corallites range from 2.5 mm to nearly 4.0 mm. Tabulae may be flat or arched. Tabulae spacing is variable, especially in lensoidally shaped specimens, averaging anywhere from .5 mm to 2.5 mm. Gross morphologies of this species exemplify the phenomenon of morphologic plasticity. This concept will be discussed in the following section of this report.

*Favosites cf. F. beechensis* Amsden 1949 displays aseptate corallites averaging about 1.0 mm in diameter. They are polygonal in transverse cross section. Tabulae are very closely spaced, being less than 1.0 mm apart at their maximum spacing. Amsden (1949) described the species as being "hemispherical or button shaped." In adherence to the premise that tabulate corals indeed were highly morphologically variable, lensoidal corals exhibiting the aforementioned corallite features have been included within this taxon.

*Astrocerium venustum* Hall 1851 is distinguished from other favositid corals in this study by the presence of twelve septal spines. Calical openings average around 1.2 mm in mature corallites. Corallites are prismatic, forming cerioid coralla. Tabulae are closely set and moderately arched. Coralla of this species at Card Canyon appear lensoidal in cross section.

Corals of a genus fitting the description of *Platyaxum* Amsden 1949 and *Planalveolites* Hill 1956, p. F466, were noted in Card Canyon.
These corals will henceforth be referred to as *Platyaxum* cf *P. planostiolutum* because of their resemblance to the description of this species by Amsden (1949). These thin, plate-like corals appear to have been encrusting masses. Corallites are much wider than high, calical relief being a small fraction of a millimeter. At the surface of the coralla, these corallites bend giving an almost horizontal orientation. No septa or tabulae are visible.

**Rugose Genera**

In contrast to the tabulates, rugose corals are noted for their strong development of septa relative to tabulae. In many rugose corals, the tabularium (space occupied by tabulae) is surrounded by a dissepimentarium (zone around the inside wall of the corallite consisting of dissepiments) and/or a stereozone (area outside of the corallite consisting of thick skeletal tissue). Unlike tabulate corals, rugose corals may be solitary as well as colonial.

Following rugose corals were identified in the field. Because they could not be extracted from their lithologic matrices, they were not collected.

The genus *Cyathophylloides* is characterized as having polygonal corallites and septa extending to corallite centers where they form incipient axial structures. These prismatic corallites collectively form cerioid coralla. Mature corallites are greater than 3.0 mm in diameter. Tabulae, although somewhat indistinguishable in longitudinal sections prepared for this study, are arched downward along corallite walls. Marginaria in these corals are lacking. Specimens
of the genus collected near White Pine Lake are assigned to the species *Cyathophylloides gothlandicus* Edwards and Haime 1850.

Two species of *Paleophyllum* have been tentatively differentiated into separate species based on the statistically significant disparity in mean corallite diameters (see Table 12). A lensoidal specimen with a mean corallite diameter of 4.3 mm is referred to *P. halysoideae* Wilson 1936. Its corallite arrangement is best described as fasciculate, although many corallites are in contact. *P. raduguini* Nelson 1963 is distinguished by a mean corallite diameter of 3.3 mm. The specimen included within this taxon displays a pronounced vertical component of growth and a halysitoid packing arrangement. It is entirely possible that these two species are actually only one species. As only two specimens of the genus were available for inspection, no continuum of mean calical widths was discernible. When appressed against one another, the corallites of the specimens of *Paleophyllum* acquire a subpolygonal aspect. Where free, the corallites are circular to oval in transverse section. In mature corallites 18 to 20 primary septa extend nearly to the centers where they coalesce to form a small axial structure. Most tabulae are horizontal, but may deflect downward on the margins.

The genus *Streptelasma* comprises solitary rugose corals with funnel-shaped calices furnished with numerous septa. Marginaria are thin and simple whereas tabulae are rare or lacking. *Streptelasma* aff. *S. latusculum* Billings form trochoid coralla, i.e., solitary
horn-shaped corallite with sides regularly expanding from the apex at an angle of about 40 degrees (Hill 1956, p. 251). Coralla do not become cylindrical in adult stages (Hill 1956, p. 251). Axial structures in members of this species are virtually nonexistent. *Streptelasma aff. S. prolongatum* Wilson 1935 is angulate along the trace of the cardinal septum (initial septum along the plane of bilateral symmetry). Generally an elongate axial structure is discernible. Mature coralla are cylindrical in transverse section. Field identification of *Streptelasma* was usually restricted to the generic level.
AUTECOLOGY

Description of External Features

The various genera and species found in the strata under discussion display differing degrees of morphologic plasticity, or the ability of a species to modify its shape. Such modification is induced by environmental factors, predominantly sedimentation. It has been demonstrated by various 20th-century coral workers that a wide spectrum of morphologies for any given species is possible. Recognition of the effect of the environment on corallum morphology prompted Hickson (1898), Bernard (1901), and Wood-Jones (1907) to suggest that species in living corals could not be recognized. Mayor (1924) and Stephenson and Stephenson (1933) concluded that variation takes place within definite morphologic limits for any particular scleractinian species.

Hoffmeister (1926) cited studies which aptly demonstrated the role of environment in modifying coral morphology. In these experiments coral colonies were divided and placed in dissimilar environments. After a year halves "... were often so different in growth form and calicular character that it was impossible to tell that they belonged to the same species."

From his observations, the present author concurs with the view of Wells (1957, p. 1088-1089) who stated, "Some species show little plasticity of form and each is indicative of a certain ecologic niche. Others are highly plastic and may be found in a
variety of situations, in each case showing a form adapted not only to survival but for successful competition with other organisms."

From the Fish Haven and Laketown Formations of the Bear River Range, *Favosites gothlandicus* displays remarkable plasticity. Other species and genera show more intermediate ability to modify their gross morphology.

Other evaluations of variation in fossil corals have followed trends similar to those described for studies of living corals. Jones (1936) reviewed several European species of *Favosites* and reduced some to "formae" interpreted as environmentally-induced characters. This taxonomic revision was prompted by the identification of characteristics of different "species" within the same coralla. Tripp (1933), in a similar reexamination, reduced ten species to three in a study of *Favosites* from Gotland, Sweden. These and other studies resulted in reconsideration of the Linnean species concept in fossil colonial corals.

The following morphologic types are modes within a continuum of shapes from lenticular to forms with a strongly predominant vertical component of growth. It is assumed that these are the optimum morphologies for their respective environments and that morphologies intermediate between modes did not flourish because their optimum environmental conditions were not prevalent. This continuity of shapes is more relevant to species with greater morphologic plasticity and applies to a lesser degree to corals characterized by minimal plasticity. The environmental impact upon morphology will be further discussed later in this paper.
Radial-lensoidal corals have a far greater horizontal dimension than vertical. Height to width ratios of these coralla range from 1/3 to 1/5. These corals are also distinguished by a general predominance of individual corallites growing nearly parallel to the substrate. All specimens of this morphotype, except WPL20 (*Paleophyllum*), taper at their margins and are generally thickest at their centers. These corals are, for the most part, analogous to the Type II Corals of Miller (1977). They may be subdivided by symmetry.

Asymmetric radial-lensoidal corals display growth of individual corallites from essentially parallel to the substrate to a divergence of 30 degrees to 40 degrees from the substrate. The asymmetry resulted from preferential lateral expansion in one direction from the budding center of the colony. Specimens of *Lichenaria* and *Paleophyllum* from the White Pine Lake site demonstrate these characteristics (Figure 17 and 18). The corallites of WPL20 (*Paleophyllum*) bend upward (perpendicular to the substrate) at the margin of the corallum.

Symmetric radial-lensoidal corals demonstrate no directional preference regarding lateral expansion. In this aspect they are similar to hemispherical corals. *Cyathophylloides* and *Lichenaria* from White Pine Lake typically display this morphology. In addition, they commonly are seen to encrust pebbles of chert or wackestone.

Other features seen on some symmetric radial-lensoidal corals are "balding" and the downward growth of corallites from the "base" of coralla. The former characteristic is distinguished by the
Figure 17. Top and bottom views of asymmetrical specimen WPL22 (Calapoecia anticostiensis). Note clast protruding through corallum.
Figure 18. Asymmetric radial-lensoidal specimen of *Paleophyllum* from White Pine Lake collecting site.
presence of areas lacking corallites on the surface of a colony. This surface is recessed on all corals collected by the author displaying this character. Coralla exhibiting downward growth of corallites around lateral margins of coralla will henceforth be described as umbrellic (Figure 19). Mean corallite size for the downwardly oriented corallites of the umbrellic, symmetric radial-lensoidal coral WPL10 *Cyathophylloides* is the same as for corallites on the upper surface of the colony. Noteworthy is the affinity of these umbrellic corals for basal encrustation on lithiclasts (Figures 20 and 21). Downward growth of corallites and balding (Figure 22) are primarily associated with *Cyathophylloides*, although umbrellic shapes have been observed in *Lichenaria*.

The bases of radial-lensoidal corals may be planar, concave downward, or convex downward. Bases of those coralla encrusting pebbles and/or with downward facing corallites are without exception concave downward.

Tabular corals (Figure 23) seemingly show no preferential lateral growth about their budding center. The reservation conveyed in this statement concerning symmetry results from the obscurity of budding centers on the bases of corals of this morphotype. This vagueness results from the uniform parallelism of corallites with respect to one another. These corals are similar to radial-lensoidal corals in cross-sectional outline and in their predominance of lateral growth. However, the chief means by which they achieved lateral expansion differed drastically. Whereas radial-lensoidal corals grew
Figure 19. Downward growth in corallites on radial-lensoidal specimen (*Cyathophylloidens*). Left and right halves are top and bottom of corallum, respectively.
Figure 20. Longitudinal cross section of radial-lensoidal corallum (*Lichenaria*) from White Pine Lake. Note clast which it encrusts.
Figure 21. Radial-lensoidal corallum (*Lichenaria major*) from White Pine Lake collecting site. Note concentric circles drawn on surface.
Figure 22. Bald, radial-lensoidal coral (*Cyathophyllloides gothlandicus*) from White Pine Lake collecting site.
Figure 23. Tabular-lensoidal corallum, longitudinal cross section (*Favosites gothlandicus*) from the Blacksmith Fork collecting site.
horizontally by growth of individual corallites, non-radial corals expand parallel to the substrate by "... frequent budding rather than a higher growth rate of individual polyps" (Philcox 1971).

Mean corallite size for corallites on the margin and for corallites on a transect through the approximate middle of the colony were determined from a sectioned surface of the tabular-lensoidal specimen BF3. The t-test showed the corallites on the margin to be significantly smaller than those in the center of the corallum (Table 5). In addition, the variance of the corallites of the two measured areas of the corallum were subjected to the F-test (Table 5). The variance of corallite diameters on the margin is significantly greater than for those widths measured along the transect through the middle portion of the colony. Thus, the supposition that corals of this morphotype grew predominantly by lateral budding at their margins is correct if this specimen is representative of tabular-lensoidal corals.

Other favositid morphotypes produced buds essentially intermurally. It must be noted that in BF3, buds were observed in the interior of the corallum, but the data suggest this mode of increase to be secondary. As Stel (1979) has shown, intermural increase is actually a special case of lateral increase and the actual process of asexual reproduction among cerioid tabular corals and massive corals with radiating corallites did not differ. The disparity was in the location of the majority of buds on the respective coralla.
Table 5. Comparison of Mean and Variance in Corallite Size Between the Mid-Portion and Perimeter of Specimen BF3 (Measurement in Millimeters)

<table>
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<th>Perimeter</th>
<th></th>
<th>Mid-Portion</th>
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</thead>
<tbody>
<tr>
<td>n = 14</td>
<td>$\bar{X} = 2.4$</td>
<td>n = 14</td>
<td>$\bar{X} = 3.7$</td>
</tr>
<tr>
<td>s = 1.2</td>
<td></td>
<td>s = 0.6</td>
<td></td>
</tr>
</tbody>
</table>

$t = 3.6255$

critical value = 1.771
for df = 13, alpha = 0.5

$F = 4.0$

critical value = 2.58
for df = 13, alpha = .05

Maximum, Minimum Widths

| 1.8, 1.2 | 3.8, 3.6 |
| 2.8, 2.5 | 4.2, 3.6 |
| 2.0, 1.8 | 4.3, 4.2 |
| 2.1, 1.8 | 4.1, 3.5 |
| 2.8, 2.2 | 3.3, 3.2 |
| 1.8, 1.8 | 3.5, 2.5 |
| 1.8, 1.8 | 4.5, 3.4 |
| 2.2, 1.8 | 3.0, 2.8 |
| 2.0, 2.0 | 3.2, 3.2 |
| 2.2, 2.0 | 4.5, 4.5 |
| 1.8, 1.8 | 3.6, 3.5 |
| 3.8, 3.8 | 4.9, 4.5 |
| 2.0, 2.0 | 5.0, 3.4 |
| 1.8, 1.8 | 3.2, 3.2 |
A second series of measurements undertaken on transversely sectioned slabs of BF3 was the measurement of calical diameters on a section through a part of the corallum exhibiting narrow tabulae spacing and on a section through a portion characterized by relatively wide tabulae spacing. Although the variance of the two measurements did not differ significantly, corallites associated with wide tabulae spacing proved to be statistically larger than those associated with narrow tabulae spacing (Table 6). Differences in tabulae spacing on different parts of the corallum will be discussed in the section of this report on internal features of corals.

Whereas the tapering at the lateral margins of the radial-lensoidal corals is attributed to greater horizontal than vertical growth of individual corallites, tapering in tabular-lensoidal coralla is accounted for by the relative immaturity of polyps on the lateral periphery.

With respect to radial-lensoidal and tabular-lensoidal-colonial corals, it must be mentioned that many corals herein classified display an intermediate configuration. That is, whereas corallites radiate in all directions, lateral budding has resulted in the disjunction of most corallites from the actual budding center.

Coralla with no restrictions of either vertical or horizontal growth developed essentially hemispherical morphologies. The bases of these coralla appear either as fundamentally planar surfaces parallel to the substrate (when in growth position) or as slightly convex downward surfaces. Upper surfaces, although
Table 6. Comparison of Mean and Variance in Corallite Size Between Corallites Associated with Narrow Tabulae Spacings and Wide Tabulae Spacings of Specimen BF3 (*F. gothlandicus*) (in Centimeters)

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td></td>
<td>n = 37</td>
<td>n = 44</td>
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<tr>
<td></td>
<td>$\bar{x} = 3.32$</td>
<td>$\bar{x} = 2.88$</td>
</tr>
<tr>
<td></td>
<td>$s = .67$</td>
<td>$s = .72$</td>
</tr>
</tbody>
</table>

$t = 2.845$

critical value = 1.645
for df = 36,43; alpha = .05

$f = 1.15$

critical value = 1.69
for df = 36,43; alpha = .05
idealized as hemispherical, are usually dome-shaped with slightly flattened uppermost surfaces.

Several specimens from the Sharp Mountain collecting site are distinguished by a lateral dimension as much as three times greater than its corresponding vertical dimension. Corals with a generally hemispherical shape displaying this eccentricity will henceforth be referred to as elongate-hemispherical corals. In addition, these elongate coralla often exhibit asymmetry of growth about their budding centers along with their longest horizontal dimension.

Other favositids and halysitids appear virtually symmetrical about their budding centers and with respect to overall morphology. Figure 39 is an elongate hemisphere whereas Figures 27 and 43 are hemispherical (sensu strictu) corals. The height to width ratios of hemispherical corals range commonly from 3/4 to 1.

Columnal corals include coralla in which the vertical component clearly exceeds the horizontal component of growth. Such a morphology is achieved by a preponderance of vertical growth of individual corallites. Budding on these coralla account for a relatively minor portion of total colony growth. Height to width ratios characteristically range from 3/2 to 2 (Figure 24).

Corals whose lateral margins taper toward the base, or budding center, are an abundant subdivision of columnal coralla. This subdivision is designated by the term conic-columnal, or conic. An example is seen in Figure 24.

Specimen WPL 19 (Figure 25) is a columnal coral in which the colony diameter does not appreciably change from top to bottom of the coralla. This morphology may be labeled straight-columnal.
Figure 24. Conic-columnal corallum (*Favosites gothlandicus*) from Sharp Mt. collecting site.
Figure 25. Columnal specimen of *Paleophyllum* from White Pine Lake collecting site.
Circumrotary corals are modifications of radial-lensoidal or hemispherical corals. Corallites on these coralla completely envelope the colonies. Morphologies range from virtually spherical to flattened ellipsoidal. Many specimens of *Calapoecia* approximate this configuration. However, most of these corals display a flattened basal surface smaller than their maximum lateral dimensions. Figure 26 shows the fusion of two spherical circumrotary corals of the genus *Lichenaria*.

Composite corals are those that are comprised of more than one morphotype or a repetition of the same morphotype. These coralla reflect a change in growth form during the astogeny of the colony. For example, several specimens of *F. gothlandicus* show an initially strong vertical component of growth followed by relatively greater lateral expansion. Repetitions representing either the usage of the surface of one colony by the other for a fixation surface of the initiation of a second "subcorallum" by the polyps on a small area of the upper surface of the first "subcorallum" have also been observed.

Sample SM5 (Figure 27) exhibits a columnal protuberance jutting out at 45 degrees from the vertical axis of a hemispherical corallum. Such relatively small modifications of original morphotypes as these are referred to as satellite colonies. They reflect the survival of an isolated groups of polyps on the surface of a corallum.

The specimen shown in Figure 28 exemplifies the phenomenon of geniculation, normally associated with solitary rugose corals. Early in the astogeny of the colony, a columnal shape was attained.
Figure 26. Fused, circumrotary coralla (*Lichenaria*) from the White Pine Lake collecting site.
Figure 27. Hemispheric corallum with satellite colony projecting from right surface of main colony at 45 degrees. *Favosites gothlandicus* from the White Pine Lake collecting site.
Figure 28. Geniculate colonial coral (*Favosites gothlandicus*) from the White Pine Lake collecting site.
Subsequent to toppling over, the coral expanded to form a hemispherical shape.

Specimen WPL21 (Figure 29) displays a wrinkling toward the bottom of the corallum. This reflects a renewal of growth after a period of nongrowth. Originally the coral attained a spherical shape. Renewed growth was principally vertical. The sample is of the genus *Calapoezia*.

Figure 30 is a specimen of *Cystihalysites brownsportensis*. Initially a plate-shaped morphology developed. An even more lenticular projection is seen expanding to the right of the original main portion of the corallum.

The coralla of rugose corals can be subdivided readily into two general morphotypes, those that are straight and those that are geniculate, or that show at least one gentle or sharp curve, in longitudinal profile. However, rugose corals are relatively scarce in the strata under study. Furthermore, those observed are only partially exposed or appear to have been fragmented after lithification and exposure to weathering and erosion.

Besides geniculation, certain other features may or may not have characterized solitary rugose corals of the Fish Haven and Laketown Formations. One peculiarity is constrictions of the corallum, which form a ledge of older calice around the constricted part. It (the constriction) then increases in diameter, and the process may be repeated." (Hill 1956, p. F246) These constrictions are manifestations of rejuvenescence of the organism.
Figure 29. Wrinkled surface of specimen WPL21 (*Calapoezia anticostiensis*) from the White Pine Lake collecting site.
Figure 30. Lenticular specimen of *Cystihalysites brownsportensis* from Card Canyon collecting site. Photo taken of vertical cliff.
Other features that may be obscured by lack of exposure of preservation are talons ("a buttress produced by outgrowth of corallite wall, served as an aid in fixation." (Hill 1956, p. F247)) and flat basal attachment scars (Sando 1977).

Three general packing arrangements have been recognized in the corals from the Fish Haven and Laketown Formations. The term cerioid describes a pattern in which "... walls of adjacent polygonal corallites are closely united." (Hill 1956, p. F246) Favositid corals are ideal examples of cerioid coralla. The term plocoid describes "Massive coralla in which corallites have separated walls and are united by costae, dissepiments, or coenosteum." The tabulate genus Calapoecia illustrates this arrangement. Fasciculate coralla are those with cylindrical corallites which are somewhat separated from one another but may be joined by connecting tubules. Syringopora and Paleophyllum characteristically developed this packing arrangement. Cateniform corals have "coralla with corallites united laterally as palisades which appear chainlike in (transverse) cross section, the palisades commonly forming a network." (Hill 1956) Halysitid corals display this packing pattern.

Several analyses were performed to compare intercorallum and intracorallum differences in corallite geometry, size, and variance. Concentric circles of increasing radii (increasing in increments of 1.0 centimeter) were made around points on top of coralla above budding centers (when ascertainable). If these points were obscure, transects were made across coralla. Maximum and minimum diameters,
greatest septal length, number of septa, calical relief, and shape were recorded for each corallite touched by the concentric circles or transects.

Maximum to minimum width ratios of corallites along concentric circles on top of and on sides of six coralla, encompassing four genera, were subjected to statistical analysis (Table 7). The t-test demonstrated a significant difference in corallite geometry between crown and edge in only one specimen. SMR (Favosites gothlandicus) an elongate hemispherical corallum, was shown to have a statistically greater mean maximum/minimum ratio on its crest than on its edge. Furthermore, the F-test showed greater variance of geometries on the edge of specimen WPL1 (Cyathophylloides) and WPL8 (Calapoezia) than on their upper surfaces. Concentric circles used on the corallum of the Lichenaria specimen are seen in Figure 21. The results on the tests on corallite geometry are shown in Table 7.

Analysis of variance was applied to mean corallite sizes of concentric circles on sixteen coralla from the White Pine Lake collecting site. No significantly different means were indicated between concentric circles on any coral scrutinized. Table 8 displays values used and their results.

When coralla were fragmented or budding centers obscure, transects were drawn across coralla. Diameters of corallites on these transects were noted. These data, along with that obtained along unit circles, were used to determine means, standard deviations, and coefficients of variation (standard deviation/mean) or corallite diameters with respect to entire coralla in order to compare intermorphotypic vs. intramorphotypic variation.
Table 7. Comparison of Mean and Variance of Maximum/Minimum Ratios of Corallites on Concentric Circles Along Crests and Sides of Coralla (in Centimeters)

<table>
<thead>
<tr>
<th>WPL1 - Cyathophyllumoides gothlandicus</th>
</tr>
</thead>
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<tr>
<td><strong>Tops</strong></td>
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<td>n = 15</td>
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<tr>
<td>$\bar{x} = 1.3$</td>
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<tr>
<td>$s = 0.2$</td>
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<tr>
<td><strong>Sides</strong></td>
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<tr>
<td>n = 16</td>
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<tr>
<td>$\bar{x} = 1.3$</td>
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<tr>
<td>$s = 0.4$</td>
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</tbody>
</table>

$t = 0$

*critical value* = 1.758

$df = 14, 15$; $alpha = 0.5$

$F = 4.00$

*critical value* = 1.758

for $df = 14, 15$; $alpha = .05$

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<tbody>
<tr>
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Table 7. (Continued)

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<thead>
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<th>WPL3</th>
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<tr>
<td>( s = 0.4 )</td>
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</tbody>
</table>

\[ t = 1.2 \]
\[ \text{critical value} = 1.8 \]
\[ \text{for df} = 13, 9; \alpha = 0.05 \]

\[ F = 1.00 \]
\[ \text{critical value} = 2.71 \]
\[ \text{for df} = 13, 9; \alpha = 0.5 \]

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<table>
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<tr>
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<td>( n = 15 )</td>
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<td>( \bar{x} = 1.0 )</td>
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<tr>
<td>( s = 0.1 )</td>
<td>( s = 0.1 )</td>
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</tbody>
</table>

\[ t = 0 \]
\[ \text{critical value} = 1.73 \]
\[ \text{for df} = 26, 14; \alpha = 0.5 \]
Table 7. (Continued)

WPL6 - *Calapoezia anticostiensis* (Continued)

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WPL8 - *Calapoezia anticostiensis*

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<tr>
<td>( \bar{x} = 1.1 )</td>
<td>( \bar{x} = 1.1 )</td>
</tr>
<tr>
<td>s = 0.1</td>
<td>s = 0.2</td>
</tr>
</tbody>
</table>

\[ t = 0 \]
\[ \text{critical value} = 1.73 \]
\[ \text{for df = 20, 17; alpha = 0.5} \]

\[ F = 4.00 \]
\[ \text{critical value} = 2.19 \]
\[ \text{for df = 10, 17; alpha = 0.5} \]
Table 7. (Continued)

WPL8 - *Calapoezia anticostiensis* (Continued)

<table>
<thead>
<tr>
<th>Tops</th>
<th>Sides</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>1.0</td>
<td>1.1</td>
</tr>
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<td>1.0</td>
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</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
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<tr>
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<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

WPL14 - *Lichenaria grandis*

<table>
<thead>
<tr>
<th>Tops</th>
<th>Sides</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 11</td>
<td>n = 20</td>
</tr>
<tr>
<td>$\bar{x} = 1.2$</td>
<td>$\bar{x} = 1.3$</td>
</tr>
<tr>
<td>$s = 0.2$</td>
<td>$s = 0.3$</td>
</tr>
</tbody>
</table>

$t = 1.9$

critical value = 1.8

for df = 10, 19; alpha = 0.5

$F = 2.25$

critical value = 4.25

for df = 10, 19; alpha = 0.5
Table 7  (Continued).

<table>
<thead>
<tr>
<th>SM4 - <em>Favosites gothlandicus</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tops</strong></td>
</tr>
<tr>
<td>n = 18</td>
</tr>
<tr>
<td>$\bar{x} = 1.32$</td>
</tr>
<tr>
<td>$s = 0.39$</td>
</tr>
<tr>
<td><strong>Sides</strong></td>
</tr>
<tr>
<td>n = 16</td>
</tr>
<tr>
<td>$\bar{x} = 1.1$</td>
</tr>
<tr>
<td>$s = 0.2$</td>
</tr>
</tbody>
</table>

$t = 2.10$

critical value = 1.74

for df = 17, 15; alpha = 0.5

$F = 3.803$

critical value = 2.31

for df = 17, 15; alpha = 0.5

<table>
<thead>
<tr>
<th><strong>Tops</strong></th>
<th><strong>Sides</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>1.6</td>
<td>1.7</td>
</tr>
<tr>
<td>1.1</td>
<td>1.0</td>
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<tr>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>1.4</td>
<td>1.7</td>
</tr>
<tr>
<td>2.5</td>
<td>1.0</td>
</tr>
<tr>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>1.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Table 8. Analysis of Variance of Mean Calical Widths Along Concentric Circles of Increasing Radii by 1 Centimeter (All Measurements in Millimeters)

<table>
<thead>
<tr>
<th>Genus</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>Composite</th>
<th>Analysis of Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cylanthophyllides</em></td>
<td>n 15</td>
<td>25</td>
<td>17</td>
<td>13</td>
<td>16</td>
<td>86</td>
<td>$s^2/s_{n-1}^2 = 0.14/0.78 = 0.19$</td>
</tr>
<tr>
<td></td>
<td>$\bar{x}$</td>
<td>2.90</td>
<td>3.51</td>
<td>1.86</td>
<td>2.69</td>
<td>3.79</td>
<td>Critical Value = 2.54 for df = 4.81</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>.88</td>
<td>.94</td>
<td>.96</td>
<td>.78</td>
<td>.90</td>
<td></td>
</tr>
<tr>
<td><em>Lichenaria</em></td>
<td>n 27</td>
<td>30</td>
<td>23</td>
<td>26</td>
<td>18</td>
<td>108</td>
<td>$s^2/s_{n-1}^2 = 0.12/0.095 = 0.126$</td>
</tr>
<tr>
<td>WPL1</td>
<td>$\bar{x}$</td>
<td>1.08</td>
<td>1.20</td>
<td>1.07</td>
<td>1.30</td>
<td>1.16</td>
<td>Critical Value = 2.72 for df = 3.104</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>.32</td>
<td>.34</td>
<td>.30</td>
<td>.26</td>
<td>.32</td>
<td></td>
</tr>
<tr>
<td><em>Lichenaria</em></td>
<td>n 14</td>
<td>26</td>
<td>31</td>
<td>24</td>
<td>10</td>
<td>115</td>
<td>$s^2/s_{n-1}^2 = 0.03/0.070 = 0.043$</td>
</tr>
<tr>
<td>WPL2</td>
<td>$\bar{x}$</td>
<td>1.13</td>
<td>1.19</td>
<td>1.21</td>
<td>1.54</td>
<td>1.51</td>
<td>Critical Value = 2.67 for df = 4.101</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>.36</td>
<td>.21</td>
<td>.29</td>
<td>.22</td>
<td>.20</td>
<td></td>
</tr>
<tr>
<td><em>Lichenaria</em></td>
<td>n 13</td>
<td>22</td>
<td>9</td>
<td>12</td>
<td>12</td>
<td>60</td>
<td>$s^2/s_{n-1}^2 = 0.032/0.215 = 0.167$</td>
</tr>
<tr>
<td>WPL3</td>
<td>$\bar{x}$</td>
<td>1.75</td>
<td>1.86</td>
<td>1.42</td>
<td>1.75</td>
<td>1.74</td>
<td>Critical Value = 2.78 for df = 3.56</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>.57</td>
<td>.49</td>
<td>.25</td>
<td>.34</td>
<td>.38</td>
<td></td>
</tr>
<tr>
<td><em>Lichenaria</em></td>
<td>n 12</td>
<td>19</td>
<td>35</td>
<td>44</td>
<td>11</td>
<td>121</td>
<td>$s^2/s_{n-1}^2 = 0.021/0.237 = 0.09$</td>
</tr>
<tr>
<td>WPL4</td>
<td>$\bar{x}$</td>
<td>2.15</td>
<td>2.01</td>
<td>2.22</td>
<td>2.09</td>
<td>2.10</td>
<td>Critical Value = 2.46 for df = 4.116</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>.53</td>
<td>.53</td>
<td>.53</td>
<td>.50</td>
<td>.48</td>
<td></td>
</tr>
<tr>
<td><em>Calypooecia</em></td>
<td>n 23</td>
<td>30</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>73</td>
<td>$s^2/s_{n-1}^2 = 0.013/0.085 = 0.153$</td>
</tr>
<tr>
<td>WPL5</td>
<td>$\bar{x}$</td>
<td>2.61</td>
<td>2.51</td>
<td>2.38</td>
<td>2.52</td>
<td>2.52</td>
<td>Critical Value = 3.13 for df = 3.105</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>.30</td>
<td>.26</td>
<td>.33</td>
<td>.28</td>
<td>.28</td>
<td></td>
</tr>
<tr>
<td><em>Lichenaria</em></td>
<td>n 24</td>
<td>26</td>
<td>26</td>
<td>29</td>
<td>29</td>
<td>109</td>
<td>$s^2/s_{n-1}^2 = 0.027/0.078 = 0.346$</td>
</tr>
<tr>
<td>WPL6</td>
<td>$\bar{x}$</td>
<td>2.29</td>
<td>2.30</td>
<td>2.39</td>
<td>2.01</td>
<td>2.26</td>
<td>Critical Value = 2.69 for df = 3.105</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>.28</td>
<td>.30</td>
<td>.26</td>
<td>.28</td>
<td>.28</td>
<td></td>
</tr>
<tr>
<td><em>Calypooecia</em></td>
<td>n 21</td>
<td>31</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>70</td>
<td>$s^2/s_{n-1}^2 = 0.05/0.078 = 0.346$</td>
</tr>
<tr>
<td>WPL7</td>
<td>$\bar{x}$</td>
<td>3.36</td>
<td>3.34</td>
<td>3.23</td>
<td>3.22</td>
<td>3.32</td>
<td>Critical Value = 3.14 for df = 2.66</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>.18</td>
<td>.27</td>
<td>.34</td>
<td>.41</td>
<td>.41</td>
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</tbody>
</table>
Table 8. (Continued)

<table>
<thead>
<tr>
<th>Species</th>
<th>Cl</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>Composite Analysis of Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lichenaria</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WPL9</td>
<td>24</td>
<td>23</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>1.90</td>
<td>1.48</td>
<td>1.79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>s</td>
<td>.18</td>
<td>.27</td>
<td>.34</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
|                      |     |     |     |     |     | $s^2/\sigma^2 = .977/1.61 = .605$
|                      |     |     |     |     |     | Critical Value = 4.35
|                      |     |     |     |     |     | for df = 2.66                   |
| Caliquocea          | 22  | 19  |     |     |     |                                |
| WPL11               |     |     |     |     |     |                                |
| x                   | 2.32| 1.97|     |     |     |                                |
| s                   | .47 | .37 |     |     |     |                                |
|                      |     |     |     |     |     | $s^2/\sigma^2 = .013/.757 = .0208$
|                      |     |     |     |     |     | Critical Value = 4.35
|                      |     |     |     |     |     | for df = 1.20                   |
| Lichenaria          | 15  | 23  |     |     |     |                                |
| WPL12               |     |     |     |     |     |                                |
| x                   | 2.36| 2.66|     |     |     |                                |
| s                   | .95 | 1.30|     |     |     |                                |
|                      |     |     |     |     |     | $s^2/\sigma^2 = .051/1.40 = .037$
|                      |     |     |     |     |     | Critical Value = 4.08
|                      |     |     |     |     |     | for df = 1.38                   |
| Lichenaria          | 13  | 18  | 21  | 22  |     |                                |
| WPL14               |     |     |     |     |     |                                |
| x                   | 1.22| 1.12| 1.23| 1.20|     |                                |
| s                   | .42 | .26 | .33 | .27 |     |                                |
|                      |     |     |     |     |     | $s^2/\sigma^2 = .003/.102 = .029$
|                      |     |     |     |     |     | Critical Value = 2.76
|                      |     |     |     |     |     | for df = 2.59                   |
| Lichenaria          | 13  | 18  | 11  |     |     |                                |
| WPL15               |     |     |     |     |     |                                |
| x                   | 1.27| 1.08| 1.13|     |     |                                |
| s                   | .36 | .39 | .32 |     |     |                                |
|                      |     |     |     |     |     | $s^2/\sigma^2 = .010/.172 = .082$
|                      |     |     |     |     |     | Critical Value = 3.14
|                      |     |     |     |     |     | for df = 2.59                   |
| Caliphylloides      | 5   | 11  | 9   |     |     |                                |
| WPL18               |     |     |     |     |     |                                |
| x                   | 4.46| 4.13| 4.03|     |     |                                |
| s                   | .75 | 1.00| .86 |     |     |                                |
|                      |     |     |     |     |     | $s^2/\sigma^2 = .051/.879 = .058$
|                      |     |     |     |     |     | Critical Value = 3.44
|                      |     |     |     |     |     | for df = 2.22                   |
| Lichenaria          | 22  | 42  | 44  |     |     |                                |
| WPL21               |     |     |     |     |     |                                |
| x                   | 1.26| 1.28| 1.15|     |     |                                |
| s                   | .37 | .32 | .30 |     |     |                                |
|                      |     |     |     |     |     | $s^2/\sigma^2 = .001/.104 = .014$
|                      |     |     |     |     |     | Critical Value = 3.09
|                      |     |     |     |     |     | for df = 2.105                  |
| Caliphylloides      | 12  | 74  | 63  | 35  |     |                                |
| WPL10               |     |     |     |     |     |                                |
| x                   | 2.90| 2.73| 2.63| 2.60|     |                                |
| s                   | 1.20| .94 | .84 | .80 |     |                                |
|                      |     |     |     |     |     | $s^2/\sigma^2 = .013/.757 = .017$
|                      |     |     |     |     |     | Critical Value = 2.67
|                      |     |     |     |     |     | for df = 3.109                  |
None of the comparisons between morphotypes indicated a significant difference in mean coefficients of variance, as seen in Table 9. Intramorphotypic analysis of mean coefficients of variance were also performed. The radial-lensoidal genera *Cyathophylloides* and *Lichenaria* showed no significant difference in mean values (Table 10). However, when hemispherical specimens of *Catenipora gracilis* and *Favosites gothlandicus* were compared, mean coefficients of variance proved to be statistically dissimilar (Table 10). Thus, interspecific, intramorphotypic variation exceeds intermorphotypic variation regarding calical widths.

Sets of three circles on two portions of the specimen of *Cystihalysites brownsportensis* from Blacksmith Fork were drawn to compare corallite density from the two different portions of the colony (Figure 31). Although one section of the corallum appeared to have a greater density of ranks and corallites, no significant difference was indicated by t-testing the groups of unit circles (see Table 11).

Mean calical widths cannot be compared justifiably between morphotypes of various species because of the genetic control over this feature. However, within the more morphologically plastic species, such as *Favosites gothlandicus*, comparisons of the mean may be made between conspecific specimens of various shapes. The t-test revealed no significant difference between tabular and hemispherical members of this species for this parameter (see Table 12). However, the mean calical widths of two specimens of *Paleophyllum*, WPL19 and WPL20, differed significantly (Table 12). The former
Table 9. Cross Reference of T/Critical Values of Interspecific Comparisons of the Mean Coefficients of Variance of Calical Widths for the Major Coral Morphotypes

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>H</th>
<th>R</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>--</td>
<td>0.61/2.58</td>
<td>0.45/2.73</td>
<td>0.60/2.42</td>
</tr>
<tr>
<td>H</td>
<td>--</td>
<td>--</td>
<td>0.30/1.85</td>
<td>1.15/2.08</td>
</tr>
<tr>
<td>R</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>1.06/2.09</td>
</tr>
<tr>
<td>N</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>H</th>
<th>R</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>3</td>
<td>8</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>\bar{x}</td>
<td>.27</td>
<td>.24</td>
<td>.25</td>
<td>.31</td>
</tr>
<tr>
<td>s</td>
<td>.07</td>
<td>.08</td>
<td>.08</td>
<td>.12</td>
</tr>
</tbody>
</table>

C - columnal
H - hemispheric
R - radial-lensoidal
T - tabular lensoidal
Table 10. Interspecific, Intramorphotypic Analyses of Mean Coefficients of Variance of Calical Widths

<table>
<thead>
<tr>
<th>Radial-Lensoidal Coralla</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cyathophyelloides</strong></td>
<td></td>
</tr>
<tr>
<td>( n = 5 )</td>
<td></td>
</tr>
<tr>
<td>( \bar{x} = .33 )</td>
<td></td>
</tr>
<tr>
<td>( s = .10 )</td>
<td></td>
</tr>
<tr>
<td><strong>Lichenaria</strong></td>
<td></td>
</tr>
<tr>
<td>( n = 11 )</td>
<td></td>
</tr>
<tr>
<td>( \bar{x} = .26 )</td>
<td></td>
</tr>
<tr>
<td>( s = .05 )</td>
<td></td>
</tr>
<tr>
<td>( t = 1.483 )</td>
<td></td>
</tr>
<tr>
<td>critical value = 2.100</td>
<td></td>
</tr>
<tr>
<td>for ( df = 4, 10 ); alpha = .05</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hemispherical Coralla</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Catenipora</strong></td>
<td></td>
</tr>
<tr>
<td>( n = 3 )</td>
<td></td>
</tr>
<tr>
<td>( \bar{x} = .17 )</td>
<td></td>
</tr>
<tr>
<td>( s = .02 )</td>
<td></td>
</tr>
<tr>
<td><strong>Favosites</strong></td>
<td></td>
</tr>
<tr>
<td>( n = 5 )</td>
<td></td>
</tr>
<tr>
<td>( \bar{x} = .29 )</td>
<td></td>
</tr>
<tr>
<td>( s = .06 )</td>
<td></td>
</tr>
<tr>
<td>( t = 4.11 )</td>
<td></td>
</tr>
<tr>
<td>critical value = 2.26</td>
<td></td>
</tr>
<tr>
<td>for ( df = 2, 4 ); alpha = .05</td>
<td></td>
</tr>
</tbody>
</table>
Table 11. Comparison Between Mean Number of Corallites Per Unit Circle in Circles Drawn on Colony Margin and Mid-Portion of a Colony of *Cystihalysites brownsportensis* from Blacksmith Fork

<table>
<thead>
<tr>
<th></th>
<th>Colony Margin</th>
<th>Colony Mid-portion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>n</strong></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>X</strong></td>
<td>82.3</td>
<td>51.3</td>
</tr>
<tr>
<td><strong>s</strong></td>
<td>15.3</td>
<td>11.0</td>
</tr>
<tr>
<td><strong>t</strong></td>
<td>2.85</td>
<td></td>
</tr>
<tr>
<td>Critical value</td>
<td>2.92</td>
<td></td>
</tr>
<tr>
<td>fpr df</td>
<td>2; alpha = .05</td>
<td></td>
</tr>
</tbody>
</table>

Number of corallites in each circle

<table>
<thead>
<tr>
<th>Colony Margin</th>
<th>Colony Mid-portion</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>64</td>
</tr>
<tr>
<td>99</td>
<td>44</td>
</tr>
<tr>
<td>69</td>
<td>46</td>
</tr>
</tbody>
</table>

Circle diameters = 3.6 centimeters
Table 12. Comparison of Means of Mean Calical Widths of Tabular Lensoidal vs. Hemispheric Specimens of *Favosites gothlandicus* (in Centimeters)

<table>
<thead>
<tr>
<th></th>
<th>Tabular</th>
<th>Hemispherical</th>
</tr>
</thead>
<tbody>
<tr>
<td>n (coralla)</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>$\bar{x}$</td>
<td>3.06</td>
<td>3.17</td>
</tr>
<tr>
<td>s</td>
<td>.64</td>
<td>.74</td>
</tr>
</tbody>
</table>

$t = .28$

Critical value = 1.98

$df = 6, 5; \alpha = .05$

Comparison of mean calical widths of columnal and radial-lensoidal specimens of *Paleophyllum*.

<table>
<thead>
<tr>
<th></th>
<th>Columnal</th>
<th>Radial-Lensoidal</th>
</tr>
</thead>
<tbody>
<tr>
<td>n (corallites)</td>
<td>16</td>
<td>43</td>
</tr>
<tr>
<td>$\bar{x}$</td>
<td>3.32</td>
<td>4.29</td>
</tr>
<tr>
<td>s</td>
<td>.74</td>
<td>.96</td>
</tr>
</tbody>
</table>

$t = 4.11$

Critical value = 1.71

For $df = 15, 42; \alpha = .05$
Figure 31. Unit circles on margin and midsection of halysitid coral from Blacksmith Fork collecting site.
is a columnal morphotype, whereas the latter is categorized as an asymmetric radial-lensoidal corallum.

Mean and standard deviation of coefficients of variance of tabulae spacing were calculated for pooled species of the four general morphotypes. The value obtained for each morphotype was t-tested with the corresponding value of every other morphotype. Tabular corals had significantly greater values for this parameter than columnal or hemispherical coralla. No other statistically different mean coefficients of variance were noted (see Table 13).

The t-test was similarly employed to compare average mean tabulae spacings of tabular and hemispheric specimens of *Favosites gothlandicus*. As seen in Table 12, the value computed for hemispherical colonies is significantly greater than that obtained for tabular lensoidal corals for the species.

On longitudinally sectioned specimen SM1 (*Favosites gothlandicus*), an elongate hemisphere, a light-colored lens characterized by narrow tabulae spacing through the middle (transversely) of the corallum were observed to contrast with the upper half of the corallum, which contained notably wider corallite spacing (Figure 32). Measurements of tabulae-spacing were taken from corallites diverging from the budding center of the colony at 45 degrees, 70 degrees, 80 degrees, and 90 degrees to the horizontal both within the narrowly and widely tabulated portions of the corallum. The t-test statistically confirmed the disparity in mean tabulae-spacing as seen in Table 14. Regression values comparing mean tabulae spacing
Table 13. Cross Reference of T/Critical Values of the Interspecific Comparison of the Mean Coefficients of Variance of Tabulae Spacings of the Major Coral Morphotypes

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>H</th>
<th>R</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>--</td>
<td>.75/3.17</td>
<td>2.12/2.78</td>
<td>4.57/2.74</td>
</tr>
<tr>
<td>H</td>
<td>--</td>
<td>--</td>
<td>.62/1.90</td>
<td>3.45/1.89</td>
</tr>
<tr>
<td>R</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>1.89/1.90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n</th>
<th>2</th>
<th>7</th>
<th>7</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>.30</td>
<td>.37</td>
<td>.54</td>
<td>.81</td>
</tr>
<tr>
<td>s</td>
<td>.07</td>
<td>.21</td>
<td>.27</td>
<td>.30</td>
</tr>
</tbody>
</table>

C - columnal
H - hemispheric
R - radial-lensoidal
T - tabular
Table 14. Comparison of Mean Tabulae Spacing of Upper Portion of Corallum vs. Middle Portion of Corallum of Specimen SM1 (*P. gothlandicus*) (Centimeters)

<table>
<thead>
<tr>
<th></th>
<th>Upper Portion</th>
<th>Middle Portion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 57</td>
<td>n = 44</td>
</tr>
<tr>
<td></td>
<td>$\bar{x} = 1.51$</td>
<td>$\bar{x} = .94$</td>
</tr>
<tr>
<td></td>
<td>$x = .49$</td>
<td>$s = .34$</td>
</tr>
</tbody>
</table>

$t = 6.89$

Critical value = 1.645

for df = 43, 56; alpha = .05

Mean tabulae spacings of corallites diverging from the horizontal at 45, 70, 80, and 90 degrees within upper and middle portions of specimen SM1 (*P. gothlandicus*) (centimeters).

<table>
<thead>
<tr>
<th>Degrees</th>
<th>Upper Portion</th>
<th>Middle Portion</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>1.30</td>
<td>1.17</td>
</tr>
<tr>
<td>70</td>
<td>1.67</td>
<td>.76</td>
</tr>
<tr>
<td>80</td>
<td>1.60</td>
<td>--</td>
</tr>
<tr>
<td>90</td>
<td>1.48</td>
<td>.75</td>
</tr>
</tbody>
</table>

$r =$

0.49

-0.9
Figure 32. Vertical cross section of specimen SM1 (*Favosites gothlandicus*) from the Sharp Mt. collecting site. Note thin, light-colored, narrowly tabulated lens through middle.
and divergency from the horizontal were calculated for the two
aforementioned portions of the coral. A moderately positive
correlation (r = 0.49) between mean tabulae spacing and increased
angle of growth from the base of the corallum was obtained for the
upper portion of the coral characterized by wider tabulae spacing.
The thin lens noted for its narrowly divided tabulae showed a
strong negative correlation (r = -0.9) between the two variables.
Thus, during periods when individual coral polyps elevated them­selves minimal distances between secretion of successive tabulae,
relatively greater lateral expansion of the corallum prevailed.
At times when relatively large tabulae spacings were formed, the
converse can be said to be true, although with less certainty due
to the smaller absolute value of r.

On specimen SM2 (*Favosites gothlandi*us), another elongate
hemispherical coral, measurements of tabulae were made on the
middle and flanks of a transverse cross section of the corallum.
As Table 15 indicates; the mean tabulae-spacing of the midsection
is significantly greater than either flank, the two of which show
no statistical difference. This disparity did not result in a
relatively large vertical dimension of the entire corallum because
corallites are less numerous in the middle section in compensation
for the greater spacing of their tabulae.

**Function of Internal Morphologic Features**

Investigations undertaken on modern corals by Hubbard and
Pocock (1972) have resulted in the association between calical
Table 15. Comparison Between Means of Tabulae Spacings of Flanks vs. Mid-Section of Specimen SM2 (in Centimeters)--Data and Cross Reference

<table>
<thead>
<tr>
<th></th>
<th>Right Flank</th>
<th>Mid-Section</th>
<th>Left Flank</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>32</td>
<td>32</td>
<td>49</td>
</tr>
<tr>
<td>x</td>
<td>2.18</td>
<td>2.64</td>
<td>2.26</td>
</tr>
<tr>
<td>s</td>
<td>.95</td>
<td>.95</td>
<td>.98</td>
</tr>
</tbody>
</table>

Cross-reference of t/critical values

<table>
<thead>
<tr>
<th></th>
<th>R</th>
<th>M</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>--</td>
<td>1.94/1.70</td>
<td>0.37/1.68</td>
</tr>
<tr>
<td>M</td>
<td>--</td>
<td>--</td>
<td>1.74/1.68</td>
</tr>
<tr>
<td>L</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
features and relative sediment rejection capabilities. Fundamental differences between corallites of Paleozoic and modern scleractinia corals are the presence of tabulae (which render the calice flat-floored) and relatively simply septa in the former. According to the functional interpretations of the researchers, these characteristics suggest the relative inefficiency of Paleozoic corals as sediment rejectors (Hubbard and Pocock 1972).

According to Hubbard and Pocock (1972), coral polyps discard sediment by four methods: 1) distension by the stomodeal uptake of water, an esophagus-like connection between the mouth and the gastrovascular cavity (Vaughan and Wells 1943, p. 13); 2) tentacular action; 3) ciliatory beat; and 4) mucus entanglement. Hubbard and Pocock (1972) found the first of these methods to be the most common in modern corals. Coordinated inflation and deflation of tissue is represented diagramatically in Figure 33. Wave-like motion of distended regions disrupts and removes particles. Reportedly, large particles are removed principally by tentacular action. Silt and fine fractions are shed chiefly by means of ciliary action (Hubbard and Pocock 1972).

According to Hubbard (1973), the "angle of intersection between the calical elements and the direction of tension which may be exerted by the three sheets of polypal tissue, "are determined by calical shape."

In other words, an angular calical floor provides a fulcrum allowing greater leverage for distension. The physical exertion required of the polyp is thereby reduced. By further mechanical consideration, arched floors further enhance sediment
DISTENSION OF HEMISPHERICAL COLONIES

1. POLyps RETRACTED
2. MAXIMUM DISTENSION AT SUMMIT
3. DISTENSION MOVES DOWNWARDS

CALICAL DISTRIBUTIONS & PARTICLE MOVEMENT

1. CERIOD
2. PLOCoid
3. MEANDROID

LEAST EFFICIENT:
up & downhill movement except when fully distended

tendency to move around corallites

MOST EFFICIENT
fastest movement down valleys

INCREASE IN EFFICIENCY

Figure 33. Diagrammatic sections through hemispherical colonies to show the downward migrating paths of controlled distension shown by most hemispherical forms. The lower diagram shows tangential view of hemispherical coral surfaces to demonstrate the relationship between the main calical distributions found in such colonies and their relationship to the movement of sedimentary particles. Cerioid forms present an inconvenient undulating topography for movement of particles: plocoid calices periodically block the path of movement, but are generally more efficient; meandroid forms show a totally coordinated polystomous condition. (From Hubbard (1973))
rejection capability (see Figure 34 for a diagramatic representation of this relationship). Polyps inhabiting flat-floored calices are inferred to have had to distend themselves infrequently to rarely. Similar reasoning led Hubbard and Pocock (1972) to conclude that greater calical relief allowed greater ease in distension.

Longitudinal structures, namely septa and columellae, are considered to enhance cleansing abilities of corals by allowing increased surface area for muscle attachment (Hubbard and Pocock 1972). Sediment rejection capability then, increases with septal length and abundance. Elliptical corallite shape, when not induced by pressure from crowding may have also been a modification for the creation of more surface area in proportion to volume.

As a result of the direct proportionality between strength and size, large polyps, where shape is equivalent, are characterized by increased sediment rejection capability. Large corallites and wide apical angles characterize corals that inhabit high energy conditions, whereas corals living in calmer conditions develop smaller corallites with more prevalent tabulae (Sheehan 1980). Manten (1971, p. 430) reasoned that corals with small polyps had to rely on water movement to remove sediment from their upper surfaces.

Hubbard and Pocock (1972) labeled those polyps with considerable distensional efficiency as active polyps. This terminology was prompted by the capability of some modern corals to move their entire coralla by crawling, uncover themselves from sediment, overturn, and climb (Goreau and Yonge 1968; Hubbard and Pocock 1972). Morphologic and structural features of active and passive calices are summarized and contrasted in Table 16.
Table 16. Skeletal Features of Active and Passive Polyps

<table>
<thead>
<tr>
<th>Active Polyps</th>
<th>Passive Polyps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Larger number of septa</td>
<td>Fewer septa</td>
</tr>
<tr>
<td>2. Complex septal ornament</td>
<td>Comparatively smooth septa</td>
</tr>
<tr>
<td>3. Fenestrate septa</td>
<td>Solid septa</td>
</tr>
<tr>
<td>4. Higher calical relief</td>
<td>Lower calical relief</td>
</tr>
<tr>
<td>5. V-shaped calical floors</td>
<td>Horizontal skeletal floors</td>
</tr>
<tr>
<td>6. Lighter skeleton</td>
<td>Heavier skeleton</td>
</tr>
</tbody>
</table>

†From Hubbard and Pocock 1972, p. 617.
Figure 34. Schematic longitudinal sections through some calical geometries which appear to have functional significance with respect to capability for sediment rejection (Hubbard 1973, p. 37).
Calical relief, geometry, number of septa, and length of septa of the various coral species from the Fish Haven and Laketown Formations are summarized on a relative scale in Table 17. Numbers 1 through 4 represent poor, fair, good, and very good capabilities, respectively. The sum of values for these features is also shown. Interspecific comparisons of these sums must be made with more reservation than comparison of individual features. An inherent assumption made when computing these sums is that the features represented have equal importance regarding sediment rejection capability. For example, a polyp that dwelled in a corallite with a rating of, say 3, for both calical geometry and septal length may have exploited the former more than the latter in its rejection of sediment.

Thus, the solitary and compound rugose corals possessed more efficient corallites than the tabulate corals of the Fish Haven and Laketown Formations. Favositids in general probably had notably poor cleansing ability.

Those characteristics interpreted to have increased distensional ease may have also given corals more structural rigidity. Whereas angular calices and longitudinal structures imply a functional response to larger grain sizes, the larger grains themselves connote relatively high energy conditions. Noteworthy is the relegation of the solitary rugose corals to inferred low energy regimes with appreciable sedimentation rates, as indicated by fine grained, frequently marly matrices (Budge 1970; Manten 1971, p. 430; Hubbard 1970). If the assertion of Hubbard and Pocock (1972) that finer fractions are
Table 17. Summary of the Relative Sediment-Rejection Efficiency of the Coral Genera Based on Calical Features

<table>
<thead>
<tr>
<th>Coral</th>
<th>Calical Relief</th>
<th>Calical Shape</th>
<th>Number of Septa</th>
<th>Septal Length</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lichonaria</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Calapoezia</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Syringopora</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Halysites</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Foerstephyllum</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Favosites</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Astrocerium</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Platyaxum</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Cyathophyloides</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Paleophyllum</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Streptelasma</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>16</td>
</tr>
</tbody>
</table>

1 - poor
2 - fair
3 - good
4 - very good
removed by ciliary action rather than polypal distension is true, the reasons for the presence of numerous, long septa, V-shaped calices, and axial structures must be reconsidered. The individual corallites of colonial corals may have acquired structural strength partly owing to their position within coralla. As solitary corals were not afforded this support, they may have had to rely on internal features for rigidity. Structural strength may have been needed during storms which may have occasionally created increased turbulence.

**Interpretation of External Features**

Several independent variables account for the differing external and internal features of corals. Their impact results from the necessity (or lack of necessity) for corals to undertake certain activities and possess certain attributes which not only allow them to survive, but to successfully compete and to reproduce. These necessary functions and requirements are cleansing themselves of sediment, reproduction, nutrient intake, the maintenance of stable orientations, and optimal exposure to light. It is assumed that the various morphologies and structures of the corals in this study were functional responses to environmental stimuli or selective pressure. Many of these features, such as tabulature and septal character, have phylogenic bases. Those qualities under astogenic control, such as gross morphology, more assuredly reflect prevailing environmental conditions.

Philcox (1971) aptly described the effect of sedimentation rates on the non-growth surface (base) of favositid coralla from Silurian
strata in Iowa. Unrestricted horizontal growth of both the coralla as a whole and of individual corallites was shown to be possible only when sedimentation was nil. Increasing basal angles with respect to the substrate reflected increasing sedimentation rates. Sediment accumulating around the sides of a colony allowed only corallites above the water-sediment interface to survive and grow. With continued growth and sedimentation, the shape of the non-growth surface became conical. The greater the rate of sedimentation, the more conical became the corallum. This relationship is graphically represented in Figure 35. By similar reasoning, corals exhibiting concave downward bases are interpreted in this study to reflect net removal of sediment from the substrate.

Philcox (1971) considered composite growth forms to be indicative of "... a variety of changes in the immediate environment, particularly fluctuations in the sedimentation rate." Figure 36 illustrates the effect of variable sedimentation rates on the shape of coralla. Upon consideration of the necessity for corals to keep up with accumulating sediment by means of vertical growth, it becomes obvious that corals exhibiting low cross-sectional profiles could not have lived in environments where appreciable sedimentation prevailed. Philcox stated that these corals "... could develop only during long periods of negligible sedimentation." Grave difficulties were imposed upon flat colonies when confronted with increased sedimentation (Manten, 1971).

The factors of light penetration and water depth have an inverse relationship. Implicit in inferences concerning positive phototropism
Figure 35. Upper diagram summarizes the effect of increasing sedimentation rate on growth-form of radial favositids. Lower diagram is a schematic representation of a sheet-form colony which was forced by accumulating sediment to migrate back and forth during growth (Philcox 1971, p. 342 and 344, respectively).
Figure 36. Simplified diagrams of favositid colonies, showing how fluctuations in sedimentation rate are reflected in the corallum. Corallite growth directions shown by arrows. Sediment surfaces shown at time of changes in coral growth form. a) Colony expanded during brief interval in otherwise rapid sedimentation. b) Colony nearly killed by excess of sediment, but recovered to live some years during moderate sedimentation. c) Colony nearly killed at early stage by unknown event, followed by non-radial expansion across crust on own former surface, and subsequent growth during rapid sedimentation. d) Sedimentation remained slow, but colony nearly killed by unknown event. Two satellite colonies are visibly continuous with earlier corallum (Philcox 1971, p. 343).
of Paleozoic corals is the assumption that they indeed lived in symbiosis with zooanthellae.

Based on computer simulation, Graus and MacIntyre (1976) noted growth trends with increasing water depth and correlated them with the "... systematically varying underwater light field." These tendencies with increasing depth were: 1) a gradient in corallum morphology from hemispherical to columnar to platy; and 2) a decrease in the mean skeletal accretion rate. Goreau (1963) also related growth form to light intensity. He considered modern hemispherical forms to be shallow water dwellers and flat coralla to inhabit deep water.

Because there is a proportionate increase in calcification with increased light intensity, Graus and MacIntyre (1976) concluded that hemispherical forms predominate in shallow water. Miller (1977, p. 90) implied that this is due to the larger amount of calcification needed in hemispherical corals. Indeed, Goreau and Goreau (1959, p. 25) have documented the positive correlation between light intensity and calcification rate. However, calcification takes place only on the surface of corals regardless of shape; calcification per surface area should not differ for plate-shaped versus hemispherical forms under equal illumination. The present author contends that a flat morphology at depth allows individual polyps to receive sunlight at its maximum angle of incidence, thus allowing the greatest possible absorption by the algae incorporated with their tissue. In shallow water, illumination is generally sufficient for absorption by algae regardless of the angle of incident light upon the associated polyp.
Asymmetric growth has been attributed to unidirectional or limited light supply (Goreau 1959; Roos 1967). Multer (1969) listed subaerial exposure and concurrent desiccation as a cause of balding.

Nutritional requirements may have also played a role in the determination of coral morphology. As suspension feeders, corals depend upon currents to supply them with food (Vaughan and Wells 1943). As phytoplankton and zooplankton abundance ordinarily decreases with depth (Suchanek and Levington 1974), feeding adaptations by relatively deep-water corals may have been required. Miller (1977) interpreted asymmetry in corals displaying flattened morphologies as being a positive rheotropic response. By "facing" the currents, polyps would be directly exposed to nutrients. Anstey and Delmont (1972) reported that flat bryozoan colonies are an adaptation to deep, quiet waters where food is a more limiting factor than in shallow waters. In the more agitated shallow waters, a larger volume of the more nutrient-rich water passes by each zooid in a given time.

The nature of the substrate undoubtedly influenced coral morphologies as well. Colonial corals adapted themselves to fluid substrates by attaining low, encrusting coralla (Sokolov 1971). Their broad flat bases prevented them from sinking (Perkins 1963). From the preceeding discussion, it is apparent that only negligible sedimentation could have prevailed where these flat corals lived, even though the sediment remained entirely unconsolidated. A lensoidal or lenticular shape would have allowed maximum surface
area in proportion to weight, thus providing stability. On firmer substrates, greater weight per surface area could have been supported. Philcox (1971) attributed asymmetry of coralla to growth on sloping substrates.

Consideration of energetics must also be made when accounting for coral morphology. Graus, Chamberlain and Boker (1974) made several conclusions regarding the adaptations of modern corals to minimize hydraulic stress. They noted a morphologic trend with increasing water motion from a "branching phenotype to a compact, massive, and ultimately encrusting form." An alternative strategy listed was the retention of the branching type, but with "reorientation of branches toward the current or wave direction." Evidently, corals with large vertical components of growth were restricted from excessively turbulent waters because of their inherent instability in this energy regime. They also concluded that with increasing water energy, colony shape in plan view becomes increasingly eccentric. Such eccentricity is a characteristic of the elongate hemispherical corals from Sharp Mountain.

Hubbard and Pocock (1972) linked asymmetric growth to "... unequal forces, such as heavy surge from a constant direction." They further noted that asymmetric corals in such conditions take on a solid, encrusting form. Broadhurst (1966) attributed asymmetry in stromatoporoids to positive rheotropism, i.e., a current induced growth response. Coates and Oliver (1973) considered the sequence of phaceloid, cateniform, and cerioid packing arrangements to
indicate progressively stronger adaptation to the rigors of the physical environment.

Spherical, or circumrotary growth form, has been attributed (Kissling 1973) to frequent rolling of colonies in constant, heavy surf. He reported that in the modern coral *Siderastrea radians*, coralla consistently display circumrotary growth on windward calcirudite margins of elevated carbonate mudbanks. A similar environmental setting was inferred for the Silurian favositids from the Brassfield Formation of Ohio.

Hubbard (1974) interpreted a growth form in which lateral expansion was impeded as being due, in part, to overcrowding. A similar interpretation might initially be applied to the elongate hemispherical and columnal corals from Sharp Mountain, in which lateral growth in one or more directions was impeded. However, Ordovician and Silurian corals did not create the ecologic reefs of Dunham (1970) in northern Utah. Therefore, crowding is not considered to account for morphologies accented in the vertical dimension.

Balding, observed in some specimens of *Cyathophylloid es* in this study, was investigated in modern corals by Multer (1969). Boring activities of diverse classes of organisms were cited as causes of this phenomenon.

Environmental factors "molded" morphologies of solitary rugose as well as colonial corals. Due to their dearth and fragmentation, solitary rugose coral morphologies have simply been classified as geniculate and non-geniculate in this text. No geniculation has been observed in the field or on specimens collected.
Hubbard (1974) has interpreted straight coralla as having resulted from vertical growth subsequent to an original stable attachment. Toppling could not have occurred. Furthermore, she added that sedimentation rates could never have been rapid enough to imperil solitary coralla with smothering. These preconditions were applied to solitary corals oriented obliquely to the substrate as well as those positioned vertically.

"Geniculation is an environmentally induced variation." (Miller 1977) It resulted from instability of initial attachment orientation of the substrate, inconsistency of magnitude and/or direction of currents, or increasingly rapid sedimentation. Geniculation is a compensatory response to reorientation resulting from one or more of these environmental conditions.

Based on the previous survey of causes of morphotype-modifications, gross morphologies of corals cannot be accounted for unless the interplay of several environmental parameters is examined. Radial-lensoidal corals are interpreted as having inhabited a high energy environment, necessitating massive (cerioid) structures. Their basal shapes and radiating corallites indicate negligible sedimentation.

Those radial-lensoidal corals displaying concave downward bases adhering to clasts must have lived during intervals of scouring. The downward growth seen on specimens of *Cyathophyllumoides* and *Lichenaria* indicates excellent illumination and considerable reflectivity off of the substrate. Such pedestals allowed for downward growth of corallites. Coralla exhibiting bases curving convexly
downward have not been observed to encrust clasts. They are interpreted to have experienced very slight sedimentation.

Symmetric, radial-lensoidal coralla occasionally display "balding." Although inferred to have lived in shallow waters, balding on most of these corals is not attributed to desiccation induced by subaerial exposure. The position of these areas on sides of coralla prompt an alternate explanation. Parasitic boring is not held accountable because of the large sizes of the recessions. Coralla would likely feature perforated surfaces had they been bored.

Predation, probably by nautiloids, is strongly suggested by the jagged perimeters and elliptical outlines of the recessed areas. Striations, indicative of shearing and tearing of coralla by nautiloid beaks, have not been observed, however. Their absence may have resulted from the "healing" of corallites on the margins of the recessed areas. Furthermore, striations within the recessed areas may not have originally formed if nautiloids with indistinct striae on their beaks had preyed upon the coralla. The absence of nautiloid fossils at the White Pine Lake collecting site where the balded coralla were collected does not preclude predation by nautiloids. Their conchs could easily have drifted away and stranded on the shoreline following their death (see Reyment 1968).

One colony features a deeply recessed area on its upper surface. The perimeter of this recession is smooth. Death of the polyps on the upper surface of the colony due to desiccation during a period of subaerial exposure is apparent. These polyps positioned on the
sides of the colony survived and continued to grow. The result was a deeply recessed, centralized depression which formed a corallum with a "microatoll" appearance.

It is doubtful that the asymmetry in massive radial-lensoidal corals resulted as a consequence of positive rheotropism, as this feeding response is generally associated with lower energy conditions than is inferred from radial-lensoidal morphology. In addition, growth direction about the budding center in asymmetric specimen WPL21 (Figure 28) is overwhelmingly away from the current direction, which is indicated by the imbrication of the clast that juts obliquely through the colony. Asymmetry in massive radial-lensoidal corals apparently resulted from growth on sloping substrates, as suggested by their occurrence with circumrotary corals. The asymmetric fasiculate specimen of *Paleophyllum* (WPL20) is subject to a similar interpretation, although it may have experienced less hydraulic stress than the massive forms.

Tabular corals are interpreted as having dwelled in relatively deep, quiet waters. In contrast to the radial-lensoidal corals, poor illumination required each corallite to grow vertically. This adaptation provided the polyps maximum exposure to light. Whereas radial-lensoidal corals maintained a low profile for stability in agitated water, flatness of tabular forms prevented sinking into soft substrates.

Figure 37 shows two tabular corals oriented at an angle to each other. This relationship cannot be explained as being due to
Figure 37. Tabular lensoidal coralla from Blacksmith Fork oriented obliquely to one another.
disturbance; which resulted in the disorientation and repositioning of the corals on a firm substrate. The oblique orientation to the bedding in which they are now seen could not have been a stable position on a firm bottom. Instead, soft sediment slumping, whether prompted by the weight of the coral or inherent instability, is inferred.

The lensoidal halysitid corals of Card Canyon display corallite arrangements of intermediate nature, between tabular and radial-lensoidal corals. This results from the budding of the first corallite of each rank at an angle to the rank from which it was budded (Buehler 1955). This relationship is seen in Figure 38. These corals are considered to have lived on soft substrates, although probably firmer than substrates tabular favositids encrusted.

Their lenticularity may have been a response to increased turbulence. Halysitids were "... attached to their substratum very lightly if at all." (Buehler 1955) Moderate turbulence may have inhibited vertical growth. Alternatively, lensoidal shape may have been prompted by the need for increased stability on soft substrates. The downward concavity of bases (see Figure 38), favors the former interpretation. Among Card Canyon specimens, the wide angles formed between the long lateral dimensions of lensoidal halysitid corals and bedding planes indicate inhabitance on softer substrates.

Hemispherical corals are interpreted as having inhabited shallow water although not as shallow as the radial-lensoidal corals. Sedimentation rates were nil to very low, as indicated by the corals' basal shapes. Substrates were fairly firm. Hubbard and Pocock (1972)
Figure 38. Coralla of *Cystihalysites brownsportensis* displaying concave downward base (vertical profile).
considered hemispherical corals to form only when "... three factors unite: uniform food supply, equal illumination, and current strength."

Eccentric hemispherical corals are considered to reflect stronger, more unidirectional currents than non-eccentric hemispherical forms. The asymmetric expansion about budding centers noted in these corals was most likely a positive rheotropic response.

Columnal corals, those that exhibit a strong vertical component of growth, inhabited environments in which a high sedimentation rate prevailed. Implicit are low current energy and a soft substrate. Waters were probably comparatively turbid, resulting in decreased light penetration. The four general morphotypes and associated environmental parameters are summarized in Table 18.

As noted previously, composite corals are those displaying more than one growth form or a repetition of the same growth form. They are considered to be the result of changing environmental conditions, notably, variable sedimentation.

Figure 39 is a longitudinal section through the short axis of an eccentric hemispherical specimen of *F. gothlandicus*. Apparently, the colony was nearly killed by an influx of sediment. A portion on top of the colony survived. When preexisting environmental conditions again prevailed, a morphology similar to the initial form was developed.

A similar event is inferred for the specimen of *Cystihalysites* in Figure 38. A small portion of the uppermost surface of the lower colony apparently survived a temporary influx of sediment. The surviving polyps then formed the nucleus of the upper colony. The
Table 18. Environmental Parameters Associated with Coral Morphology

<table>
<thead>
<tr>
<th>Morphology</th>
<th>Sedimentation Rate</th>
<th>Water Depth</th>
<th>Illumination</th>
<th>Current Energy</th>
<th>Substrate</th>
<th>Nutrient Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tabular</td>
<td>Very Low</td>
<td>Deep</td>
<td>Poor</td>
<td>Low</td>
<td>Soft</td>
<td>Low</td>
</tr>
<tr>
<td>Radial-Lensoidal</td>
<td>Very Low</td>
<td>Very Shallow</td>
<td>Good</td>
<td>High</td>
<td>Hard</td>
<td>High</td>
</tr>
<tr>
<td>Hemispherical</td>
<td>Low to Moderate</td>
<td>Shallow</td>
<td>Good</td>
<td>Moderately High</td>
<td>Moderately Firm</td>
<td>High</td>
</tr>
<tr>
<td>Columnal</td>
<td>High</td>
<td>Moderate to Deep</td>
<td>Poor</td>
<td>Low</td>
<td>Soft</td>
<td>Low</td>
</tr>
</tbody>
</table>
Figure 39. Cross section across short lateral dimension of composite, elongate hemispheric corallum (*Favosites gothlandicus*).
lower colony depicted in Figure 38 was quite possibly entirely covered by the sediment that smothered most of the polyps. However, it is much more likely that the lower corallum was not completely covered by sediment, but rather the polyps on most of its surface were probably unable to cleanse themselves sufficiently after being silted over.

Figure 27 displays a branching protuberance extending from a hemispherical colony at 46 degrees. This is consistent with inferred high energy conditions. As previously noted, survival of a small portion of the colony ensued.

The reorientation of growth direction seen in Figure 28 exemplifies geniculation, usually associated with solitary rugose corals. Initially, the colony grew as fast vertically as horizontally. At the onset of temporary or permanently increased turbulence, the coral toppled over. A hemispherical coral then was initiated by budding from polyps in corallites on the exposed portion of the toppled "protocolony."

Hubbard (1973) outlined the selective sediment rejection efficiencies of three packing arrangements. As seen in Figure 33, cerioid coralla are considered to be least efficient because of the necessity to move particles up and down. A plocoid arrangement as in _Alapoezia_, allows particles to be moved between corallites. A meandroid arrangement, not observed in the corals of the Fish Haven or Laketown Formations, enables grains to be passed through "valleys."

Miller (1977) stated that fasciculate corals would have difficulty removing sediment because of corallite separation. It seems likely,
however, that corals displaying such packing could have disposed of sediment by merely depositing it between corallites. Fasciculate coralla are considered to have had less problem disposing of sediment than coralla with other packing arrangements. Manten (1971) supposed that halysitid corals stored "... all sorts of material, ... in the spaces between ranks of corallites." This process was credited with enhancing the stability of these corals.

Hubbard and Pocock (1972), in their report on sediment rejection capabilities of corals, described the occurrence of different packing arrangements in Carboniferous limestone deposits of northwestern Ireland. Cerioid coralla are found within calcarenitic sequences while fasciculate forms are associated with "finer-grained intervals." These occurrences were inferred to reflect the sediment rejection capabilities of the packing arrangements. However, it seems just as likely that the packing arrangements were adaptations to different levels of hydraulic stress. Calcarenites are generally interpreted to represent moderate to high energy environments. Massive, cerioid coralla would have been the most structurally sound forms in this environment. Conversely, fine-grained sediments are associated with low energy. Less massive coralla would have sufficed in such conditions.

It is interesting to note the lack of correspondence between sediment-shedding capabilities inferred from calical geometry and cleansing capabilities of the coralla affected by packing arrangement. For example, the cerioid coralla of Cyathophyloides, inefficiently constructed for the sediment rejection, contain
corallites that suggest they housed polyps which were capable of considerable activity. Fasciculate coralla, such as Syringopora contained corallites that enclosed polyps inferred to have had low capabilities for sediment rejection. Furthermore, the inferentially highly inefficient construction of corallites of Lichanaria are housed in radial-lensoidal coralla which are interpreted to have endured turbulent waters with which arenaceous sediments are commonly associated.

These and other seemingly inconsistent combinations will be reconciled in the forthcoming environmental analysis of the various collecting sites.

The four-fold categorization of coral morphologies made in the preceding descriptive section of this report, although comprehensive, is a convenient generalization. In several instances, corals exhibiting similar gross morphologic features may have been exposed to subtle environmental differences. These differences are extrapolated, with all due caution and reservation, by considering difference in packing arrangements and internal calical features. Examples of these differences will be noted when relevant to specific discussion throughout the remaining interpretive portion of this report. Furthermore, sedimentologic aspects associated with corals will be subject to interpretation and correlation with coral morphology.

Nutritional intake provides individual corals with a finite quantity of energy at any specific time. This food is partitioned for reproduction, growth, and removal of sediment. The proportions allotted for each function depend on the needs of the coral, which
are dictated by environmental conditions. Such partitioning can be referred to as the energy budget of the coral.

Jones (1936) related the relative importance of growth (as compared to "gemmation") to variation in corallite width. He proposed that when vertical growth of individual corallites was necessary to keep up with high sedimentation rates, reproduction was minimal and calical widths remained uniform. Slow growth and rapid budding were considered to result in unequally sized corallites. Pressure due to crowding during periods of rapid budding, as well as the budding itself, was held to account for disparities in corallite diameters.

Under this premise intermorphotypic comparison of variation in corallite diameters were made. Several explanations for the lack of correlation between corallite variability and morphology are subject to consideration.

1. Lack of crowding.
2. Effect of different rates of cleansing.
3. Dimorphism and polymorphism.
4. Radial growth—columnar corals reproduce and grow at the same rates as hemispherical corals.
5. Uniform widths of corallites.

In coralla with domed surfaces, crowding may have been eliminated by ever increasing upper surface areas. As the radius of a coral increased linearly by means of growth of constituent corallites, the coral's upper surface area would have increased exponentially. Thus,
only slight growth may have made enough room on the upper surface of the coral to considerably reduce pressure from mutual crowding.

Occasional minor influxes of sediment may have temporarily reduced reproductive precocity in corals that normally budded frequently. Energy would have had to have been diverted from reproduction to continuous cleansing. This would have resulted in a more uniform distribution of calical widths than would have existed ordinarily. Comparison of variance of calical width of such a coral with a coral of similar morphology whose surface represented a period of frequent budding (and therefore displaying a high variability in calical widths) would result in high intramorphotypic variance of corallite diameters.

Progressively slighter variances would be expected with relative increase in vertical dimensions of the corallum if it is assumed that coralla with considerable relief grew rapidly and experienced a low reproductive rate. However, Philcox's (1971) discussion of the effect of sedimentation rates on the shape of coral bases and the data on corallite variability from this study prompt an alternate conclusion. It appears that columnal corals actually grew no faster vertically than other corals in which vertical growth was unrestricted, i.e., hemispherical forms. Rather, this morphology resulted from restriction of lateral growths. Similar reasoning can be applied to radial corals with low relief. Vertical growth was inhibited by turbulence. The greater lateral dimension was not achieved by frequent budding.

In tabular-lensoidal corals the relatively great lateral dimension seemingly was attained by lateral budding. A predominance of budding at the margins of the colony minimized the restrictive
effect of crowding on corallites. Furthermore, budding at the base of corallites (described in halysitid corals by Buehler 1955) and rapid growth to maximum corallite width result in low variability in corallite dimensions.

Dimorphism or polymorphism (of polyps) may have existed in the tabulate corals of the Paleozoic Era. Oliver (1968) stated that "... genetic uniformity leaves room for phenetic differences ... and microenvironmental factors (situation within the colony) may cause enough individual variation to effectively mask the restrictive effects of genetic similarity." The consequence of polymorphism would account for the high coefficients of variation of calical width.

Functional polymorphism is described by Mash (1975, p. 122-123). Polyps are (were) specialized to carry out distant functions even though their genetic constituencies are identical. The position of the polyp in the colony determines function. Different functions include the trapping of prey, reproduction, and locomotion. Those polyps involved in digestion pass on soluble food to one another through connective tissue. This specialization is said to result in individual polyps that appear different from one another. A system of chemical gradients is believed to keep individuals in "communication."

Another factor that may have affected size distribution of corallites may have been the rapid maturation of polyps. The bottoms of corallites widen very rapidly with upward growth. Unless constricted by pressure from crowding, this rapid widening would distort any size distribution of relative age differences.
Elliptical corallites (quantified as having relatively high ratios of maximum/minimum dimensions) seemingly would have had greater capability of rejecting sediment than round corallites because of the greater wall area available for muscle attachment. Hubbard (1973) described the greater ease with which inclined corallites reject sediment. It would be reasonable to expect, then, that corallites on the crowns of coralla might tend to be more elliptical than those on the crests. The lack of significant differences in corallite geometry from crown to crest (Table 7) indicates that corallite geometry is strongly controlled genetically and/or that shape was of no advantage in cleansing. Mutual pressure caused by crowding could also have kept corallite geometries uniform.

The results of the intramorphotypic analysis of variance of calical width indicate that caution must be used when comparing variances of different species. Although displaying similar external geometry, which implies life under similar environmental conditions, calical widths of hemispheric specimens of *Favosites gothlandicus* vary significantly more than those of hemispherical specimens of *Catenipora gracilis* (Table 10).

Variability in tabulae-spacing appears to have been more strongly determined by the environment than variability in calical widths. T-tests show variability in tabulae-spacing in tabular corals to be significantly greater than in either hemispherical or columnal corals, (Table 13). Furthermore, most tabular corals have more narrow tabulae-spacing in the lower portion of their coralla than in their upper portion. Apparently, these coralla began their initial
expansion when sedimentation was virtually nil. As sedimentation increased, the constituent polyps were required to move further upward in the water column.

The disparity in mean tabulae-spacing between the middle and upper portions of specimen SM1 requires an alternative explanation. The flat base of the corallum and the horizontal orientation of many corallites in the narrowly tabulated mid-section suggests that the housed polyps could not have endured under prolonged high sedimentation rates. As the narrowly tabulated lense was positioned well above the substrate, it is unlikely to have been endangered by smothering. Fewer offsets are seen within the narrowly tabulated lense than in the upper, widely tabulated lense. Therefore, the narrowly spaced tabulae were not formed during an interval of frequent budding (reproduction).

The thinness of lenses noted for narrow tabulae spacing relative to the thickness of widely tabulated lenses in corals examined in this study indicates that the former were established during stressed conditions. This observation is contrary to Hubbard's (1970) assertion that narrow tabulae spacings represent benign conditions. If the assumption made by Ma (1962) and Duncan (1956) that tabulae are secreted at regular intervals is correct, narrow tabulae spacing correlates with decreased corallite growth. Less energy apparently was available for construction of corallite walls on which the polyps ascended before secreting successive tabulae. The validity of the assumption that tabulae are secreted at regular time intervals is not beyond dispute, however (Alexander 1980, personal communication).
That lateral expansion was more prevalent than upward growth during the interval in which narrowly spaced tabulae were formed suggests that the narrowly tabulated lense was formed during a time of comparatively high turbulence. Corallites housing widely spaced tabulae are always inclined more than 45 degrees from the horizontal in this upper lense. The difference in color of the two lenses is attributed to diagenesis.

Tabulae-spacings in the elongate hemispherical favositid SM2 were shown by the t-test to have a similar distribution to that of the upper portion of favositid SM1 (Table 14). Apparently, a slower growth rate on the flanks than in the middle of the corallum led to the establishment of the hemispherical outline (when viewed longitudinally and perpendicular to the coral's long horizontal axis. This could not have occurred if the constituent corallites had grown entirely radially about a common point. If intermural (and lateral, sensu strictu) budding had not been partially responsible for lateral expansion, higher growth rates of individual corallites on the flanks of the colony would have had to prevail in order to establish the long horizontal dimension. This combination of budding and lateral growth developed under conditions of intermediate turbulence (as signified by hemispherical form). As has been previously discussed, expansion of lensoidal coralla entirely by radial growth alone and by intermural budding alone are interpreted as indicative of extremely turbulent and placid conditions, respectively.

Growth lines are generally not noted on Fish Haven and Laketown corals. Their absence might be accounted for by lack of preservation.
Only specimens of *Cystihalysites* seem to display these growth lines, but they are too indistinct to measure their spacing.
The following synecological section of this report is comprised of two subsections. The first part includes lithologic and faunal descriptions of the various collecting sites. A regional paleoenvironmental reconstruction is presented in the second part. Results of the analyses of insoluble residues and diversity computations are discussed.

Two types of diversity values were figured. Calculations of equibility dependent diversity (DE) are essentially sensitive to the evenness of abundances of component species and is given by the formula \( DE = \frac{n}{\sum_{i=1}^{n} \ln p_i} \); where \( p \) is the proportionality of individuals belonging to species \( i \). Density dependent (DT) measurements of diversity are more dependent on numbers of species in proportion to the total number of individuals. It is defined by the equation \( DT = \frac{m}{\log N} \) where \( m \) is the number of species and \( N \) is the number of individuals for all species. In most cases, diversity measurements were made at more general taxonomic levels than the species level, so that diversity may actually be greater than is indicated.

Community diversity can be applied in the interpretation of resource stability and abundance. According to Valentine (1973), high diversity correlates positively with low supply and high stability of nutrients. Spatial heterogeneity also influences diversity.

Trophic-level considerations are evaluated when relevant to the following discussion of the community paleoecology of the various
collecting sites. The following general trophic relations, proposed by Turpaeva (Walker 1972), are useful to consider when analyzing community structures.

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.

The type and amount of data varied considerably from site to site. For example, the Tony Grove Lake bedding plane represents a contemporaneous group of organisms. The Card Caynon site, by contrast reveals temporal rather than spatial relationships because of the vertical, rather than horizontal, exposure.

The Green Canyon Site

The color of the Fish Haven Formation at the Green Canyon collecting locality is grayish black. It is the darkest of any
dolomite observed in the strata included in this study. Upon fracturing a fresh surface, a sulfurous odor is emitted. The texture is fine grained while bedding is thick to massive. With exception of corals and stromatoporoids, it is non-fossiliferous. Insoluble residue results of coral matrices where 0.64%, 0.38%, and 0.25% ($\bar{x} = 0.42\%$, s = 0.20%). The insoluble residue values are from samples associated with specimens of *Catenipora*. The gross morphology of only one of the collected samples was discernible. The shape is a hemisphere with an obtuse-angled, conic base (see Figure 40). More of the specimens collected are mere fragments of coralla. Although the faunal constituency is remarkably uniform (comprised almost exclusively of *Catenipora*), a few specimens of *Streptelasma* were collected. Stromatoporids collected display a lenticular shape (see Figure 41).

Due to post-lithification fragmentation and general occurrence in talus, no spatial or orientational measurements were measured at the site. Calical outlines on coralla are fairly obscure. This is evidently due to diagenetic effects and, in part, to post lithification fragmentation evidenced by short, discontinuous, fragmented ranks paralleling one another. Utah State University sample 3484 (*Catenipora*) is enclosed in a matrix similar in color to that of corals from the Fish Haven Formation in Green Canyon. As it was taken from the same stratigraphic unit, on Wellsville Mountain, and is relatively well preserved, its tabulation and calical aspects were gauged.
Figure 40. Longitudinal cross section of a hemispheric specimen of *Catenipora gracilis* from the Green Canyon collecting site.
Figure 41. Lenticular stromatoporoid or algae from the Fish Haven formation in Green Canyon.
Density and equitability sensitive diversity computations from the site were 2.073 and 0.409, respectively (Table 19). These were the lowest values of both diversity calculations of any collecting sites.

The fouling of the water column a few centimeters above the substrate is not held to account for the dearth of low level suspension feeders. No traces of burrowing activity are evident. If diagenesis had obliterated burrowing structures, it would also have destroyed the cryptalgal laminae observed in the Fish Haven and Laketown Formations.

The corals of the Green Canyon site are interpreted as having lived in placid waters on a soft substrate. The dark color, fine texture, and sulfurous odor of the lithology suggest reducing conditions within the original sediment. X-ray diffraction patterns of insoluble residues indicate that no pyrite, or only an indetectable amount of pyrite, is present in the lithology of the Fish Haven Formation in Green Canyon. The insoluble residues themselves are predominantly organic material. Dysaerobic conditions at or slightly above the sediment-water interface probably restricted low-level suspension feeders from the habitat. Some very high-level suspension feeders such as crinoids which were common elsewhere in the Late Ordovician, were apparently restricted from the Fish Haven sea floor by their inherent instability on soft substrates. Continuous sedimentation of fine-grained carbonate material is evidenced by the conic base of the sole, complete specimen of *Catenipora gracilis* collected.
Table 19. Summary of Diversity of the Data Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>DT</th>
<th>DE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Canyon</td>
<td>2.07</td>
<td>0.41</td>
</tr>
<tr>
<td>Tony Grove Lake</td>
<td>2.61</td>
<td>1.38</td>
</tr>
<tr>
<td>White Pine Lake</td>
<td>6.74</td>
<td>2.00</td>
</tr>
<tr>
<td>Blacksmith Fork</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>Card Canyon</td>
<td>3.57</td>
<td>0.83</td>
</tr>
<tr>
<td>Sharp Mountain</td>
<td>2.48</td>
<td>0.88</td>
</tr>
</tbody>
</table>

$DT = m/\log N$

where: $m =$ number of species

$N =$ number of individuals

\[
DE = \sum_{i=1}^{k} p \ln p
\]

where: $p =$ the probability of an individual belonging to species $i$.

$I =$ Indeterminate
Infaunal deposit feeders were probably present within the sediment. Lack of skeletal tissue and diagenetic obliteration of burrowing structures would account for their seeming absence in the strata. Thus, the diversity calculations for this site probably are considerably lower than those that would have been obtained if all species were preserved. Reasons for lack of other suspension feeding organisms will be discussed in the subsequent intersite discussion. An interface between reducing and oxidizing conditions slightly above the sediment water boundary, could have precluded many low-level suspension feeders, such as brachiopods, which are absent from this locality.

The Tony Grove Lake Site

The lithology of the Tony Grove Lake bedding plane is a medium dark gray, fine-grained dolomite. The strata are thick to massively bedded. Stratigraphically it is located eight feet below the Fish Haven-Laketown contact. Lenses and stringers of chert are ubiquitous on the cliffs above and below the bedding plane. Except for the generally unfragmented corals, invertebrate skeletons such as brachiopod shell fragments and crinoid columnal segments are not present. Insoluble residue values associated with specimens of *Catenipora* were 1.28%, 0.68%, 0.73%, and 0.81% (\( \bar{x} = 0.82\% \), \( s = 0.27\% \)). The bedding "plane" itself is very gently concave upward, whether due to an originally undulating surface, differential erosion, or tectonic compression. Plate 1 is a map of the bedding plane.
In terms of biomass, *Catenipora* is the most dominant genus. Budding centers from which corallites radiate on many specimens of this taxon are near the margins of coralla. The direction of the projection from geometric centers of such corals to budding centers were subjected to a goodness of fit test to detect any preferential growth of corallites (see Table 20 and Figure 42). No significant departure from random orientation was distinguished. It is considered that corals with off-centered radiation nuclei experiences pre-lithification disorientation, whether alive or dead. The bedding plane truncates many coralla, which are seen essentially only in two dimensions. Corallite radiation centers on the very margins of the truncated coralla were considered to indicate a 90 degree disorientation. Corals with corallite radiation centers on or near margins of their coralla exhibit hemispherical cross-sections with rounded conical bases. The net effect is a near circular outline on the bedding plane (see Figure 43).

The size-frequency histogram of *Catenipora* on the bedding plane shows a bimodal distribution (Figure 44). Such a trend may be indicative of periodic rather than continuous or random sexual reproduction, which results in the formation of new colonies. As there were consistently only two horizontal dimensions distinguishable on the bedding plane, many measurements may be in error. Therefore, the accuracy of their size-frequency histogram is open to question.

In terms of numbers, the rugose coral *Streptelasma* is virtually equivalent to the aforementioned chain coral on the bedding plane (see Figure 45). Orientations of proximal (direction toward point
Table 20. Test for Goodness of Fit for Data in a Circle for Direction of a Projection from Geometric Center to Budding Center for Halysitid Coralla on the Tony Grove Lake Bedding Plane

The test statistic is:

$$X^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E}$$

where $O_i$ 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.

$$E = \frac{16}{4} = 4.0$$

<table>
<thead>
<tr>
<th>Sector</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 90 degrees</td>
<td>5</td>
</tr>
<tr>
<td>91 - 180 degrees</td>
<td>4</td>
</tr>
<tr>
<td>180 - 270 degrees</td>
<td>3</td>
</tr>
<tr>
<td>270 - 360 degrees</td>
<td>4</td>
</tr>
</tbody>
</table>

$$X^2 = 9.50$$

$$CV = 7.815$$

for df = 3; alpha = 0.05
Figure 42. Rose diagram of directions of projections from geometric centers to budding centers of halysitid coralla from the Tony Grove Lake bedding plane.
Figure 43. Two-dimensional view of *Catenipora gracilis* corallum on the Tony Grove Lake bedding plane. Note corallite radiation nucleus toward margin of colony.
Figure 44. Histograms of various species from various sites.
Figure 45. *Streptelasma* on Tony Grove Lake bedding plane. Note otherwise non-fossiliferous nature of matrix.
origin of corallites) portion of these tapering, solitary corals were also determined (Table 21, Figure 46). Again, no statistically significant bearing was discerned. Thus, no evidence is found for rheotropism in corals of this Late Ordovician strata; it appears that life orientations have been obscured by post-mortem perturbations.

Other genera present in lesser abundance are Syringopora, Calapoezia, and Lichenaria. The former coral is noted for its seeming randomness of corallite orientation. Those specimens of Calapoezia and Lichenaria which experienced approximately 90 degrees disorientation from life position display longitudinal cross-sections intermediate in corallite configuration from radial to non-radial. Generally, they did not attain sizes comparable to corals of the same genera found at the White Pine Lake collecting site.

The nearest neighbor method of Clark and Evans (1954) which analyzes distribution patterns of populations was applied to this bedding plane. The method, as originally described, employs a ratio (R) of actual mean nearest neighbor per expected mean nearest neighbor for members of the same population. The procedure was modified in this study. Mean nearest neighbors of all other genera were determined for every individual of each genus. Expected nearest neighbor in a random distribution is determined by the value of $1/\sqrt{2p}$, where $p = \text{the density of the observed distribution expressed as the number of individuals per unit area}$. Thus, under conditions of maximum aggregation, the ratio (R) equals zero. In a random distribution $R = 1$, whereas at complete uniformity of distribution $R$ attains a value of 2.141 (Clark and Evans 1954).
Table 21. Test for Goodness of Fit for Data in a Circle for Orientations of Direction to Point of Origin of Rugose Corals on the Tony Grove Lake Bedding Plane

The test statistic is:

\[ x^2 = \frac{n \sum (O_i - E_i)^2}{E} \]

where \( O_i \) 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.

\( E = 16/4 = 4.0 \)

<table>
<thead>
<tr>
<th>Sectors</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 90 degrees</td>
<td>11</td>
</tr>
<tr>
<td>91 - 180 degrees</td>
<td>9</td>
</tr>
<tr>
<td>181 - 270 degrees</td>
<td>8</td>
</tr>
<tr>
<td>270 - 360 degrees</td>
<td>9</td>
</tr>
</tbody>
</table>

\[ x^2 = 0.52 \]

\[ CV = 7.812 \]

for \( df = 3 \), \( \alpha = 0.05 \)
Figure 46. Rose diagram of directions to proximal portions of rugose corals from the Tony Grove Lake bedding plane.
The results of these measurements are cross-referenced in Table 22. All values indicated more random than spaced or clumped distribution with three exceptions. *Calapoecia* showed a weak tendency to be in proximity to *Catenipora* and *Streptelasma*. *Syringopora* showed a slight tendency to be found nearer to *Lichenaria* than would be expected in a random distribution. Of course, it must be assumed that the distribution of the corals on the bedding plane has not resulted from some disruptive event in which appreciable displacement of the inhabitants transpired. The micritic lithology of this bed is indicative of a semi-fluid substrate. Continuous sedimentation is evidenced by downward convex bases of halysitids.

Lang (1971) described a hierarchy of coral species which maintain unoccupied, circumscribing territories through tissue destruction. If recessed areas developed as a result of tissue destruction of the corals at Tony Grove Lake, they either were recolonized or are indistinguishable due to the two-dimensional exposure of the corals. Because Paleozoic corals generally did not have calical features indicative of active polyps, the mildly aggregative tendencies noted are not considered to reflect such a "pecking order." Loose clustering may also be the result of similar resource requirements in an environment characterized by subtle, small-scale habitat heterogeneity. Because entirely evenly spaced environmental conditions exist only hypothetically, it is not surprising that high values of R attained are more indicative of random rather than evenly spaced conditions. The causes of aggregation will be further considered in the ensuing intersite comparisons.
Table 22. $R = \text{Actual Mean Nearest Neighbor}/\text{Expected Mean Nearest Neighbor}$ Ratios of Coral Genera from Tony Grove Lake Bedding Plane-Cross Reference

<table>
<thead>
<tr>
<th>Symbol</th>
<th>c</th>
<th>h</th>
<th>l</th>
<th>s</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>1.53</td>
<td>0.47</td>
<td>1.3</td>
<td>0.47</td>
<td>1.44</td>
</tr>
<tr>
<td>h</td>
<td>1.15</td>
<td>1.43</td>
<td>1.1</td>
<td>1.0</td>
<td>1.00</td>
</tr>
<tr>
<td>Measured from: 1</td>
<td>0.85</td>
<td>0.68</td>
<td>0.81</td>
<td>0.65</td>
<td>0.53</td>
</tr>
<tr>
<td>s</td>
<td>0.87</td>
<td>1.12</td>
<td>0.95</td>
<td>1.57</td>
<td>0.77</td>
</tr>
<tr>
<td>y</td>
<td>1.15</td>
<td>1.00</td>
<td>0.38</td>
<td>0.58</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Measured to:

<table>
<thead>
<tr>
<th>Genus</th>
<th>Number of Individuals</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calapeocia</td>
<td>7</td>
<td>c</td>
</tr>
<tr>
<td>Cystihalysites</td>
<td>28</td>
<td>h</td>
</tr>
<tr>
<td>Lichenaria</td>
<td>11</td>
<td>l</td>
</tr>
<tr>
<td>Streptalasma</td>
<td>31</td>
<td>s</td>
</tr>
<tr>
<td>Syringopora</td>
<td>5</td>
<td>y</td>
</tr>
</tbody>
</table>

Actual Mean Nearest Neighbor = \[ \frac{n}{\sum \frac{r}{N}} \]

where \( r = \text{distance to nearest neighbor} \)

Expected Mean Nearest Neighbor = \[ 1/2\sqrt{P} \]

where \( P = N/\text{unit area of genus of nearest individual} \).
When subjected to a goodness of fit test, long dimensions of coralla on the bedding plane showed no significant differences in orientation (Table 23, Figure 47). Apparently, currents were too weak or too mixed for preferential orientation to occur. Infrequent and probably irregularly occurring storm activity is considered to have resulted in the disorientation of the fossils on the bedding plane, although a muddy substrate may have prevented their transportation.

Measures of diversity sensitive to density and equitability of the corals preserved on the bedding plane are 2.61 and 1.38, respectively (Table 19). These low values rank relatively high compared to diversity figures from the other sites. The environment represented by the Tony Grove Lake bedding plane is interpreted, on the basis of coral morphology, as having been generally calm water from which sediment continuously settled out of suspension onto the substrate. The paucity of insoluble residue from matrices associated with the corals indicates an offshore location. Effective wave base is considered to have been above the sediment-water interface. Occasional storm-generated turbulence is held accountable for the disorientation and fragmentation noted of many of the corals.

The White Pine Lake Site

The lithology of the White Pine Lake collecting site is a medium gray, medium to coarse crystalline dolostone. Bedding is medium to thin. Stratigraphically, it is located 25-30 feet above the Fish Haven-Laketown contact. Insoluble residue results of
Table 23. Test for Goodness of Fit for Data in a Semi-Circle for Long Dimensions of Coralla on the Tony Grove Lake Bedding Plane

The test statistic is:

\[ X^2 = \sum_{i=1}^{n} \frac{(O_i-E_i)^2}{E_i} \]

\( O \) 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.

\[ E = \frac{56}{4} = 14 \]

<table>
<thead>
<tr>
<th>Sector</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 45 degrees</td>
<td>16</td>
</tr>
<tr>
<td>46 - 90 degrees</td>
<td>16</td>
</tr>
<tr>
<td>90 - 135 degrees</td>
<td>12</td>
</tr>
<tr>
<td>136 - 180 degrees</td>
<td>12</td>
</tr>
</tbody>
</table>

\[ X^2 = 1.143 \]

Critical Value = 7.815

for df = 3; alpha = .05
Figure 47. Rose diagram of long dimensions of coralla on the Tony Grove Lake bedding plane.
chips taken from rock slabs (Figure 48) with radial-lensoidal corals ranged from 2.34% to 8.73%. As with other insoluble residues taken from matrices of the corals in the Laketown Formation, diagenetic quartz has invalidated quantitative consideration. Furthermore, Mecham (1973) reported much lower insoluble residue values from Fish Haven and Laketown samples not associated with fossils. His values, the highest of which was 2.14%, are undoubtedly a more accurate representation of the proportion of non-carbonate materials in the original sediment.

The White Pine Lake collecting site is comprised of a more diverse fauna (Table 19) than any of the other sites. The radial-lensoidal *Cyathophylloides*, noted for its downward growing corallites from bases of umbrellic coralla, is ubiquitous on the slabs and among specimens that have weathered free of their matrices.

Radial-lensoidal specimens of *Lichenaria* and *Calapoezia* are abundant. Many circumrotary specimens of the latter genus are also found at the White Pine Lake site. As mentioned previously, the fused *Lichenaria* specimen (WPL3, Figure 26) is comprised of two circumrotary colonies.

Specimens of *Catenipora* exhibit generally more hemispherical profiles than other genera at the White Pine Lake site. However, the maximum size they attain there is considerably smaller than mature coralla of the genus on the Tony Grove Lake bedding plane. Specimens of the compound rugosan *Cyathophylloides* exhibit a similar morphology (see Figure 19), namely, a form intermediate between hemispherical and radial-lensoidal. As noted before, collected specimens of *Paleophysillum* display an asymmetric lensoidal shape.
Figure 48. Bedding slab at White Pine Lake collecting site. Note radial-lensoidal coralla positioned above bedding plane.
The other collected sample of this genus exhibits a large vertical component of growth; it is probable that it lived during an interval of more quiet water conditions than did the rest of the corals collected. Alternatively, it may have been washed into the high energy habitat. *Streptelasma* is seen in Figure 49.

Two genera of brachiopods are found at the site. *Dinorthis* is associated with the fauna under discussion (Figure 50). On the basis of its bulbous form and prominent ribbing, it is considered to have dwelled in relatively high energy conditions. Conversely, *Strophomena* (Figure 51) is considered to have been a quiet water form as indicated by its flat, smooth shell (Thayer 1975; Furisch and Hurst 1974). Moreover, it is found in beds lacking fragmented shell material and the corals under consideration. Present also are cyclostomate and trepostomate bryozoans. Crinoids are represented by segments of columnals.

Orientation and sizes were noted for specimens of *Lichenaria* and *Calapoezia* (Table 24). It was subsequently determined that no size class was selectively disoriented. Kobluk et al. (1977) cited weakening of hard substrate basal attachments, soft substrate instability induced by increasing skeletal size, and hydraulic stress as factors that might affect size-selective disorientation. Apparently, none of these factors influenced size-specific disorientation of these corals near White Pine Lake. It appears that infrequently occurring storms created unusually turbulent waters resulting in disorientation of all sizes and species.
Figure 49. *Streptelasma* on bedding surface at White Pine Lake site. Note fossiliferous nature of matrix.
Figure 50. *Dinorthis*. Note fossiliferous nature of matrix. (Photo from White Pine Lake collecting site)
Figure 51. *Strophemena*. Note non-fossiliferous nature of matrix. (Photo from White Pine Lake collecting site)
Table 24. Comparison of Size vs. Orientation of *Calapoezia* and *Lichenaria* from the White Pine Lake Data Site (in Millimeters)

<table>
<thead>
<tr>
<th>Life Orientation</th>
<th>Disoriented</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Calapoezia</td>
<td></td>
</tr>
<tr>
<td>n = 12</td>
<td>n = 31</td>
</tr>
<tr>
<td>( \bar{x} = 3.82 )</td>
<td>( \bar{x} = 4.25 )</td>
</tr>
<tr>
<td>s = 1.22</td>
<td>s = 1.18</td>
</tr>
<tr>
<td>t = 1.05</td>
<td></td>
</tr>
<tr>
<td>Critical Value = 1.76</td>
<td>for df = 11, 30; alpha = 0.05</td>
</tr>
</tbody>
</table>

* Lichenaria *

<table>
<thead>
<tr>
<th>Life Orientation</th>
<th>Disoriented</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 3</td>
<td>n = 19</td>
</tr>
<tr>
<td>( \bar{x} = 3.93 )</td>
<td>( \bar{x} = 4.41 )</td>
</tr>
<tr>
<td>s = 2.50</td>
<td>s = 1.62</td>
</tr>
<tr>
<td>t = .32</td>
<td></td>
</tr>
<tr>
<td>Critical Value = 2.85</td>
<td>for df = 2, 18; alpha = 0.05</td>
</tr>
</tbody>
</table>
A histogram of the size-frequency distribution of *Calapoezia anticostiensis* is seen in Figure 44. The positive skewness may be indicative of high early mortality or decreasing growth rate, both characteristics of modern invertebrates. It might be interpreted that the distribution observed resulted from selective removal of smaller coralla from elsewhere, considering the high number of colonies found preserved in non-life orientations. However, if this were the situation, the corals would more likely have been spatially scattered rather than concentrated, as they are, in one small area. The degree of relevance of size-frequency distributions to population dynamics of colonial organisms is not beyond dispute (Kobluk et al. 1974).

The large axis of the clast around which WPL22 grew lies obliquely to the basal plane of the coral. This imbrication is taken as evidence of high energy conditions. The asymmetry of growth is considered to have resulted from growth on a sloping substrate.

Further evidence for high energy conditions are the umbrellic shape of *Cyathophylloidales*, the presence of *Dinorthis* and the position on clasts of the radial-lensoidal corals *Cyathophylloidales* and *Lichennaria*, as previously discussed, and circumrotary growth.

Kissling (1974) associated circumrotary growth forms with an elevated (from 50 to 150 centimeters), agitated carbonate mudbank environment. The fossil assemblage of the White Pine Lake site lends itself to a similar interpretation. Asymmetry in growth, as seen in *Paleophyllum* (Figure 7) and *Lichennaria*, is considered to have resulted from growth on the sloping flanks of the mud mound. The
abundance of crinoids and foliate bryozoans further resembles mudbanks in the Silurian Brassfield Formation of Ohio as described by Kissling (1974).

The strophomenid brachiopods are associated with matrices noted for their general lack of shells or shell fragments. On one slab at the fossil site, fragmented shell horizons are seen to lie above and below a "clean" layer. Thus, the energy level of the environment appears to have alternated periodically, probably by shifting from above to below wave base (or vice-versa).

Chert is abundant at the site. As it is seen to replace coral in many instances, it is considered to be of diagenetic origin. Nodules and stringers within the non-fossiliferous horizons could very well have been primary siliceous gels.

**The Blacksmith Fork Site**

Rocks collected from the talus slope from Blacksmith Fork that enclose lensoidal favositid coralla are characteristically dark to medium-gray, medium to coarsely crystalline dolostones. Stratigraphically, the source of these rocks is considered to have come from the lower upper half of the Laketown Formation. Insoluble residue values ranged from 6.03% to 14.07%. Examination of the residue through the binocular microscope revealed its diagenetic origin as evidenced by translucent, well-formed crystals and lack of frosting of the outer surfaces of grain. Sheehan (1980) reported insoluble residues to be absent from this part of the Laketown. Matrices around silicified fossils in this unit seem to have been more affected diagenetically than the strata in general.
As well as tabular-lensoidal corals, small hemispherical coralla of *Favositites beechensis* were collected (Figure 52). Also present are several crinoidal slabs in the talus slope, although there is no irrefutable evidence that they were constituents of the same community. Therefore, a diversity computation was not made. Qualitatively, it can be said that diversity was low, even in consideration of the low values that characterize Laketown assemblages in general.

As previously discussed, these tabular favositids have been interpreted as having encrusted soft substrates in quiet environments. This account was based on non-parallelism of flat bases of coralla within individual rocks, which is considered indicative of small-scale sediment deformation. Flat coralla and uniformly upward facing corallites have been mentioned previously in this paper as adaptations to decreased illumination and the need for increased stability on soft substrates.

**The Card Canyon Site**

The Card Canyon data site is lithologically comprised of dark gray, fairly dark weathering, medium-grained dolomite. Bedding at the site is very thick to massive. It is situated in Budge's (1966) Member D as evidenced by stratigraphic proximity to the thin-bedded, silty dolostone of the basal Water Canyon Formation. Insoluble residue values for lensoidal corals were 8.18%, 10.25%, and 9.50%. Two corals with a more pronounced vertical component of growth values had insoluble residues of 7.38% and 12.38%. Most of the insoluble material is considered to be of diagenetic origin. However, in the two insoluble residues examined, at least a portion appeared to
Figure 52. Distribution of morphologies of *Favosites gothlandicus* based on relative proportions of vertical, basal, and diagonal dimensions.
be original detritus. This was indicated, upon inspection through
the binocular microscope, by fine granularity and dull luster
of many of the grains in the residue. Chert lenses and stringers
are common. The faint internal laminae within these stringers are
suggestive of stromatoporoid or algal structure.

Corals identified at the site included _Cystihalysites brownsport-
tensis_ and _Cystihalysites magnitubis_ (Table 25). Stratigraphic dis-
tribution of height to average width of these two species of "chain"
coral are shown in Figure 53 and 54. It is evident that within hori-
zon variation greatly exceeded between horizon variation. This is
taken to be indicative of frequent fluctuations of physical conditions,
primarily sedimentation rate. Considering that coralla with compara-
tively large height to width ratios did not attain sizes as great as
in mature lensoidal corals, it appears that conditions favoring such
higher vertical profiles were relatively short-lived.

Lensoidal coral morphologies indicate intervals of negligible
sedimentation. Corallite arrangements about budding centers are
intermediate between radial and non-radial (tabular). Whether they
grew in a relatively high or low energy environment is not readily
apparent, however. The longitudinal section depicted in Figure 30
is noted for its concave downward base and horizontal corallites on
the left side of the upper colony. These features are highly sug-
gestive of mild scouring around the sides of the corals. The lack
of scour-sedimentary structure may be due to thorough recrystalliza-
tion of the rock. Alternatively, the growth form might be attributed
Table 25. Corals of the Card Canyon Data Site (all Measurements in Centimeters)

<table>
<thead>
<tr>
<th>Patch 1:</th>
<th>T</th>
<th>L</th>
<th>Species</th>
<th>Height</th>
<th>Width</th>
<th>Orientation</th>
<th>Fragmentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>39 1  Cm</td>
<td>39</td>
<td>1</td>
<td>Av</td>
<td>2.9</td>
<td>4.9</td>
<td>S078 D29</td>
<td>1.5</td>
</tr>
<tr>
<td>43 1  Cb</td>
<td>43</td>
<td>1</td>
<td>Av</td>
<td>3.1</td>
<td>2.1</td>
<td>S049 D78</td>
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</tr>
<tr>
<td>45 1  Cb</td>
<td>45</td>
<td>1</td>
<td>Cb</td>
<td>4.4</td>
<td>7.0</td>
<td>S202 D89</td>
<td>4.0</td>
</tr>
<tr>
<td>46 1  Av</td>
<td>46</td>
<td>1</td>
<td>Sv</td>
<td>1.8</td>
<td>9.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>46 1  Cb</td>
<td>46</td>
<td>1</td>
<td>Cv</td>
<td>4.4</td>
<td>7.0</td>
<td>S202 D89</td>
<td>4.0</td>
</tr>
<tr>
<td>46 1  Cb</td>
<td>46</td>
<td>1</td>
<td>Cv</td>
<td>1.8</td>
<td>7.0</td>
<td>S092 D122</td>
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<td>46</td>
<td>1</td>
<td>Cv</td>
<td>1.3</td>
<td>5.7</td>
<td>S110 D151</td>
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</tr>
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<td>46</td>
<td>1</td>
<td>R</td>
<td>1.1</td>
<td>1.5</td>
<td>S193 D48</td>
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<td>35</td>
<td>2</td>
<td>Cb</td>
<td>3.3</td>
<td>10.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>38 2  Cb</td>
<td>38</td>
<td>2</td>
<td>Av</td>
<td>1.8</td>
<td>4.0</td>
<td>S271 S158</td>
<td>4.0</td>
</tr>
<tr>
<td>38 2  Cb</td>
<td>38</td>
<td>2</td>
<td>P</td>
<td>1.8</td>
<td>4.0</td>
<td>S271 S158</td>
<td>4.0</td>
</tr>
<tr>
<td>39 2  Cb</td>
<td>39</td>
<td>2</td>
<td>Cb</td>
<td>1.2</td>
<td>1.2</td>
<td>S? D?</td>
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</tr>
<tr>
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<td>51</td>
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<td>Cm</td>
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<td>10.6</td>
<td>S245 D44</td>
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<td>Cm</td>
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<td>6.8</td>
<td>S141 D58</td>
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</tr>
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<td>35</td>
<td>3</td>
<td>Cm</td>
<td>2.1</td>
<td>4.6</td>
<td>S082 D46</td>
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<td>38</td>
<td>3</td>
<td>Cb</td>
<td>3.5</td>
<td>15.2</td>
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<tr>
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<td>39</td>
<td>3</td>
<td>Cb</td>
<td>3.2</td>
<td>6.8</td>
<td>S101 D22</td>
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</tr>
<tr>
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<td>46</td>
<td>3</td>
<td>Cb</td>
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<td>6.4</td>
<td>S115 D46</td>
<td>3.0</td>
</tr>
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<td>49 3  Cb</td>
<td>49</td>
<td>3</td>
<td>Cb</td>
<td>4.1</td>
<td>6.2</td>
<td>S254 D52</td>
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<tr>
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<td>32</td>
<td>4</td>
<td>Cb</td>
<td>3.9</td>
<td>6.2</td>
<td>S121 D26</td>
<td>3.0</td>
</tr>
<tr>
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<td>37</td>
<td>4</td>
<td>Cb</td>
<td>4.2</td>
<td>14.2</td>
<td>S202 D25</td>
<td>2.0</td>
</tr>
<tr>
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<td>36</td>
<td>5</td>
<td>Cm</td>
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<td>9.7</td>
<td>S160 D39</td>
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</tr>
<tr>
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<td>36</td>
<td>5</td>
<td>Cb</td>
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<td>2.9</td>
<td>S140 D6</td>
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</tr>
<tr>
<td>32 6  Cm</td>
<td>32</td>
<td>6</td>
<td>Cm</td>
<td>10.5</td>
<td>9.1</td>
<td>S351 D23</td>
<td>5.0</td>
</tr>
<tr>
<td>1 7  Cb</td>
<td>1</td>
<td>7</td>
<td>Cb</td>
<td>3.2</td>
<td>8.2</td>
<td>S335 D32</td>
<td>5.0</td>
</tr>
<tr>
<td>8 7  Cm</td>
<td>8</td>
<td>7</td>
<td>Cm</td>
<td>3.1</td>
<td>14.3</td>
<td>S168 D30</td>
<td>4.0</td>
</tr>
<tr>
<td>8 7  P</td>
<td>8</td>
<td>7</td>
<td>P</td>
<td>-</td>
<td>-</td>
<td>S? D10</td>
<td>2.5</td>
</tr>
<tr>
<td>3 8  Cb</td>
<td>3</td>
<td>8</td>
<td>Cb</td>
<td>3.5</td>
<td>4.3</td>
<td>S76 D27</td>
<td>4.0</td>
</tr>
<tr>
<td>3 8  Cb</td>
<td>3</td>
<td>8</td>
<td>Cb</td>
<td>3.2</td>
<td>3.7</td>
<td>S165 D1</td>
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<td>3 9  Cb</td>
<td>3</td>
<td>9</td>
<td>Cb</td>
<td>2.8</td>
<td>3.8</td>
<td>S76 D3</td>
<td>5.0</td>
</tr>
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<td>4</td>
<td>10</td>
<td>Cm</td>
<td>3.8</td>
<td>7.5</td>
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</tr>
<tr>
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<td>3</td>
<td>10</td>
<td>Cm</td>
<td>3.8</td>
<td>8.9</td>
<td>S275 D158</td>
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</tr>
<tr>
<td>3 10  Cb</td>
<td>3</td>
<td>10</td>
<td>Cb</td>
<td>6.0</td>
<td>6.9</td>
<td>S65 D14</td>
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</tr>
<tr>
<td>2 11  Cb</td>
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Table 25. (Continued)

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<td>S121 D30</td>
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</table>

T - Vertical Transect
L - Stratigraphic Horizon (each increment = .3 meters)
S - Direction from distal to proximal portions of corallite in middle of corallum (Azimuth readings)
D - Dip of corallite in middle of corallum (e.g., 0 degrees--life orientation, 90 degrees--middle corallite horizontal, 180 degrees - middle corallite vertical but overturned.

**Fragmentation**

1 - not fragmented  
2 - probably not fragmented  
3 - uncertain  
4 - probably fragmented  
5 - fragmented

**Species**  
Cb - *Cystihalysites brownsportensis*  
Cm - *Cystihalysites magnitubis*  
Av - *Astrocerium venustum*  
P - *Platyaxum*  
R - Rugose coral  
Sv - *Syringopora verticullata*
Figure 53. Stratigraphic horizon vs. height/width ratios of halysitid corals. (Card Canyon collecting site, patch 1).
Figure 54. Stratigraphic horizon vs. height/width ratios of halysitid corals. (Card Canyon collecting site, patch 2)
to growth on a small mound. Such a mound might have been formed by
the coral itself through the storage of detrital material within
lacunae (area between ranks).

The great majority of lensoidal halysitid coralla from Card
Canyon lack downward basal concavity or upward bending of corallites
on their margins. Temporary lulls in sedimentation, during which
time an oozy substrate did not consolidate, is suggested by the
association of lensoidal coralla and very thick to massive bedding.
Furthermore, halysitid coralla whose basal dimensions are clearly
oriented obliquely, sometimes even perpendicularly, to bedding lend
themselves to an interpretation similar to that applied to lensoidal
favositid corals from Blacksmith Fork that were found oriented
obliquely to one another. Soft sediment deformation or edge-first
sinking of coralla after disruption is implicit. Furthermore,
a phaceloid corallite packing arrangement does not seem to be the
optimum structure for high energy conditions.

Conic-columnal and hemispherical halysitid coralla attest to
temporary environmental fluctuations. The flat-based hemispherical
morphology viewed in longitudinal section in Figure 55 implies
shallower water, a firmer substrate, and higher energy than inferred
for the lensoidal morphotypes of the same species. This may corres-
don with the lowering of the effective wave base. Conic halysitid
coralla (Figure 44) provide evidence of interludes of accelerated
sediment accumulation.

A distinguishing feature of Platyaxum is its extreme thinness.
This is thought to reflect a stabilizing adaptation to a fluid.
Figure 55. Overturned hemispherical corallum (Cystihalysites brown-sportensis) from Card Canyon collecting site. (View is of vertical cliff)
substrate rather than the result of heavy turbulence. The uniform orientation and inclination of corallites are interpreted as having been a rheotropic response.

A halysitid-dominated community in Card Canyon which did, in fact, experience more sedimentation of non-carbonate silty material would be congruent with the observations of Manten (1971, p. 81), who stated that Silurian halysitids were capable of living in very turbid waters after having noted their dominance in marlstone. As noted before, he considered the area between ranks to have been used to "store" foreign material. *Astrocerium*, present at the data site, is the only favositid genus observed in this study to have septal structures. This may have been an adaptation to the temporary increase in sedimentation of terrigenous material, considering that these features would improve sediment rejection capability.

Diversity of the site is quantified as follows: DT = 3.56 and DE = 0.38 (Table 26). These are intermediate values relative to those attained at the other collecting sites.

**The Sharp Mountain Site**

The matrices of corals from the Sharp Mountain data site are medium to light-gray in color and weather to a buff or very light gray color. Crystallinity is medium. Bedding varies from thin to intermediate. Insoluble residues of dolostone samples ranged from 9.24% to 16.92%. No correlation of amounts of insoluble residue values and coral morphology is evident; the residue is clearly of diagenetic origin.
As at Blacksmith Fork, the fauna is dominated numerically by the two aseptate favositid species, *F. gothlandicus* and *Favosites* cf *F. boscensis*. Two specimens of *Cystihalysites* and a few pentalmerid brachiopods were also observed.

The greatest within-site variation of morphology of any coral species is observed in the two species of *Favosites*. Figure 56 shows an enormous, chertified tabular lenticular coral. Elongate and unmodified hemispherical form is seen in Figures 39 and 27, whereas conic-columnal specimens from Sharp Mountain are represented by the colony in Figure 24. These latter forms, as previously discussed, may be attributed to rapid sedimentation or crowding.

As Silurian corals did not build framework reefs, conic morphology is attributed to temporary cessation of agitated conditions that allowed increased sedimentation, rather than to crowding. A eustatic rise in sea level likely induced this modification. During such periods, the sediment-water interface would have been well below effective wave base. Alternatively, morphologies from different parts of a heterogeneous environment may occur together as a result of transportation and mixing of coralla during storms.

The large tabular coral seen in Figure 56 lies stratigraphically above the occurrence of hemispheric and conic coralla. It is considered to reflect calm conditions in relatively deeper water.

On the basis of the preponderance of hemispherical, elongate hemispherical forms, and the low angle (to the horizontal) branching projections from specimen SMS, the Sharp Mountain data site is interpreted as having been a moderately high energy environment above
Figure 56. Tabular corallum in situ (*Favosites gothlandicus*) at the Sharp Mountain collecting site.
effective wave base most of the time. Eustatic fluctuations in water depth and effective wave base resulted in variable morphology. The low diversity of organisms (DT = 2.48, DE = .88) is attributed to crowding on a localized, relatively firm substrate (Jackson 1977).

The large quantity of coral fragments is thought to reflect storm activity. The tabular coralla (Figure 56) may attest to deepening of the sea. Alternatively, the physical destruction, from which fragmentation of corals occurred, may have also worn down a small topographically elevated habitation on which the favositid community lived. This may have contributed to the gradual placement of the locality below effective wave base and subsequent growth of conic-columnal coralla.

The lack of preferred orientation of elongate coral fragments (Table 26, Figure 57) suggests either the prevalence of multidirectional or shifting currents. Alternatively, the fragments may have become randomly oriented during infrequent storm activity. Such brief periods of increased turbulence themselves probably caused the fragmentation.

The lack of calical features associated with high sediment rejection capability is consistent with inferred high energy of the environment. Where water agitation was great enough to keep particles in suspension, the need for efficiency in cleansing was undoubtedly secondary in importance to the need for massive, cerioid coralla which stabilized the colony on the current-swept substrate. Relative abundance of faunal constituents, paleoecology, and the results of insoluble residues tests of the six collecting sites are summarized in Tables 27, 28, and 29.
Table 26. Test for Goodness of Fit for Data in a Semi-Circle for Long Dimensions of Coralla at Sharp Mountain

The test statistic is:

\[ X^2 = \frac{n}{\sum} (0_i - E_i)^2 / E \]

0 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.

\[ E = \frac{44}{3} = 14.6 \]

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<td>61 - 120 degrees</td>
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<td>120 - 180 degrees</td>
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\[ X^2 = 1.280 \]

Critical Value = 5.99

for df = 2; alpha = 0.05
Figure 57. Rose diagram for data in a semi-circle of long dimensions of coralla at the Sharp Mountain collecting site.
Table 27. Fauna and Relative Abundances of Faunal Constituents of the Various Collecting Sites

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Tony Grove Lake

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<tr>
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<td>34</td>
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<tr>
<td>Streptelasma</td>
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<td>9</td>
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<td>Syringopora</td>
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White Pine Lake--Slab 1

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<td>5</td>
</tr>
<tr>
<td>Lichenaria</td>
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<td>29</td>
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<tr>
<td>Dinorthis</td>
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<td>Calapoecia</td>
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<td><strong>Total</strong></td>
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<td>Catenipora</td>
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<tr>
<td>Catenipora</td>
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<td>C. magnitubis</td>
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<td>Astrocerium</td>
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<tr>
<td>Platyaxum</td>
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<td>8</td>
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<td>Syringopora</td>
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<tr>
<td>Rugose Coral</td>
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### Sharp Mountain

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Table 28. Paleoecology of the Collecting Sites

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<td>Low to Mod.</td>
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<td>Low</td>
<td>Mod.</td>
<td>Mod.</td>
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<td>Good</td>
<td>Mod.</td>
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<tr>
<td><strong>Nutrient Supply</strong></td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
</tr>
</tbody>
</table>

Hem. - hemispherical  
R.L. - radial-lensoidal  
Tab. - tabular  
Col. - columnal  
Mod. - moderate
Table 29. Results of the Analysis of Insoluble Residue

| Location       | Morphology          | Value  |  |  |  |  |
|----------------|---------------------|--------|  |  |  |  |
|                |                     |        |  |  |  |  |
| **Green Canyon** |                     |        |  |  |  |  |
|                | Morphology          | Value  |  |  |  |  |
|                | Hemispherical       | .38%   |  |  |  |  |
|                | Hemispherical       | .64%   |  |  |  |  |
|                | Hemispherical       | .25%   |  |  |  |  |
|                | Mean                | .42%   |  |  |  |  |
|                | Standard Deviation  | .20%   |  |  |  |  |
| **Tony Grove Lake** |                     |        |  |  |  |  |
|                | Morphology          | Value  |  |  |  |  |
|                | Hemispherical       | .68%   |  |  |  |  |
|                | Hemispherical       | .73%   |  |  |  |  |
|                | Hemispherical       | .81%   |  |  |  |  |
|                | Conic-Columnal      | 1.28%  |  |  |  |  |
|                | Mean                | .82%   |  |  |  |  |
|                | Standard Deviation  | .27%   |  |  |  |  |
| **White Pine Lake** |                     |        |  |  |  |  |
|                | Morphology          | Value  |  |  |  |  |
|                | Radial Lensoidal    | 2.34%  |  |  |  |  |
|                | Radial Lensoidal    | 8.73%  |  |  |  |  |
|                | Radial Lensoidal    | 5.07%  |  |  |  |  |
|                | Radial Lensoidal    | 5.38%  |  |  |  |  |
|                | Radial Lensoidal    | 3.49%  |  |  |  |  |
|                | Mean                | 5.00%  |  |  |  |  |
|                | Standard Deviation  | 2.42%  |  |  |  |  |
| **Blacksmith Fork** |                     |        |  |  |  |  |
|                | Morphology          | Value  |  |  |  |  |
|                | Non-radial Lensoidal| 6.03%  |  |  |  |  |
|                | Non-radial Lensoidal| 14.07% |  |  |  |  |
|                | Non-radial Lensoidal| 9.09%  |  |  |  |  |
|                | Mean                | 9.73%  |  |  |  |  |
|                | Standard Deviation  | 4.06%  |  |  |  |  |
Table 29. (Continued).

<table>
<thead>
<tr>
<th>Card Canyon</th>
<th>Morphology</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-radial Lensoidal</td>
<td>8.18%</td>
</tr>
<tr>
<td></td>
<td>Non-radial Lensoidal</td>
<td>10.25%</td>
</tr>
<tr>
<td></td>
<td>Non-radial Lensoidal</td>
<td>9.50%</td>
</tr>
<tr>
<td></td>
<td>Hemispheric</td>
<td>7.35%</td>
</tr>
<tr>
<td></td>
<td>Hemispheric</td>
<td>12.38%</td>
</tr>
</tbody>
</table>

\[ \bar{x} = 9.54\% \]

\[ s = 1.94\% \]

<table>
<thead>
<tr>
<th>Sharp Mountain</th>
<th>Morphology</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hemispheric</td>
<td>14.07%</td>
</tr>
<tr>
<td></td>
<td>Hemispheric</td>
<td>11.91%</td>
</tr>
<tr>
<td></td>
<td>Hemispheric</td>
<td>10.97%</td>
</tr>
<tr>
<td></td>
<td>Hemispheric</td>
<td>9.24%</td>
</tr>
<tr>
<td></td>
<td>Conic-Columnal</td>
<td>14.01%</td>
</tr>
<tr>
<td></td>
<td>Conic-Columnal</td>
<td>16.92%</td>
</tr>
</tbody>
</table>

\[ \bar{x} = 12.85\% \]

\[ s = 2.71\% \]
Regional Reconstruction

Coral faunas in the Fish Haven and Laketown Formations in the Bear River Range are noted for their patchy distribution. This is considered to have resulted from the combination of several factors. The shallow shelf habitat of modern seas is noted for its heterogeneity (Bathurst 1975). Furthermore, suspension feeders are characterized by more patchy distributions than deposit feeders (Levinton 1972).

Valentine (1971) considered the main causes of aggregation to be heterogeneous environment and ecological specialization. Aggregation was also attributed to larval selection of settling sites. Baggerman (1953) cited passive method of larval concentration, namely, current sorting of larvae according to their hydrographic properties.

Advantages of aggregation listed by Valentine (1973) include geographic restriction of species by limiting factors in a heterogeneous environment. For example, sessile, benthic suspension feeders need a certain minimum current velocity to provide new supplies of nutrients. Excessive turbulence, however, limits their ability to extract these nutrients from the water. Another obvious advantage of clumping of corals is that sexual reproduction between colonies is facilitated.

The best analogue among modern coral habitats to Paleozoic habitats is the lagoonal patch reef. According to Storr (1964), these reefs develop only where environmental conditions are optimum for their development. The main factor held accountable for this
zonation was tidal flow. Patch reef growth was reported as flourishing in tidal channels.

Sheehan (1980) reported the Silurian sea floor of the eastern Great Basin to have been an "undulating surface" on the basis of the lack of persistent, parallel communities. Anderson (1971) suggested that physical barriers, such as mud mounds, may form barrier zones by which habitats may be differentiated in transgressing seas. Transgression itself promoted the development of Early Devonian patch reefs. Aside from creating environmental heterogeneity as a consequence of submarine topographic features, such barriers may have set up relatively complicated circulation patterns. These flow systems may have had a similar effect on localized physiochemical and sedimentological conditions as tidal flow has on modern, nearshore lagoonal habitats. The inferred high energy environments at White Pine Lake and Sharp Mountain likely developed on elevated mounds. The distribution of low energy communities is not so patchy as the high energy communities, especially in the Fish Haven Formation. The author considers this formation a reflection of the more extensive, monotonous conditions that prevailed on the ocean floor below effective wave base. However, distinct lateral variation in sedimentological conditions during Fish Haven deposition, as evidenced by differing bitumen content, indicates that environmental gradients existed across the Late Ordovician sea.

The general low diversity and density of organisms, aside from reasons considered in the discussion of the individual sites, can be attributed to position off the west coast of a continent as
described by Stehli and Wells (1971) and Bamback et al. (1980). The former authors cited the movement of waters from east to west in tropical latitudes as hindering the eastward spread of planktonic coral larvae. They also noted the strong correlation between temperature and diversity. A cool, west coast current may have negatively affected the diversity of the coral communities under study. Furthermore, upwelling associated with west coasts have been shown by Glynn (1977) to inhibit coral growth. Glynn and Stewart (1973) found that modern corals are largely confined to north and east sides of islands because of favorable thermal conditions. Altogether, these factors account for the lack of proliferation of coral faunas as compared to, for example, the Silurian reefs on the flanks of the Michigan Basin.

Density-dependent factors may have also played a role in determining densities and diversities of coral faunas. Unstable nutrient supply might account partly for the observed within-site low diversity. Qualitatively, the between site faunal variability is greater than that of the within site diversity. This is considered to have resulted from the spatial heterogeneity of the sea floor.

Colonial organisms are reported by Jackson (1977) to be favored in stable environments. However, as Paleozoic corals were much more euryfacial organisms than modern corals (Sokolov 1971, p. 321), they may very well have been capable of employing a more generalist adaptive strategy than modern corals. This would have involved smaller size, more rapid growth, and shorter generation time. In the case of colonial organisms, this would have necessitated frequent sexual reproduction.
Several explanations are plausible for the virtual total lack, especially in lower energy environments, of such common constituents of Paleozoic biotas as brachiopods and crinoids. One possible explanation for this scarcity is their removal by storm activity, although some fragments would be expected in the lithologic matrix. A shell breccia below the Card Canyon halysitid patch appears to represent such an event.

Fouling of the water column a short distance above the water-sediment interface by vagile deposit feeders is not though to have caused the exclusion of low-level suspension feeders. Similarly, very high-level suspension feeders are not considered to have been restricted by substrate instability induced by burrowing organisms. These conclusions are prompted by the absence of traces of burrowing activity.

Conditions in and immediately above the original sediments of these low energy habitats appear to have been sufficiently dyasaerobic to preclude proliferation of low-level suspension feeders. Very high level suspension feeders, such as crinoids, were probably restricted from inhabitation in low-energy environments by their inherent instability on soft substrates. Corals may have been affected to a lesser degree by dyasaerobic conditions because of their probable incorporation of algae within their endodermic tissue. By consuming carbon dioxide, the algae would have facilitated secretion of the corals' calcareous skeletal material. Brachiopods and crinoids did not employ such a symbiotic relationship. Muscatine and Porter (1977) considered symbioses between corals and zooanthellae to be important to the former's survival in nutrient-poor environments.
Within the same community, different trophic groups are known to experience different degrees of predictability and variability of food supply. Nutrient dynamics, then, may have restricted proliferation of low and very high level suspension feeders. Experiencing nutrient shortages, corals might even have consumed larvae of other organisms. Barriers to the dispersal of larvae of brachiopods and crinoids in this area may have prevented the colonization of the sea floor by these filter-feeders.

The bathymetric profile of Anderson (1971) is employed here to graphically depict the distribution of environments of the Late Ordovician and Silurian seas of what is now northern Utah. This is shown in Figure 58. In addition, bands of communities named after characteristic brachiopods by Ziegler (1965) are correlated with the environmental pattern. The communities, from shallow near-shore to deeper offshore waters, were Linqula, Ecoelia, Pentamerus, Stricklandia, and Clorinda. Sheehan (1970) reported that a similar community structure existed in the Silurian Great Basin rocks with two exceptions: "1) corals are more abundant, and 2) the Ecoelia community has not been found." This bathymetric profile is, of course, idealized. As previously noted, the Late Ordovician and Silurian sea floor of northern Utah was probably somewhat irregular. The model is characterized by a low-high-low pattern of kinetic energy release (Figure 58).

Paucity of terrigenous material and the homogeneous carbonate composition of the Fish Haven and Laketown Formations preclude inferences of deposition in a restricted subtidal zone. Nevertheless,
Figure 58. Two environmental models for epeiric sea community patterns: Model 1 occurs in a low slope stable or transgressing seas in which most wave and current energy is dissipated in a central high energy zone; low energy tidal flat and subtidal zones develop onshore and low energy near and below wave base zones develop offshore. The scales in Figure 4 are not an attempt to define wave base for epeiric seas. It is assumed this depth might vary anywhere from 15 to 50 feet. The environmental pattern is correlated with Ziegler's community pattern. Model 2 has higher depositional slopes and is associated with prograding shorelines. Fewer broad environmental zones develop. Bretsky's communities are correlated with these environments. Circulation and rate of clastic supply may affect either model. Variation in barrier zone development is significant in Model 1.
the environment of deposition is thought to have had certain similarities to this portion of the bathymetric profile. Water depths must have been shallow enough to allow copious amounts of carbonate material to precipitate. Restricted circulation, a characteristic of restricted subtidal waters (Irwin 1965), has been invoked in the reconstruction of environmental conditions in which the corals of the Green Canyon collecting site lived. The irregularity of the sea floor may have resulted in limited circulation locally.

Despite these similarities with restricted subtidal waters, the corals of the Fish Haven and Laketown Formations are thought to have lived in the open marine shelf. The constituents of the White Pine Lake and Sharp Mountain sites are considered to have lived on geographically confined topographic elevations of the sea floor above effective wave base. Deepening of the water greatly diminished water agitation, allowing sediment to accumulate almost continuously. When conditions were sufficiently calm, rapid sedimentation restricted lateral growth of corals. During such a period of increased water depth, the beds noted for their lack of fragments and presence of strophomenid brachiopods were deposited at the White Pine Lake site.

Where evidence suggests variable conditions, such as the fluctuating sedimentation rates inferred for the intraspecific morphologic diversity of corals at Card Canyon, eustatic changes in sea level are inferred. The hemispherical forms prevailed at times when the substrate was above effective wave base, while the
non-radial lensoidal (tabular) coralla developed below effective wave base in quiet waters.

Placid conditions may have also resulted from the dissipation of wave energy due to friction with the substrate in shallow water (Anderson 1971). Such a situation might have prevailed on the inferred topographic elevations. Rising water level might actually have created more turbulent conditions.
LITERATURE CITED


Clark, P. J.; Evans, F. C. Distance to nearest neighbor as a measure of spatial relationships in populations. J. of Ecology. 35(4):445-452; 1954.


Jenes, O. A. The controlling effect of environment upon the corallum in *Favosites*; with a revision of some massive species on this basis. Annals and Mag. of Natural History 17:1-24; 1936.


Stel, J. H. Lateral increase in Paleofavosites asper (d'Orbigny, 1850) and other tabulates. Jour. Pal. 53(2); 1979.


