Paleoenvironmental and Paleoecological Reconstruction of the Chemahawin Member (Cedar Lake Formation; Silurian) at Lundar, Manitoba

by

D. Raegan Porter

A Thesis submitted to the Faculty of Graduate Studies in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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Paleoenvironmental and Paleoecological Reconstruction of the Chemahawin Member (Cedar Lake Formation; Silurian) at Lundar, Manitoba

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Abstract

A mid-Early Silurian stromatoporoid-dominated biostrome within the upper, Chemahawin Member of the Cedar Lake Formation (Interlake Group; Silurian) is exposed within a quarry near Lundar, Manitoba. This highly dolomitized structure, previously classified as a bioherm, displays little evidence of topographic relief, but the density of skeletons within the unit, and the complex interactions among fauna, justify classification as a biostrome.

Statistical tests were employed to assess the distributions of stromatoporoids and corals between localities in the quarry, and between stratigraphic intervals within localities, in order to recognize spatial and temporal trends within the biostrome. The faunal assemblage of the Chemahawin Member was analyzed in terms of abundance, species diversity and dominance, skeletal growth forms, and skeleton size. Within the Chemahawin biostrome, different microenvironments at various positions within the structure are interpreted from spatial variation in the distribution of fauna. Vertical trends in faunal distribution suggest short-term ecological succession as the biostrome transitioned from a pioneer community to a climax stage.

In the southwest corner of the quarry, closely spaced facies represent a gradual progradation of the biostrome over previously unsuitable muddy substrates. It is interpreted from directional measurements of elongate fossils that a prevailing paleocurrent originated from the northeast, and the southwest corner likely represents a protected, back-reef setting. Examination of a subsurface drill core from Lundar Quarry North revealed facies arrangements similar to those within the quarry. A second core from nearby Mulvihill West Quarry revealed correlative facies, although the interval

equivalent to the biostromal facies was not as well developed, indicating the limited lateral extent of the structure.

The Chemahawin Member represents a transgressive-regressive cycle, with reefal development at the time of maximum transgression, corresponding to the interval of geologic time when reefs were most widespread globally in the Silurian. Although large mid-Silurian reefs are common structures within other basins on the North American continent, reef development within the Williston Basin was limited and patchy, suggesting that conditions were less favourable for large-scale reef growth.

Acknowledgements

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Chapter 1: Introduction

1.1 Introduction and Objectives

The Silurian Period represents an interval of change and recovery, as colder global climates and a mass extinction event at the close of the Ordovician reduced marine diversity (Copper 2002). Ameliorating temperatures and rising sea levels allowed for the gradual expansion of reef-building in near-equatorial settings by the late Early Silurian (Copper 2002). Relatively low diversity assemblages of stromatoporoids, corals, and coralline algae constructed the majority of such reefs in the absence of predators within intracratonic basins and epeiric seas (Copper 2002). Though many ancient basins in North America accommodated significant reef development during the mid-Early Silurian, little evidence has been found within the centrally located Williston Basin for such accumulations of fauna (Figure 1.1). Along the northern flanks of the basin in southern Manitoba, however, an inactive quarry near the town of Lundar provides a rare exposure of an extremely fossiliferous unit identified in previous literature as a reef (Figure 1.2). The Chemahawin Member (Cedar Lake Formation; Interlake Group), exposed in the Lundar Quarry, is the youngest Silurian unit preserved in southern Manitoba (Figure 1.3; Stearn 1956). The Devonian erosional unconformity lies only a few kilometres west of Lundar (see Figure 1.2 for proximity of Devonian unconformity to Lundar Quarry). This unit provides a unique opportunity to examine the reef fauna of a mid-Early Silurian buildup within the Williston Basin, during the most extensive reef-building episode in the Silurian (Johnson et al. 1998).

The primary objective of this study is to describe in detail the exposed portion of the Chemahawin Member within the Lundar Quarry in order to reconstruct the paleoecologic and paleoenvironmental conditions which existed at this location during the

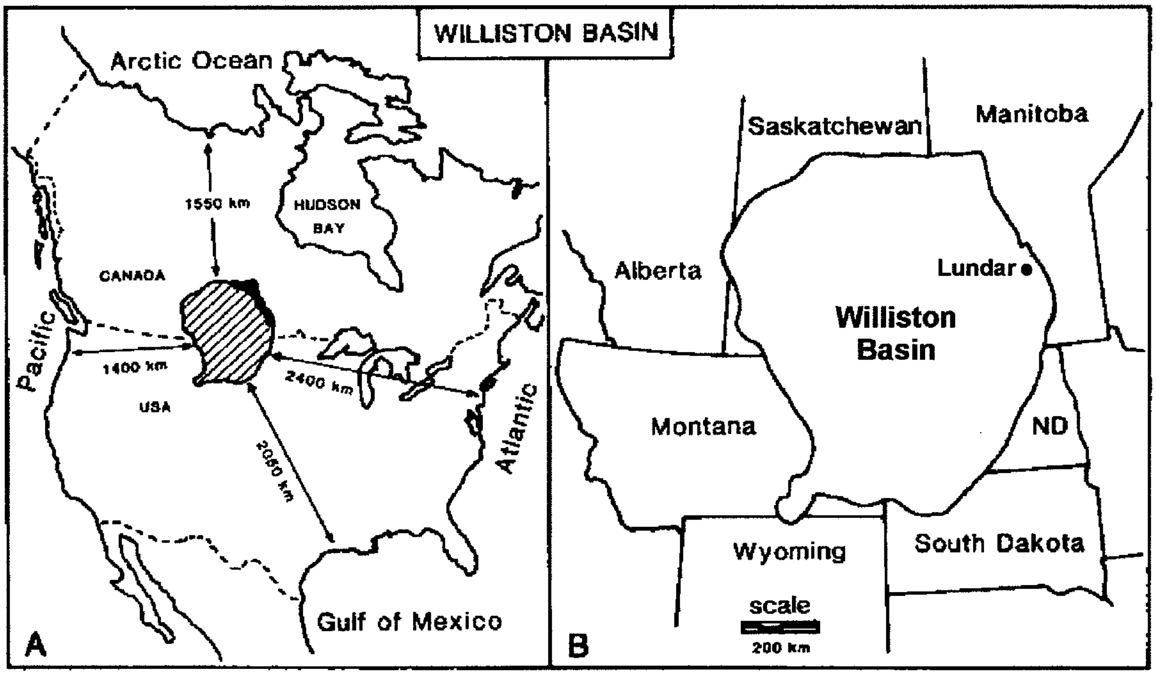
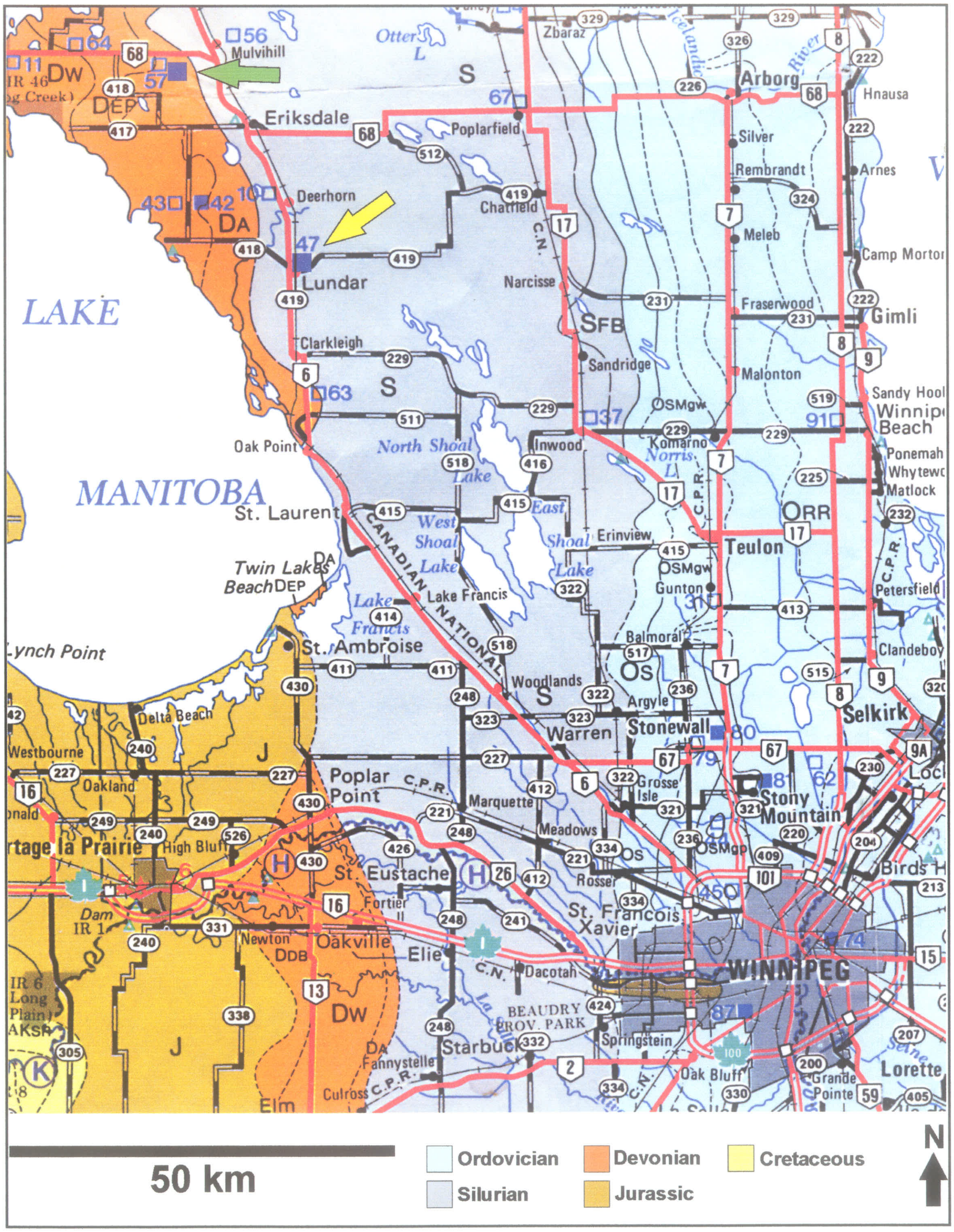


Figure 1.1: Location of the Williston Basin relative to southern Manitoba (modified from Johnson and Lescinsky 1986). A) Mid-continental position of Williston Basin (shaded, with outcrop belt in black). B) Geographic location of Williston Basin relative to Canadian provinces and U.S. states. The approximate location of Lundar is indicated within the Basin.



<u>Figure 1.2:</u> Map of Winnipeg and surrounding area (modified from Corkery 1987). Location of Lundar Quarry (number 47) is indicated by yellow arrow. Drill cores were examined from Lundar Quarry North, and Mulvihill West Quarry (number 57), which is indicated by a green arrow.

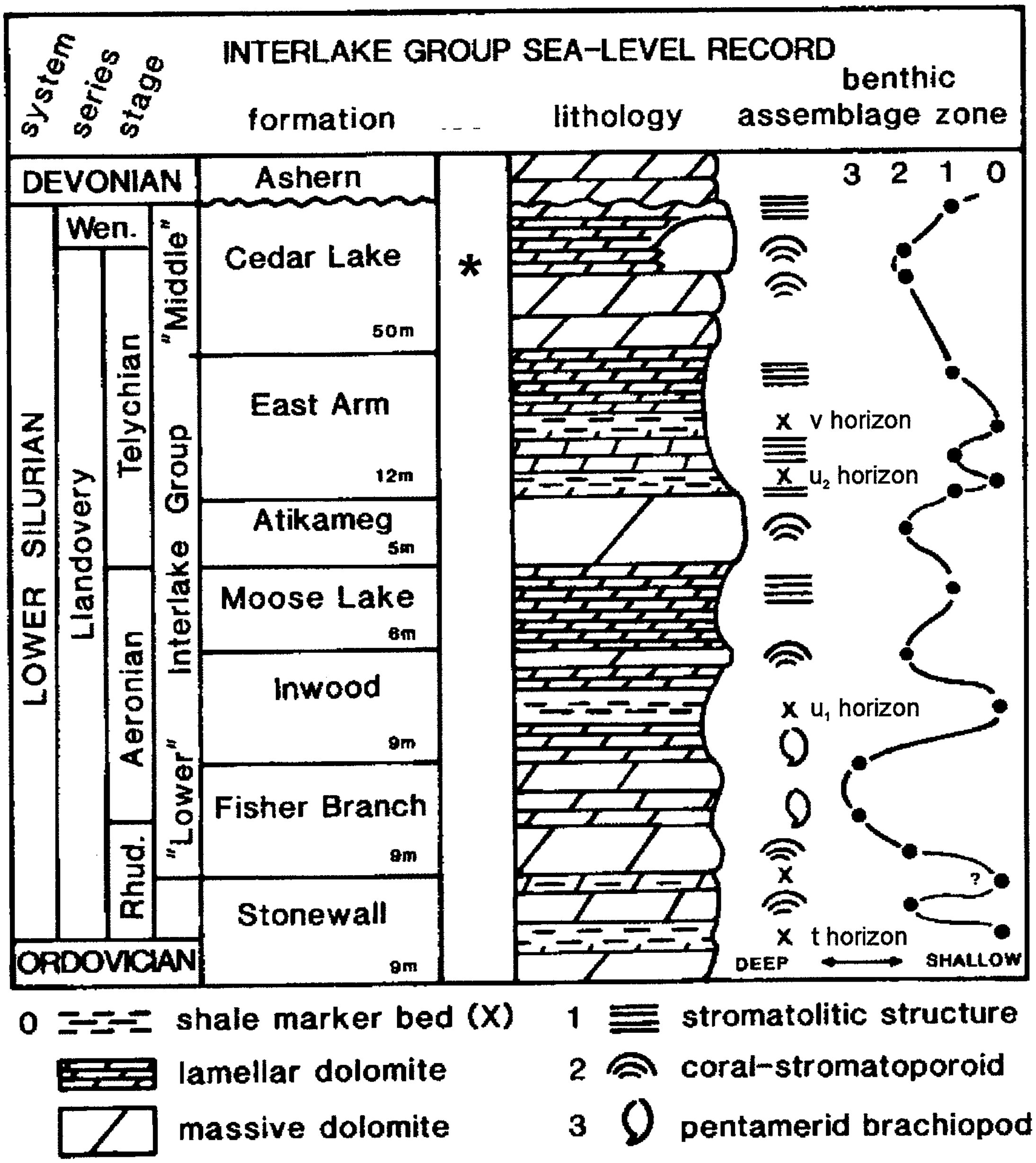


Figure 1.3: Stratigraphic section and sea-level curve for the Silurian Interlake Group of Manitoba (modified from Johnson and Lescinsky 1986, Figure 6). Rhud. = Rhuddanian; Wen. = Wenlock; * = position of Lundar Quarry locality.

mid-Early Silurian. Although structures within the Chemahawin Member have previously been identified as biohermal and biostromal, there is a lack of detailed documentation or analyses of the facies and faunal distributions within the unit. Proper identification of ancient reefs should include detailed examination and comparisons of the fauna that comprises the reef in order to understand the paleoecology of the buildup. Examination of the relationships between fauna may also provide evidence for ecological succession within the unit. Identification of distinct suites of fauna at different positions within the buildup may also aid in the recognition of paleoecological succession within the structure. As well, quantitative measurements of the relative abundances of taxa and their growth forms, and directional orientations, may provide insight into the paleoenvironmental conditions which prevailed prior to burial. Additionally, spatial trends in faunal distributions within the quarry may provide evidence for differential microenvironmental positions within the reef structure. Consideration of facies distributions within this unit may aid in the reconstruction of the depositional environments present at this location. Examination of subsurface drill cores may also assist in understanding the lateral extent of features observed within the Lundar Quarry, and aid in the correlation of facies within the Interlake area of Manitoba. Statistical methods are employed in order to compare the relative abundances of taxa and growth forms among different sites within the quarry, and at successive vertical intervals, in order to recognize paleoecological trends.

1.2 Previous Work

Tyrrell (1892) was the first geoscientist to generate an in-depth study of the physical geography and geology of southern Manitoba and Saskatchewan. In his study, Tyrrell noted "…eight to ten feet of horizontally bedded dolomite outcrops…" near the Hudson's Bay Co. trading post of Chemahawin on the Saskatchewan River, just west of Cedar Lake in central western Manitoba (N.B. this exposure has since been flooded by the development of the Grand Rapids Hydroelectric Dam on the Saskatchewan River). After closer examination, Tyrrell recognized the presence of several genera of tabulate corals, as well as one genus each of brachiopods, cephalopods, and ostracodes. The fossils collected by Tyrrell were further studied by Whiteaves (1906), who described many new species in his detailed paleontologic study of Paleozoic fossils, including many of those found within the Lundar Quarry. Baillie (1951) was the first geoscientist to name the Interlake Group of Manitoba, in which he included the Stonewall Formation as the lowest unit of this group. Stearn (1956) produced the most comprehensive and detailed stratigraphic and paleontologic study to date of the Interlake Group and Stonewall Formation, which he separated from the group. In his study, Stearn subdivided the Interlake Group into formations, including the Cedar Lake Formation and the members found within it; these terms are still used at present. As well, he presented detailed descriptions for each member, and systematic paleontology of the fauna of each unit. Stearn was the first to recognize both biohermal and biostromal components within the Cedar Lake Formation based on quarry and outcrop exposures in the Interlake area of Manitoba.

Detailed studies of the Paleozoic rocks of the Williston Basin by Porter and Fuller (1959) and Andrichuk (1959) include important subsurface data. Porter and Fuller (1959) also recognized the presence of an argillaceous marker interval dividing the Stonewall Formation, which was later identified as two successive horizons by Kendall (1976). Brindle (1960) was the first to hypothesize that the most likely position of the

Ordovician-Silurian boundary is at the t marker bed of Porter and Fuller (1959). Recent conodont biostratigraphy, however, more accurately placed the Ordovician-Silurian boundary to coincide with the upper t marker horizon (Norford et al. 1998). King (1964) recognized another argillaceous horizon within the Interlake Group, the u_2 marker bed, at the base of the East Arm Formation. Roehl (1967) compared the cyclic occurrence of carbonates within the Williston Basin to recent Bahamian deposits to generate a depositional facies model. Cowan (1971) furthered the work of Stearn (1956) by providing additional descriptions of the subsurface geology of the Interlake area. The work by Johnson and Lescinsky (1986) was pivotal to the discussion of the depositional dynamics of the Interlake Group. Their hypotheses regarding the predicted sea level fluctuations that produced the cyclic carbonates within the Williston Basin are still generally accepted today.

Chapter 2: Reef Definition

As both bioherms and biostromes have been previously identified within the Chemahawin Member, it is important to consider these terms for proper classification of the reef structure present within the Lundar Quarry. The term 'reef' is one of the most ambiguous words in geologic literature, and there is no general consensus for a reliable and concise definition. Modern analogues of ancient reef systems are not always of use, as we cannot assume that conditions affecting modern reefs are necessarily the same as those that affected a completely different community of organisms many millions of years ago. A proper definition of 'reef' should include both ecological and sedimentological concepts, as well as some reference to structure. Previous reef workers have developed criteria common to a broad range of reef structures based on similar attributes (e.g., Cumings 1932; Heckel 1974; Kershaw 1994; Riding 2002). Some criteria, however, include physical or inherent attributes which may or may not be applicable to all structures, or are vague in definition, such as a wave-resistant network (e.g., Lowenstam 1950), presence of a rigid framework (e.g., Rosen 1990) and open space within the structure (e.g., Wood 1999), presence of macro-organisms (e.g., Rosen 1990), capability of influencing local environmental conditions as a result of topographic relief (e.g., Braithwaite 1973), and a binding component (e.g., Riding 2002).

It may be more useful to develop a new definition for reefs based on a selection of previously proposed criteria that are applicable to a broader range of reef structures. In general terms, a fossilized reef should be defined as an accumulation of predominantly organic components that possesses some element of relief, and is distinctly different from the surrounding rock. Such a structure would have inherently influenced the surrounding environment to some degree, and possessed enough rigidity to withstand the hydrodynamic conditions of its environment for prolonged periods of time. Rapid cementation or encrustation by secondary organisms can provide a reef structure with additional support, and so is often considered as crucial to reef development (Riding 2002). However, cementation or encrustation is unnecessary to provide support; if reefs can be composed of adjacent organisms not in contact, or of soft-bodied organisms that lack a framework, then binding by sedimentary or biologic means should not be included as essential reef criteria (Riegl and Piller 1999; Riding 2002). Additionally, densely packed, randomly oriented fossils may suggest the development of some degree of structural rigidity due to the juxtaposition of fossils, regardless of cementation (Kershaw 1998). A reef may contain reef-derived sediment or debris within the structure, as well as external sediment incorporated into the structure by binding, baffling, or settling through the structure, which can also provide support. A lack of binding agents, however, likely hinders vertical development above the surrounding seafloor. Once a deposit is matched with these criteria, it is important to consider the reef as either biohermal or biostromal in nature.

The terms 'bioherm' and 'biostrome' were formally defined by Cumings (1932), though the criteria that characterize each structure have since been modified from the original proposed definitions. Bioherms have classically been described as mound-like or lens-like organic masses, with different sediments flanking on and draping over the structure, thus implying relief (Figure 2.1; Kershaw 1994; Riding 2002). Bioherms are typically not conformable with the beds above and/or below, and often exhibit inclined flank beds that commonly contain reef rubble (Figure 2.1; Kershaw 1994). Conversely, biostromes are considered to be biogenically constructed, often tabular or lenticular

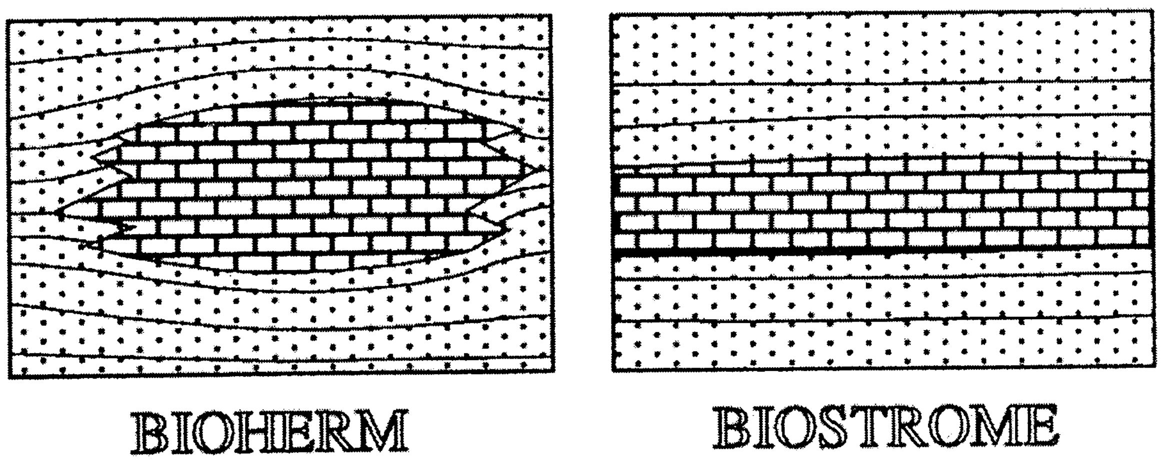


Figure 2.1: Schematic illustrations depicting outline shapes of bioherms and biostromes in vertical section, and the relationship of each structure with the surrounding sediment (Kershaw 1994, Figure 1).

bodies of similar composition that are occasionally bedded, and do not show any distinct inclined sediments draping over a bulbous body (Figure 2.1; Kershaw 1994). These two terms are obviously end-members on a continuous spectrum of buildup structures. In order to understand the scale of vertical extent implied by the two terms, Kershaw (1994) suggested size categories for biostrome thickness: very thin, for biostromes up to 0.1 m; thin, 0.1-0.5 m; medium, 0.5-2.0 m; thick, 2.0-5.0 m; and very thick, for biostromes greater than 5.0 m. The term bioherm has been used interchangeably with the word reef in the literature, thus implying demotion of biostromes to non-reefal structures (Kershaw 1994). For this study, however, the term reef is used in a broad sense to refer to any form of organic buildup, regardless of vertical extent. More specific terminology will be applied where appropriate when discussing the true form of the structures present within the Chemahawin Member.

Chapter 3: Geologic Setting

3.1 Conditions during the Silurian Period

During the early Paleozoic, Laurentia was the ancestral continent of North America, and Manitoba was situated within the tropical equatorial belt near the paleoequator (Figure 3.1). The Silurian was a period of climatic transition from the short-lived icehouse conditions of the latest Ordovician to the greenhouse world of the Devonian (Copper and Brunton 1991). The Early Silurian (Llandovery and Wenlock) represents an interval of reef recovery following a reduction in the number of reef-building genera during the Late Ordovician extinction event (Copper 2002). Reef development was limited until the late Llandovery and early Wenlock, when tropical belts were sufficiently warm to favour recovery of biotas and stimulate reef growth (Figure 3.1; Copper and Brunton 1991). Shallow carbonate shelves with open circulation and normal marine conditions were dominated by stromatoporoids, corals, and calcareous algae as typical reef-builders (Copper and Brunton 1991). Crinoids were common accessory contributors, growing in thickets both on and around reefs, resulting in abundant echinoderm debris associated with many Silurian buildups (Copper and Brunton 1991). Reef development peaked during this time interval, which corresponds to the maximum global rise in sea level estimated for the Silurian (Figure 3.2; Copper and Brunton 1991; Johnson et al. 1998). It has been suggested that this dramatic rise in sea level corresponds with an interglacial period on the paleocontinent of Gondwana, which was preceded by the most extensive glaciation recorded for the Silurian (Johnson 1996).

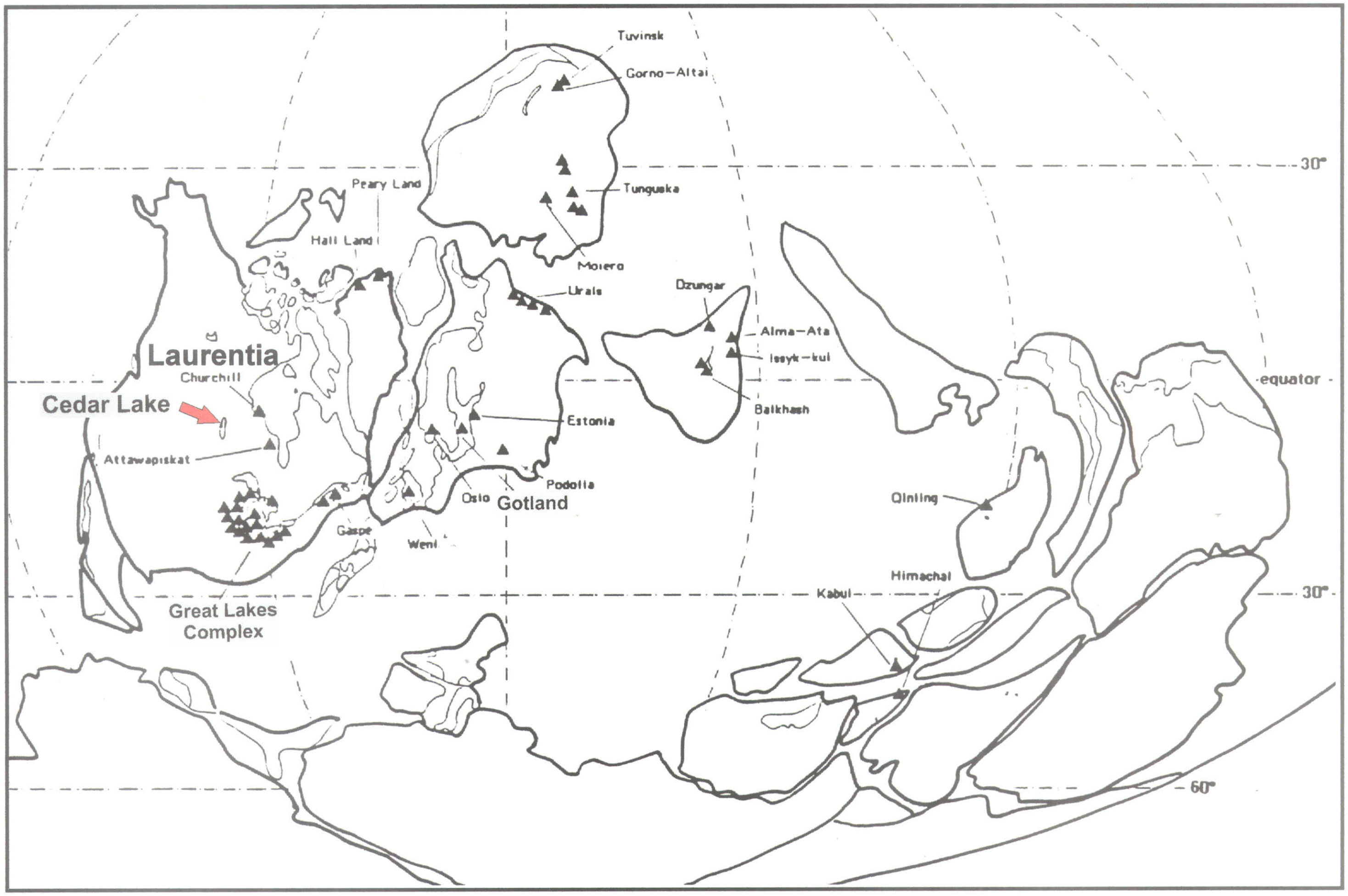


Figure 3.1: Latest Llandovery – Wenlock global reef distribution (modified from Copper and Brunton 1991, Figure 4). Note the concentration of reef buildups (triangles) within 30° of the paleoequator, including those in the Cedar Lake Formation (Manitoba; red arrow). Locations of the Great Lakes Reef Complex within the Michigan Basin and the biostromes of Gotland, Sweden are highlighted.

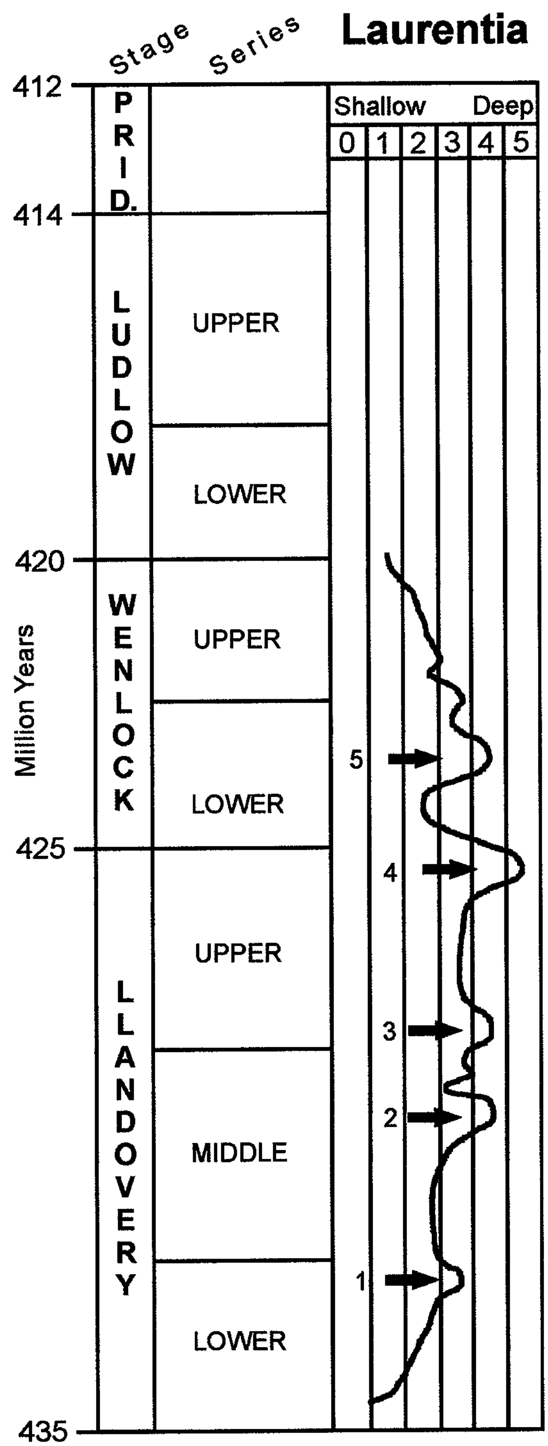


Figure 3.2: Silurian stages (Prid. = Pridoli) and Early Silurian sea-level curve for the paleocontinent of Laurentia, based on a representative section in Iowa (modified from Johnson 1996). Sea level is plotted relative to standard benthic assemblage zones 0 (shallow) to 5 (deep). Sea-level highstands (indicated by arrows) are numbered 1-5. Note that highstand 4 of the latest Llandovery is the deepest interval in the Silurian for Laurentia.

3.2 The Silurian of Southern Manitoba

In southern Manitoba, Silurian strata are intermittently exposed along a 500-km outcrop belt that extends between Lake Winnipeg and Lakes Manitoba and Winnipegosis, from north of the town of The Pas to south of the city of Winnipeg (Figure 3.3; Johnson and Lescinsky 1986). The underlying Ordovician is exposed to the east of the Silurian outcrop belt, and the overlying Devonian is exposed to the west (see Figure 1.2). The Paleozoic outcrop belt of Manitoba lies along the northeastern margin of the Williston Basin, where strata gently dip towards the southwest at 2.8 m per kilometre, or 0.16 degrees (Bezys and McCabe 1996). The Williston Basin is one of the largest North American cratonic basins, and discontinuously accumulated nearly 5000 m of marine sedimentary strata during the Cambrian to Cretaceous time interval (see Figure 1.1; Johnson and Lescinsky 1986). The Williston Basin was tectonically active through the Paleozoic, and this subsidence is considered to be the primary control on sedimentary deposition in southern Manitoba (McCabe 1971). It is interpreted that throughout Interlake time, a shallow marine to supratidal setting existed across the Williston Basin, which allowed deposition to balance basin subsidence (Cowan 1971).

3.3 The Interlake Group of Manitoba

Most Silurian strata of southern Manitoba are within the Interlake Group, proposed by Baillie (1951). The Interlake Group is known to have attained thicknesses of up to 400 m in the central part of the Williston Basin. The uppermost Silurian strata in Manitoba, however, only represent the lower portion of the Middle Interlake Group, as pre-Devonian erosion has removed the top of this unit (McCabe 1971). The Interlake Group in Manitoba is divided into six formations based on lithology. In stratigraphic

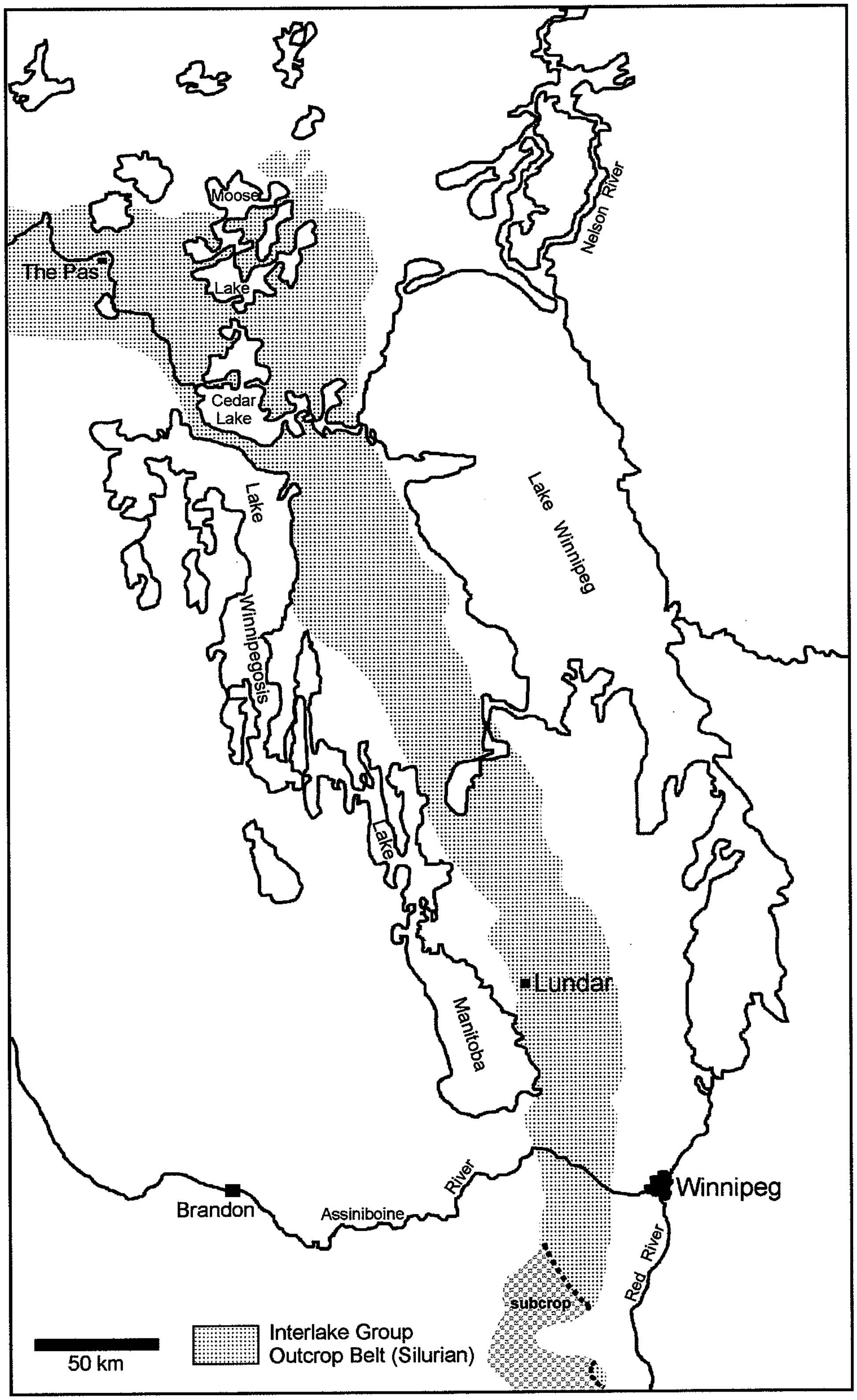


Figure 3.3: Interlake Group outcrop belt (Silurian) of Manitoba (modified from Bezys and McCabe 1996).

order from oldest to youngest, they are: the Fisher Branch, Inwood, Moose Lake, Atikameg, East Arm, and Cedar Lake formations (see Figure 1.3). The upper surface of the Interlake Group is marked by a major unconformity which separates these strata from the overlying Devonian Ashern Formation (Cowan 1971). Though the upper contact of the Stonewall Formation was originally considered to be an unconformity (Stearn 1956), the Interlake Group is now generally considered to conformably overlie the Stonewall Formation (e.g., Porter and Fuller 1959). In terms of a lower boundary for the Silurian, Baillie (1951) included the Stonewall Formation within the Interlake Group, and though it has since been removed, it will be discussed in this paper.

The Stonewall Formation is divided into two portions by an argillaceous marker interval named the t horizon by Porter and Fuller (1959; see Figure 1.3), and identified as two successive t horizons by Kendall (1976). The Stonewall Formation is a problematic unit in terms of pinpointing a definitive age. As previously mentioned, Baillie (1951) considered this unit to be Lower Silurian, whereas other workers have considered the entire unit to be Upper Ordovician (Stearn 1956; Porter and Fuller 1959). Brindle (1960), however, hypothesized that the most likely position of the Ordovician-Silurian boundary is at the t horizon of Porter and Fuller (1959). Recent conodont biostratigraphy has further pinpointed the boundary at the upper t marker (Norford et al. 1998). The lower Stonewall Formation consists of yellowish-grey, thinly bedded and slightly mottled, fossiliferous dolostone, whereas the upper portion is composed of light grey, laminar and slightly mottled dolostone with sparse fossils (Cowan 1971; Johnson and Lescinsky 1986). The lower Stonewall Formation likely represents a Late Ordovician regression episode, with the t marker beds indicating a period of subaerial exposure (Johnson and

Lescinsky 1986). This was likely followed by a short transgression-regression event, as represented by the upper Stonewall beds (Johnson and Lescinsky 1986).

The Fisher Branch Formation is composed of yellowish-grey, thickly bedded, medium-grained dolostone containing scattered favositid corals and brachiopods, as well as a brachiopod shell bed near the top of the unit (Stearn 1956; Johnson and Lescinsky 1986). The brachiopod shell bed is succeeded by a more diverse community of brachiopods, cephalopods and gastropods (Johnson and Lescinsky 1986). This unit is thought to represent slightly deeper-water conditions, with a sea-level peak associated with the introduction of molluscs (Johnson and Lescinsky 1986).

The Inwood Formation is divided into two portions by an oxidized argillaceous marker bed, the u_1 horizon (see Figure 1.3; Porter and Fuller 1959). The lower portion consists of large stromatolitic domes and brecciated fossiliferous dolostone, with interbedded fine-grained dolostone (Stearn 1956). Above the u_1 horizon are pale coloured, banded dolostone with interbedded oolitic and fragmental dolostone (Porter and Fuller 1959). The upper portion of this unit consists of a yellowish-grey dolostone dominated by bioclastic debris of a diverse suite of organisms, including corals, molluscs, crinoidal debris, and stromatolitic mounds (Stearn 1956; Johnson and Lescinsky 1986). The Inwood Formation represents another regressive episode with a period of subaerial exposure, followed by a transgression (Johnson and Lescinsky 1986).

The Moose Lake Formation is composed primarily of stromatolitic beds overlying thinly bedded, very fine-grained dolostone (Stearn 1956). This unit is very susceptible to weathering, and is thus only preserved where protected by the overlying Atikameg Formation. The presence of delicate stromatolitic laminations suggests shallow, quiet water conditions during a regressive episode (Johnson and Lescinsky 1986).

The Atikameg Formation consists of massively bedded, coarsely crystalline yellowish-orange dolostone, thought to represent a biostrome (Stearn 1956). Though scarce, the most common fossils are brachiopods, colonial corals, and stromatoporoids (Stearn 1956; Johnson and Lescinsky 1986). Vuggy porosity is prevalent in this unit, and is thought to be the result of frame-building within a thin biostrome (Stearn 1956). A transgression is interpreted for this formation in order to provide accommodation space for the biostrome (Johnson and Lescinsky 1986).

The East Arm Formation consists primarily of fine-grained, stromatolitic dolostone interbedded with brecciated laminar dolostone (Stearn 1956). Additionally, this unit contains beds of arenaceous, oolitic, and fossiliferous dolostone (Stearn 1956). A red clay marker bed, the u_2 horizon, is found at the base of this unit (see Figure 1.3). Additionally, a second marker bed, the v horizon, interrupts the middle of this unit (see Figure 1.3). It is thought that the East Arm Formation likely represents an interval of somewhat steady-state, shallow-water conditions, punctuated by at least two episodes of subaerial exposure (Johnson and Lescinsky 1986). The uppermost preserved unit of the Interlake Group of Manitoba, the Cedar Lake Formation, is described in the following section.

3.4 Cedar Lake Formation

The Cedar Lake Formation is the youngest Silurian unit found in southern Manitoba. Though there is little chronological evidence from within this unit, it is estimated that the age is late Llandovery to early Wenlock (Johnson and Lescinsky 1986). The Cedar Lake Formation is an estimated 50 m thick in Manitoba, though the entire unit is not exposed at any one outcrop (Johnson and Lescinsky 1986). This formation was divided into three intervals by Stearn (1956) based on different types of dolostone. The lower, Cross Lake Member was characterized as a stromatoporoid-coral biostromal unit, based on exposures in the vicinity of Cedar Lake (see Figure 3.3). The upper, Chemahawin Member consists of reefal and associated facies, as outcrops previously exposed around Cedar Lake prior to flooding are reported to have revealed dense accumulations of stromatoporoid and coral fossils in growth position. As well, exposures near the northern edge of Lake Manitoba are reported to display laminated dolostone draping over a coral bioherm (Johnson and Lescinsky 1986). The lateral extent of these biohermal accumulations, however, is unknown. Stearn (1956, p. 37) further noted that: "Between the two members, replacing them laterally, and to a certain extent interbedded with them, is the middle part of the Cedar Lake dolomite." In the Interlake area, however, the entire Cedar Lake Formation below the Chemahawin Member consists of intraclastic dolostone interbedded with lithographic dolostone (Cowan 1971). Thus, the lower Cedar Lake Formation cannot be subdivided into a "middle part" and Cross Lake Member. The top of the Chemahawin Member is terminated by the major unconformity surface underlying the red, argillaceous dolostone comprising the Devonian Ashern Formation (Baillie 1951).

The Chemahawin Member rarely displays bedding, but instead shows evidence of possible biohermal growth of a community dominated by stromatoporoids and tabulate corals in a sublithographic dolostone matrix (Cowan 1971). The southernmost exposure of the Chemahawin Member is at the inactive quarry near Lundar, Manitoba, which is the subject of the present study (see Figure 1.2). Within the Lundar Quarry, about two to four metres of exposure can be viewed, depending on water levels. Dolomitization has severely altered the unit, though the nature of this biologically dominated deposit can still be viewed easily in the quarry. The Ashern Formation is not seen at Lundar, however, as erosion has removed this unit. Within the Lundar Quarry, patchy occurrences of iron-stained, argillaceous deposits punctuate the exposure, grading down into the yellow dolostone of the Chemahawin Member (Figure 3.4). This feature resembles paleokarst, a diagenetic product of subaerial exposure to meteoric water, often via fractures, which causes dissolution of carbonate material (James and Choquette 1990). Previous studies referred to patches or intervals of red argillaceous material scattered within the unit, but little else is mentioned about this feature, and it has not previously been referred to as a paleokarst feature.

The Cedar Lake Formation is thought to represent a transgressive episode within the Williston Basin at this time, as evidenced by the abundance of fossils of reef-building organisms within this member (Johnson and Lescinsky 1986). The upper, unconformable surface of this unit likely represents a subsequent regressive episode (Johnson and Lescinsky 1986). Overall, the Interlake Group is interpreted as having been deposited in a shallow marine to supratidal setting (McCabe 1971).

Figure 3.4: In places, red, iron-stained, argillaceous deposits punctuate the dolostone exposed in walls within the Lundar Quarry. This feature is likely paleokarst, a diagenetic by-product of subaerial exposure to meteoric water.

Chapter 4: Introduction to the Fauna of the Chemahawin Member

The fauna of the Chemahawin Member consists of a relatively low-diversity assemblage of epifaunal, suspension-feeding organisms which are commonly associated with reef-building in the Paleozoic. Stromatoporoids are dominant at each site within the Lundar Quarry, though tabulate corals, as well as solitary and colonial rugose corals, are found within this unit in abundance. Scattered echinoderm fragments and other bioclasts are found amongst the larger organisms.

The fossils of the Chemahawin Member appear well-preserved in hand specimens, but petrographic examination reveals that large, rhombic dolomite crystals have replaced the original mineralogy. Due to the coarse, crystalline nature of the dolomite, skeletal microstructures of faunal elements are completely destroyed, making taxonomic identification difficult.

As it is impossible to determine the original mineralogy of fossils found within the Chemahawin Member due to the extent of dolomitization, a general discussion is presented. Based on comparisons with modern scleractinian corals, Sorauf (1993) suggested that both Paleozoic tabulate and rugose corals likely secreted calcite with an elevated magnesium content. Stromatoporoid mineralogy is also somewhat problematic, as their level of preservation is superior to organisms that originally secreted aragonite, but is not as well preserved as those that secreted calcite (Stearn 1989). It is generally thought that stromatoporoids secreted aragonite, though all microstructures were obscured by diagenesis (Stearn 1989). Echinoderm columnals are thought to be high-Mg calcite, ranging between 4% and 16% magnesium content within the calcite structure (Sprinkle and Kier 1987). All echinoderm debris within the Chemahawin Member has been mimetically replaced by dolomite rhombs, which maintain the optical orientation of the original calcite.

The following sections are intended as a general introduction to the defining morphological characteristics, internal structures, and paleoecological aspects of the major groups of fauna found within the Chemahawin Member. The stromatoporoids and corals are identified taxonomically and illustrated in Chapter 6.

4.1 Stromatoporoids

Stromatoporoids are sessile, epibenthic marine calcified organisms which are recurrent fossils in early to middle Paleozoic deposits, including reefs (Kershaw and Brunton 1999). These problematic organisms have been placed within the phylum Porifera, as stromatoporoids are generally believed to be a class of calcified sponges (class Stromatoporoidea; Kershaw and Brunton 1999). The class Stromatoporoidea comprises extinct invertebrate organisms that show poriferan affinities; they form calcareous basal skeletons with a distinct internal growth network of repetitive horizontal (laminae) and vertical (pillar) support components (Kershaw 1990; Stearn et al. 1999). As Paleozoic stromatoporoids are aspiculate, classification must be based on other aspects of internal morphology (Stearn et al. 1999). The stromatoporoid skeleton, or coenosteum, appears to have been initiated from a single larva and spread out laterally very quickly across the substrate, or grew rapidly upward into the water column (Stearn 1983). Although it is widely assumed that larval initiation occurred on a hard substrate, in many cases no hard objects have been found beneath the initial growth position, which suggests that stromatoporoids may have grown directly on soft substrates (Kershaw 1998).

It is believed that the growth form of the coenosteum may have been dictated by a combination of genetic and environmental factors (Kershaw 1981). Stromatoporoids may have responded to environmental fluctuations such as sedimentation rates, hydraulic energy, and water chemistry by adjusting the growth form of the skeleton best suited for the prevailing conditions. Evidence for these changes, however, can often be obscured by taphonomic processes and diagenetic alteration, both during life and shortly after death of the organism. In general, the shape of stromatoporoid coenostea can be highly variable. As stromatoporoids are extinct, their growth forms have been compared with those of modern reef-building corals and sclerosponges, which also produce massive, calcareous skeletons. Many workers have attempted classification schemes of stromatoporoid growth form (e.g. Abbott 1973; Kershaw 1998), though generally scientists will modify these systems in order to fit their data.

It is important to note some problems associated with growth-form recognition, and the paleoecological factors interpreted from the morphology. First, as stromatoporoids generally inhabited shallow, dynamic environments, the effects of environmental control may mask any inherent genetic control on growth form, resulting in complex growth forms that may make classification schemes difficult to apply (Stearn 1982). As well, skeletons seen in outcrop may be variably exposed, which may result in incorrect shape identification based solely on two-dimensional exposure (Figure 4.1; Kershaw 1998). Additionally, many species had the ability to adopt distinctly different growth forms at different stages in life, so taxonomic identification based on morphology may be imprecise (Kershaw 1990). And finally, care must be taken when interpreting the morphology of a stromatoporoid skeleton, as the shape of the coenosteum may be dictated by the underlying sediment conditions. A stromatoporoid may adopt a more laminar

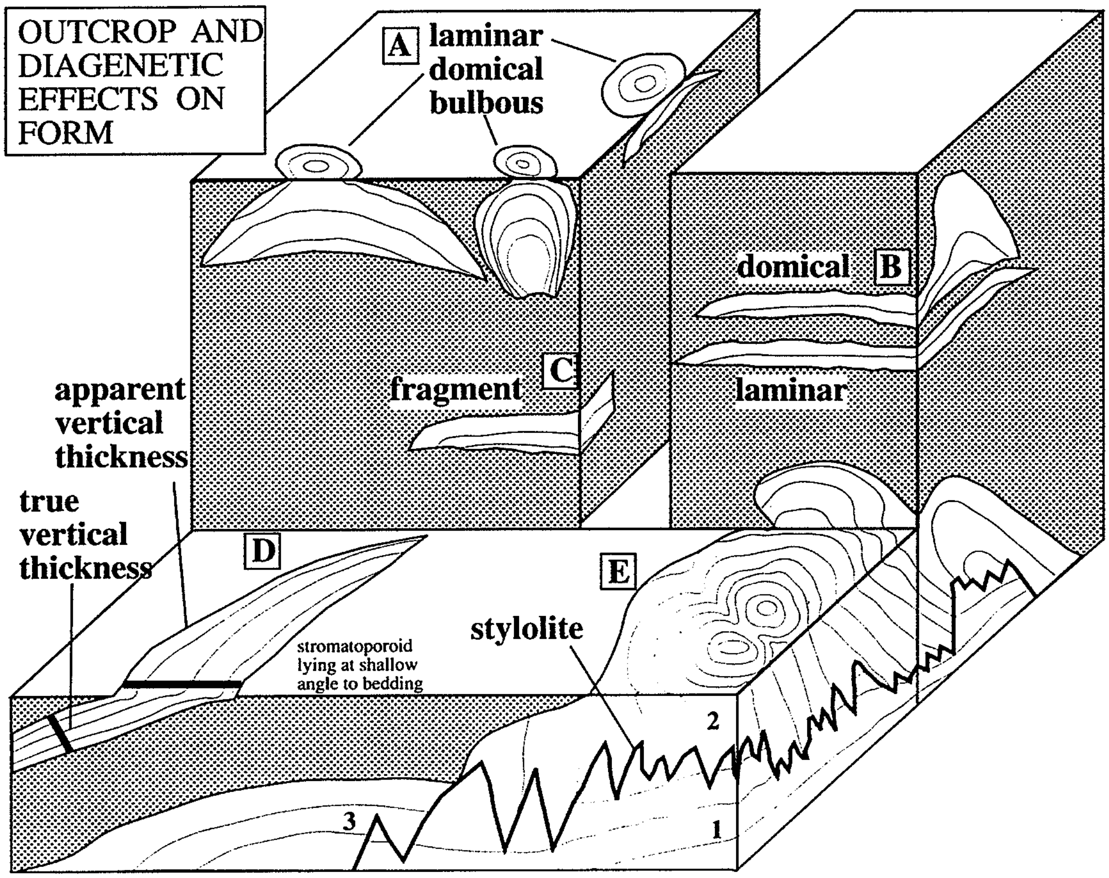


Figure 4.1: Schematic diagram depicting the difficulties in recognizing fossil form in two-dimensional outcrop (Kershaw 1998, Figure 4). A, B) Different growth forms may appear similar on an exposure surface. C) Fragments may not be recognizable in certain exposures. D) The true thickness of fossils may be skewed depending on the angle of exposure. E) Growth form may be difficult to identify if pressure solution compresses a fossil.

shape in order to stabilize soft substrate, or it may encrust around a small raised surface on a hard substrate, which may be reflected in the skeletal shape (Baarli et al. 1992). Similar problems of distinguishing growth form may also occur for colonies of colonial corals (see Scrutton 1998).

4.2 Corals

Both tabulate and rugose corals are present within the Chemahawin Member. These two orders of class Anthozoa, subclass Zoantharia, were the dominant coral groups in the Paleozoic (Scrutton 1997). These corals are common in Paleozoic outcrops in association with shallow-water reefs, but often were not the dominant reef-builders (Hill 1981). Colonial forms of these sessile, epibenthic organisms consisted of a group of soft-bodied polyps that each excreted a calcium carbonate exoskeleton, or corallite, to form a collection of corallites, termed the corallum (Hill 1981). Within corallites, radial plates (septa) or rows of septal spines, are inserted along the inside of the corallite wall. Transverse plates, or tabulae, formed perpendicular to growth and served as basal supports for individual polyps. Many Paleozoic corals show evidence of growth banding interpreted to represent annual cyclicity of growth, often observed as intervals of densely spaced tabulae and thicker corallite walls alternating with less-densely spaced tabulae with thinner walls (Scrutton 1998). The majority of Paleozoic tabulate and rugose colonial corals are thought to have initiated on soft substrates (Scrutton 1998). Like stromatoporoids, the growth forms of colonial corals are also thought to reflect a combination of genetic and environmental influences (e.g. Young and Scrutton 1991).

Solitary rugose corals consisted of a single polyp and corallite with prominent septa (Hill 1981). Septal grooves are typically visible on the outer surface of the wall, and rugae, or 'growth wrinkles' commonly occur perpendicular to septa and the growth axis. Solitary rugose corals also show evidence of growth banding similar to colonial corals. In most cases, the basic growth form of solitary rugose corals is genetically determined, though minor morphologic adaptations may occur in response to substrate conditions (Scrutton 1998). Most solitary corals lived unattached on soft sediments, or partially embedded within soupy sediments.

The following descriptions of the external morphology and internal structures of corals are derived from Hill (1981) and Scrutton (1997), unless otherwise noted.

4.2.1 Tabulata

Tabulate corals exhibit approximately horizontal, complete tabulae as the dominant internal structure, with septa playing a subdued role. Septa are generally short or absent; minor septa do not occur in tabulate corals. The most common septal elements are septal spines, which extend inward from the inner wall of corallites.

Three different groups of tabulate coral are found within the Chemahawin Member: representatives of the favositid genus *Favosites*, which are the dominant corals within the quarry; members of the heliolitid coral superfamily Proporicae; and two species of the chain coral *Halysites*. The primary feature used to distinguish the favositid coral *Favosites* is the presence of mural pores located within corallite walls, which provided a connection with neighboring corallites. In some forms, longitudinal rows of multiple pores may be visible between tabulae. The skeleton, or corallum, is cerioid, meaning that corallites are closely packed and each shares walls with several neighbouring corallites. Within corallites, septa are often present but are uniformly short and variable in number. Corallites are generally polygonal, with 'mature' corallites typically having six sides (Young and Elias 1993).

In contrast, members of the superfamily Proporicae contain common skeletal tissue which serves to separate the corallites. Corallite spacing varies among genera, depending on the amount of coenenchymal tissue present. Coenenchymal tissue generally consists of dissepiments, or curved cyst-like plates, which appear vesicular in transverse section. Corallites are typically rounded to slightly crenulate, or possess wavy edges, in cross section, and display complete, closely spaced tabulae in longitudinal section. Members of this type of coral are rare within the Lundar Quarry.

Lastly, members of the chain coral *Halysites* possess a cateniform growth habit, in which corallites are united in a chain, typically only one corallite thick, commonly forming a network. Both species of chain coral found within the Chemahawin Member consist of thick-walled corallites that are separated by smaller tubules which probably did not host polyps. These tubules are generally subrounded in cross section, and display closely spaced, coenenchymal cyst-like plates in longitudinal section. Corallites are generally elliptical to rounded in cross section, and reveal complete tabulae in longitudinal section. Both species of chain coral are limited in abundance and are represented by small fragments.

4.2.2 Rugosa

This extinct order of coral possesses an exoskeleton that is distinct from those of tabulate corals. Rugose corals display radial septal plates as the dominant structural feature within corallites. The septa are serially inserted in four positions, producing bilateral symmetry. Characteristic of rugose corals are minor septa, which are inserted between major septa. Additionally, coralla of colonial rugose corals lack interconnecting pores or openings between corallites (Scrutton 1997). Both colonial and solitary forms of Rugosa are present within the Chemahawin Member.

Colonial rugose corals found within the Lundar Quarry possess fasciculate, phaceloid coralla, meaning that corallites are parallel with each other, but are not in contact. Corallites are generally rounded to rounded-polygonal, and show no evidence of connecting processes. Tabulae are well developed and closely spaced within corallites of the Lundar specimens. The colonial rugose corals of this unit most commonly grew within the skeletal tissue of stromatoporoids, likely using the host as a support structure for the delicate corallites (Stearn 1956). Thus, size and shape of the growth form are not discussed for this type of coral.

The solitary forms of Rugosa found within the Lundar quarry possess one of three growth forms, as defined by Hill (1981): ceratoid, indicating a horn-shaped, slender, conical corallum; cylindrical, where the corallum is nearly straight and of uniform diameter, with the exception of the tapered apical section; and trochoid, where the corallum regularly expands from the apical region at an angle of about 40 degrees. Most specimens, however, are only preserved as fragments of coralla. The length of septa varies among genera of the Chemahawin Member, from very short to fully extending and meeting in the centre of the corallum. In longitudinal section, some forms reveal tabulae as the dominant structure within the axial space, whereas other forms exhibit dissepiments lining the corallite walls.

4.3 Other Macrofaunal Components of the Chemahawin Member

Within the Lundar Quarry, various other biologic components were found within the Chemahawin Member. Abundant echinoderm columnals, most likely representing crinoids, can be found within the matrix of the fossiliferous facies of the Chemahawin Member. In general, columnals are found completely disarticulated and broken, with only a few examples of articulated segments. Additionally, molds of a few brachiopods and gastropods were recovered from various positions within the Lundar Quarry.

Chapter 5: Methodology

This chapter includes all methodology and scientific techniques utilized for this study. Both field and laboratory analyses were conducted on the rocks and fossils of the Lundar Quarry, including instrumental analysis of select samples. Data were analyzed using statistical methods in order to recognize spatial, temporal and overall community trends.

5.1 Field Methods

Field work for this study was conducted at the Lundar Quarry, approximately two kilometers east of the town of Lundar, Manitoba on provincial road (PR) #419 (see Figure 1.2). This municipal quarry is no longer in operation, and has since been flooded by groundwater. Access permission was obtained from the municipality of Coldwell. The quarry is approximately 500 m in diameter. A smaller quarry on the south side of PR#419 is currently being used as a disposal site (Figure 5.1). The majority of field excursions occurred during the summer months of 2003 and 2004, when an inflatable boat was used to gain access to most of the quarry walls. In addition, two trips were organized during the winter when water within the quarry was frozen, allowing for viewing of areas that are inaccessible in the summer due to shallow-water and rough-bottom conditions.

The walls within the main quarry were examined for fossil content and general observations. Twelve exposure surfaces at various locations within the quarry that revealed *in situ* sections of at least 1 m vertical extent were initially selected for study (Figure 5.1). In a portion of the quarry interpreted to be important, two additional study sites of less than 1 m vertical exposure (sites R and V) were later added. Due to the

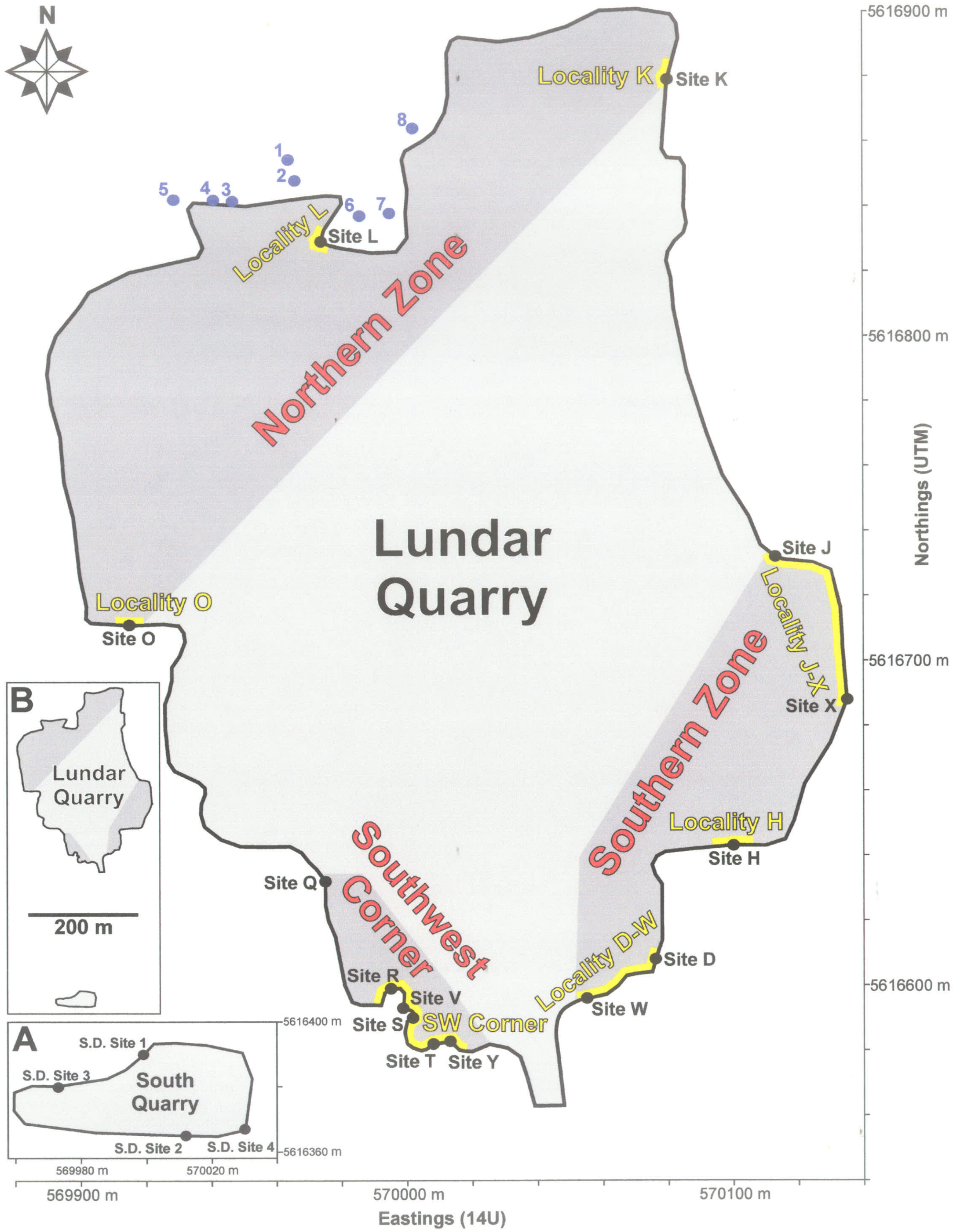


Figure 5.1: Map of the Lundar Quarry, plotted using Global Positioning System (GPS; NAD27) data. Solid circles represent study sites used for analysis. Yellow lines denote localities for which data from closely spaced sites were combined in order to achieve sufficient numbers for statistical analysis. Darker shaded areas represent zones of combined localities for which similar distributions of fauna were recognized. Blue circles (1-8) indicate areas used for paleocurrent analysis (see Chapter 12). Inset A) depicts quarry on the south side of PR#419, and the sites where hand samples were collected. Inset B) depicts relative positions of main Lundar Quarry and south quarry.

extent of dolomitization and weathering of the quarry walls, however, mapping of features in the quarry was not possible. Therefore, hand samples were obtained at regular 10-cm stratigraphic intervals measured up from water level within a 20-cm-wide section from each of the fourteen study sites (Figure 5.2). In some instances, samples could not be obtained within the 20-cm-wide section for every interval, so samples were collected from areas adjacent to the selected section. Also, at some intervals it was impossible to obtain a sample of adequate size due to the presence of massive, unfractured strata, or highly fractured strata that were not certain to be *in situ*. At sites where quarry walls extended below water level, additional samples were collected from just below water level. An orientation arrow was drawn on each sample in order to maintain an upward orientation relative to the quarry when in the laboratory. The water level was approximately 32 cm higher in 2004 than in 2003, so the heights of samples obtained during that year were standardized to the water level of 2003 in order to maintain conventions. A total of 158 stratigraphic samples were obtained from the fourteen selected sites within the quarry (Appendix A). As well, 169 additional samples were obtained during subsequent excursions from areas adjacent to previously collected samples in order to obtain a better perspective of the lateral continuity of features seen in hand sample. A total of 76 well-preserved fossil specimens were also collected both from random positions along the quarry exposure, and from rubble piles within the quarry.

Sampling of the south quarry was conducted during the winter months. Thick snow cover prevented accurate measurements of samples relative to water level. A total of 16 samples was obtained from four sites within the south quarry, and the stratigraphic position of each sample was measured relative to each successive sample at each site. Though vertical lithologic changes could be documented at individual sites, direct lateral

Figure 5.2: Example of sampling procedure used for this study on exposures of greater than 1 m vertical extent (length of measuring tape = 1 m). Where possible, hand samples (green circles) were collected at regular 10-cm intervals measured up from water level within a 20-cm-wide section. At stratigraphic levels where samples could not be collected from within the section, samples were taken at the same height from the closest position possible. Samples could not be collected for each level at every site. Additional samples were later obtained in order to gain perspective on the lateral extent of features seen in hand samples (blue squares).

comparisons between sites in the south quarry, and between the south and main quarries, could not be made.

A handheld Global Positioning System unit (GPS) was utilized to obtain accurate geographic positions of study sites within the main quarry and the south quarry (using map datum NAD27). As well, GPS data were obtained from around the quarry in order to properly delineate the quarry boundaries. GPS data were also collected from eight areas on the bedrock exposure surface along the northern edge of the quarry where paleocurrent analysis was conducted.

5.2 Hand Sample Analysis

Hand samples were brought to the laboratory, where they were cut parallel to the face of the rock, approximately three centimetres behind the face. Both cut surfaces were polished for hand sample analysis. Etching of a few hand samples was also attempted in order to better define fossil contacts and to accentuate detail, but this process yielded mixed results and was thus not widely utilized.

Hand sample analysis involved detailed descriptions of the sedimentologic and paleontologic character of each sample. From this information, facies analysis was conducted to determine the different facies within the quarry. A total of 138 thin sections was made to supplement hand sample analysis. A representative number of slides was made for each of the facies present within the quarry, as well as for interesting or otherwise unidentifiable features. Additionally, slides were made for each of the different types of fossils present within the quarry in order to examine macro- and microstructures for taxonomic placement.

In order to produce comparable data between samples for fossil analysis, a standardized area of 20 cm^2 was selected for detailed analysis in the centre of each polished hand sample. This was the largest area that could be used which would afford a large number of samples to be included in the study. A template was cut out of cardboard and placed over the polished faces of hand samples to ensure a standardized area of study. The dimensions of fossils that extended outside the study area, however, were measured to their full extent. Within the 20 cm^2 area of each sample, fossils were documented based on species, shape, and size (Appendix B). As well, faunal relationships were noted for each sample. Determination of growth form was based not only on the overall morphology exposed in hand sample, but also on the internal structures of each organism in order to present the most accurate interpretation. Size classes for stromatoporoids and corals were created in order to generate discrete data that could be compared among other samples from the same site, and among samples of other sites. It is important to note that the recognition of the true form and dimensions may be influenced by skeletal breakage and the attitude of exposure (see Figure 4.1). Thus, the shape of fossils recorded for this study may be imprecise, and size documentation is generally assumed to represent smaller dimensions than the true size of the fossil.

For stromatoporoids, specimens were divided into taxonomic types based on observed physical characteristics. Coenosteum shape was divided into three categories based on the observed growth forms present within the quarry (Table 5.1): tabular, in which specimens possess a width to height ratio of greater than 2:1 and laminae/latilaminae are approximately perpendicular to the growth direction; domical, in which specimens exhibit some degree of convexity upward with a relatively flat base, and laminae/latilaminae maintain approximately curved growth concentric with the point of

Table 5.1: Growth forms applied to stromatoporoid and tabulate coral skeletons of the Chemahawin Member, following terminology of Kershaw (1998) and Young and Elias (1995). Abbreviations are as follows:

w:h = width to height ratio   w/ = with
// = parallel   h = height

Growth Form	Stromatoporoids	Tabulate Corals
Tabular	w:h > 2:1, latilaminae // growth	w:h ≥ 3:1, corallite growth // to basal surface
Domical	convex, latilaminae concentric w/ point of initiation	w:h between 1:1 and 1:3, corallite growth concentric w/ central basal position
Irregular	shape could not be classified	shape could not be classified
Domico-Columnar	(not applicable)	central vertical axis w/ corallite growth curving outwards, widest point of corallum < ½ h

initiation; and irregular, in which the stromatoporoid shape could not be classified under current classification schemes (e.g. Abbott 1973; Kershaw 1998). Irregular forms may include specimens which are cut at an oblique angle, obscuring the true shape, or they may be encrusting forms which have adhered to an irregular surface. All shape classes may also include broken coenosteal fragments if the general shape or the orientation of latilaminae growth could be recognized.

Stromatoporoid size was measured as the maximum width of coenostea. For irregular forms in which orientation could not be established, the maximum exposed dimension was measured. Stromatoporoids were grouped into three size classes (Table 5.2): size 1, which included individuals with a maximum dimension of less than or equal to 15 mm wide; size 2, which included individuals with a maximum dimension between 16 mm and 50 mm wide; and size 3, for stromatoporoids greater than 50 mm wide. All stromatoporoids within this unit display smooth lateral margins.

Tabulate corals were assigned genus or species names based on observed physical characteristics which make each type distinct. Corallum shape was divided into four categories according to the classification system of Young and Elias (1995), based on the observed growth forms present within the quarry (see Table 5.1): tabular, in which specimens possess a width to height ratio of greater than or equal to 3:1 and corallite growth is perpendicular to the basal surface; domical, in which specimens have a width to height ratio of between 1:1 and 3:1 and corallite growth radiates from a central basal position; domico-columnar, in which the corallum has a central vertical axis from which corallite growth curves outward and the widest point of the corallum is less than half the height; and irregular, in which corallum shape could not be classified under current

Table 5.2: Size classes for major faunal groups within the Chemahawin Member. Measurement conventions are as follows:

Stromatoporoids - maximum width of coenosteum (or maximum dimension for specimens in which the orientation could not be established)
Tabulate corals - maximum width of corallum, perpendicular to axis of corallum growth
Solitary rugose corals - maximum diameter of corallum

Size Class	Stromatoporoids	Tabulate Corals	Solitary Rugose Corals
1	≤ 15 mm	≤ 10 mm	< 6 mm
2	16 – 50 mm	11 – 20 mm	6 – 10 mm
3	> 50 mm	> 20 mm	> 10 mm

classification schemes. All shape classes may include broken coralla if the growth form could be recognized.

For tabulate corals, the size of a corallum was measured as the maximum width, perpendicular to the axis of corallum growth, regardless of whether the corallum was intact or merely a fragment. Three size classes were created to accommodate the data (see Table 5.2): size 1, which included coralla less than or equal to 10 mm wide; size 2, including coralla between 11 mm and 20 mm wide; and size 3, for coralla greater than 20 mm wide.

Rugose corals were assigned to a particular species or genus based on the observed internal physical characteristics which make each type distinct. Colonial rugose corals were not assigned shape or size classifications, as both genera present within the quarry are commonly found within stromatoporoid coenostea, and thus their size and shape may be dependent on the growth form and size of the host stromatoporoid. The sizes of solitary rugose corals were classified according to three categories based on the corallum diameter (Table 5.2): size 1, including coralla less than 6 mm in diameter; size 2, including coralla of between 6 and 10 mm in diameter; and size 3, for coralla greater than 10 mm in diameter. Length and curvature were not suitable for measurements, as many coralla are found as broken fragments, or embedded in the face of the rock.

5.3 Supplementary Analyses

Drill core obtained from the Lundar Quarry was examined in order to compare the surface exposures to the subsurface geology (Appendix C). As well, a second core was examined from the nearby Mulvihill West Quarry in order to gain a better understanding of the lateral extent of facies within the Chemahawin Member (Appendix C; see Figure

1.2). Stratigraphic contacts of the Chemahawin Member were examined. Additionally, the amount of strata missing within the Lundar Quarry below the pre-Devonian unconformity was estimated by correlating equivalent facies in both cores. The core from Lundar was logged only down to a red, argillaceous rubble interval, which is presumed to represent the v-marker in the East Arm Formation (see Figure 1.3; Cowan 1971; Johnson and Lescinsky 1986).

Paleocurrent analysis was conducted on a glacially scoured horizontal bedrock surface at the north end of the Lundar Quarry. The directional orientations for the long axis of elongate fossils were measured with a compass to the nearest degree, and the GPS position was taken for each of eight exposed areas in order to map the results (Appendix D; see Figure 5.1).

Microfossil analysis allows for the recognition of microfossils within the Chemahawin Member, including facies which are devoid of macrofossils. Microfossil analysis was conducted by Ed Dobrzanski at the Manitoba Museum. Loose samples of dark red argillaceous karst material and all lithologies devoid of macrofossils were analyzed for the presence of conodonts or other indicative microfossils. Hand samples were digested with buffered 10% acetic acid, and the residue was filtered through screens ranging from 2 mm to 125 μm. Microfossil specimens and noteworthy grains were hand-picked under a microscope.

5.4 Statistical Analysis

Analyses of spatial and temporal fossil distributions, as well as faunal relationships, were conducted using Jandel SigmaStat software (Appendix E). A Chi-square (χ^2) test is typically used to compare the distributions of two or more groups with individuals falling into two or more different classes (see Mendenhall 1971). Thus, this test was selected in order to determine if the relative abundances of species or growth forms within major groups of fauna were related to location within the Lundar Quarry. Contingency tables were constructed, with the faunal variable at each site contrasted against the variable at each other site. In some cases, low values of observations within certain classes selected for comparison prevented maintaining a minimum average class frequency of five (see Reyment 1971). When the results indicated that faunal variables were significantly related, a series of Chi-square tests was performed contrasting each pair of localities separately in order to determine which localities were distinctly different.

Cluster analysis, using Unweighted Pair-Group Average (AMPGA) algorithm and Bray-Curtis similarity measure, was conducted using PAST software (Hammer et al. 2001). This multivariate statistical test arranges samples according to similarity, forming clusters of samples in a hierarchical dendrogram (Ludwig and Reynolds 1988). This test was performed on abundance data for all stromatoporoid and coral taxa at all localities in order to determine the presence of spatial patterns within the quarry (Appendix F).

Paleocurrent analysis was conducted using the mathematical functions of Microsoft Excel. A Chi-square test was generated to test for randomness of directional data. For this test, bi-directional data (measured to the nearest degree) were grouped into classes (e.g. 1° - 10°, 11° - 20°, etc.). The number of classes (k) was selected based on the total number of measured values (n) in order to maintain an average class frequency of at least five (Reyment 1971). Classes in which observed values were greater than or less than one standard deviation from the overall class average were considered to be anomalously high or low, respectively. Degrees of freedom (d.f.) equal the number of classes minus one, which accounts for the inherent linear restriction in which the sum of the values in all classes must equal the value *n* (Mendenhall 1971). Data sets were considered to exhibit a preferred orientation when the value for χ^2 was greater than the critical value based on $\chi^2_{0.05}$ and the number of degrees of freedom (see Mendenhall 1971, Appendix II, Table 5).

Chapter 6: Fossil Descriptions of the Chemahawin Member Fauna

Dolomite recrystallization has destroyed the internal microstructures of the fossils found within the Chemahawin Member. Thus, taxonomy was based on the internal macrostructures present. Most species found within the Lundar Quarry have been previously identified by Stearn (1956), so his descriptions were used as a guide. As well, Stearn (personal communication 2004) provided additional assistance for classifying stromatoporoids that were not previously recognized within the Lundar Quarry. As systematic taxonomy was not possible for these specimens, informal names are assigned to groups of fossils with similar internal features for which species or genus names could not be applied with confidence.

6.1 Stromatoporoids

Stromatoporoid Type CY

This is the most common type of stromatoporoid within the Chemahawin Member. The dominant internal features are laminae, which randomly inflect upward to produce short pillars that often do not extend up to the next lamina (Figure 6.1 A). The distinguishing features of this species are short, discontinuous pillars connecting continuous laminae, producing a cystose structure of gallery space (CY = cystose). Laminae appear wavy in cross section, thus enhancing a cystose appearance. Growth

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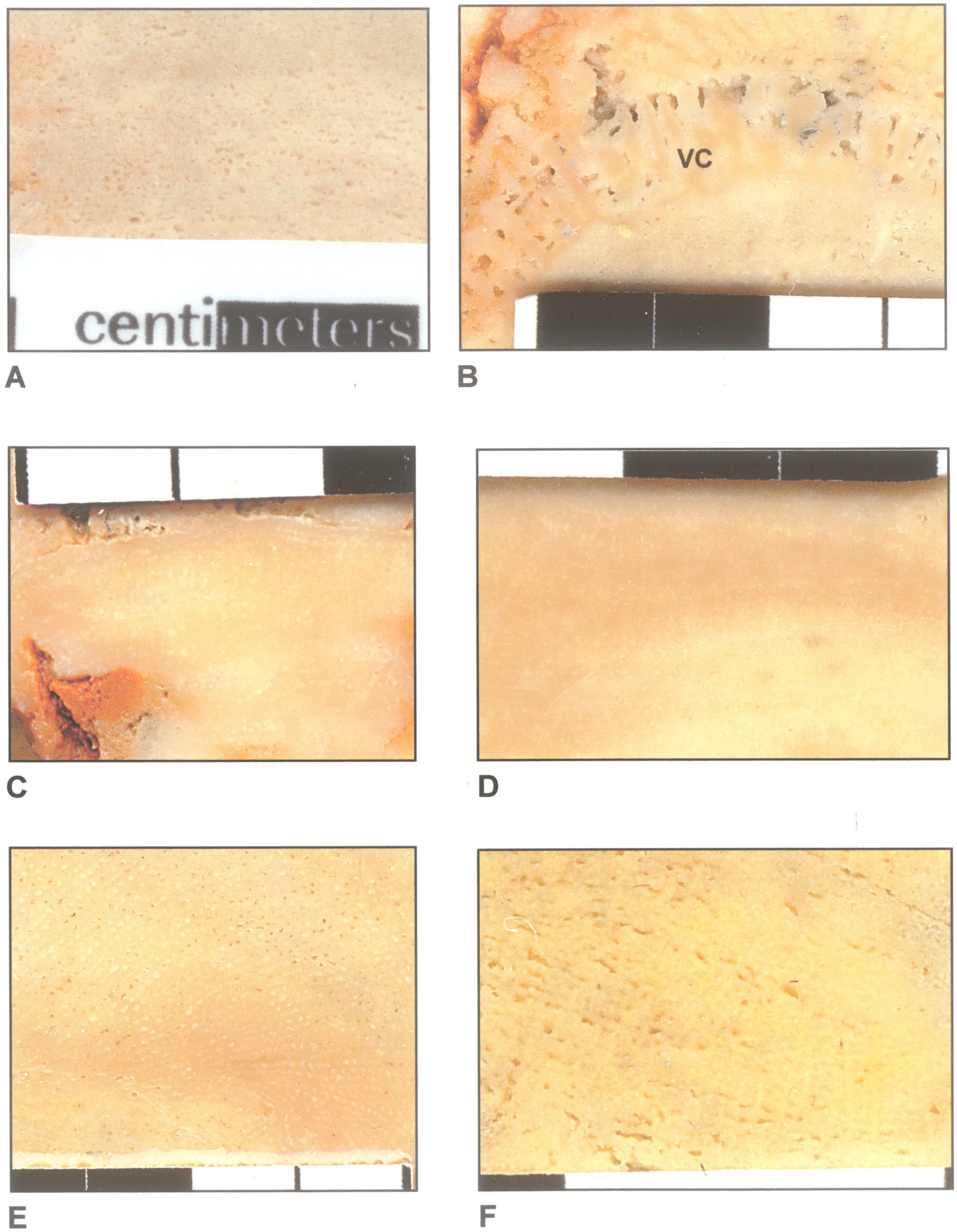
Figure 6.1 (see next page): Polished longitudinal sections showing internal structures of each type of stromatoporoid (scales shown, each wide white or black bar = 1 cm). A) Stromatoporoid Type CY, showing the characteristic vesicular, cystose internal structures. B) Stromatoporoid Type VC, displaying very thick, coarse pillars as the dominant structure (specimen is encrusted by a favositid coral). C, D) Stromatoporoid Type PI, showing thick pillars as the dominant structure, and a lack of definable laminae. E, F) Stromatoporoid Type CP, displaying prominent coarse pillars that are thicker than those of Type PI.


centimeters
VC
A
B
C
D
E
F

forms of this type of stromatoporoid include all shapes presented as categories for this study. Astrorhizae were observed in some specimens, but lacking in others. This type closely resembles *Clathrodictyon* cf. *cystosum* of Stearn (1956).

Stromatoporoid Type PI

This type of stromatoporoid exhibits pillars as the prominent internal structure (PI = pillar). Horizontal elements are obscured either by the nature of the pillars or by recrystallization (Figure 6.1 C, D). In thin section, internal features are difficult to distinguish, though this type reveals a distinct undulating extinction pattern under crossed polarized light. Astrorhizae are absent. Coenostea of these stromatoporoids exhibit all growth forms used for categorization in this study. Stearn (1956) did not recognize any stromatoporoids with this same internal arrangement.

Stromatoporoid Type CP

This type of stromatoporoid also exhibits pillars as the prominent internal structure, but these pillars are significantly coarser than in Type PI (CP = coarse pillar). Pillars may be continuous, or long and discontinuous, through coenostea (Figure 6.1 E, F). Laminae of these stromatoporoids are thin, continuous, and regularly spaced. Astrorhizae are absent. Coenostea of these stromatoporoids exhibit all growth forms used for categorization in this study. This type of stromatoporoid is difficult to classify, as the internal features are variable. It is suggested that these stromatoporoids represent a species that is different from *Clathrodictyon* cf. *cystosum*, though the internal features also resemble *Gerronostroma* and possibly *Densastroma*. Thus, to even suggest a family name would not be appropriate for these stromatoporoids.

Stromatoporoid Type VC

Only one specimen of this type of stromatoporoid was obtained from the Lundar Quarry. A second specimen was observed within drill core from Lundar. The dominant internal structures of this stromatoporoid are very coarse, stout, continuous pillars (VC = very coarse pillar). Pillars appear rounded in cross section and are relatively closely spaced, approximately 0.2 mm from centre to centre (Figure 6.1 B). Thin, regularly spaced laminae or cyst plates are visible between pillars. Stearn (1956) did not recognize any stromatoporoids similar to this during his study. This type of stromatoporoid is suggested to belong to Family Labechiidae, though more specimens would be needed for further classification (Stearn, personal communication 2004).

6.2 Tabulate Corals

Favosites niagarensis lundarensis Stearn, 1956

Favosites niagarensis lundarensis is the most prevalent of all corals within the Chemahawin Member. This subspecies is characterized by small corallites of generally uniform size (Figure 6.2 A, B). Corallites are polygonal, and range in diameter from 0.8 to 1.2 mm. Corallite walls are thin and straight. Mural pores are visible within the walls of corallites in some specimens. Septal spines are very short or, in some specimens, absent. Tabulae are straight and spaced approximately 18-24 per 10 mm.

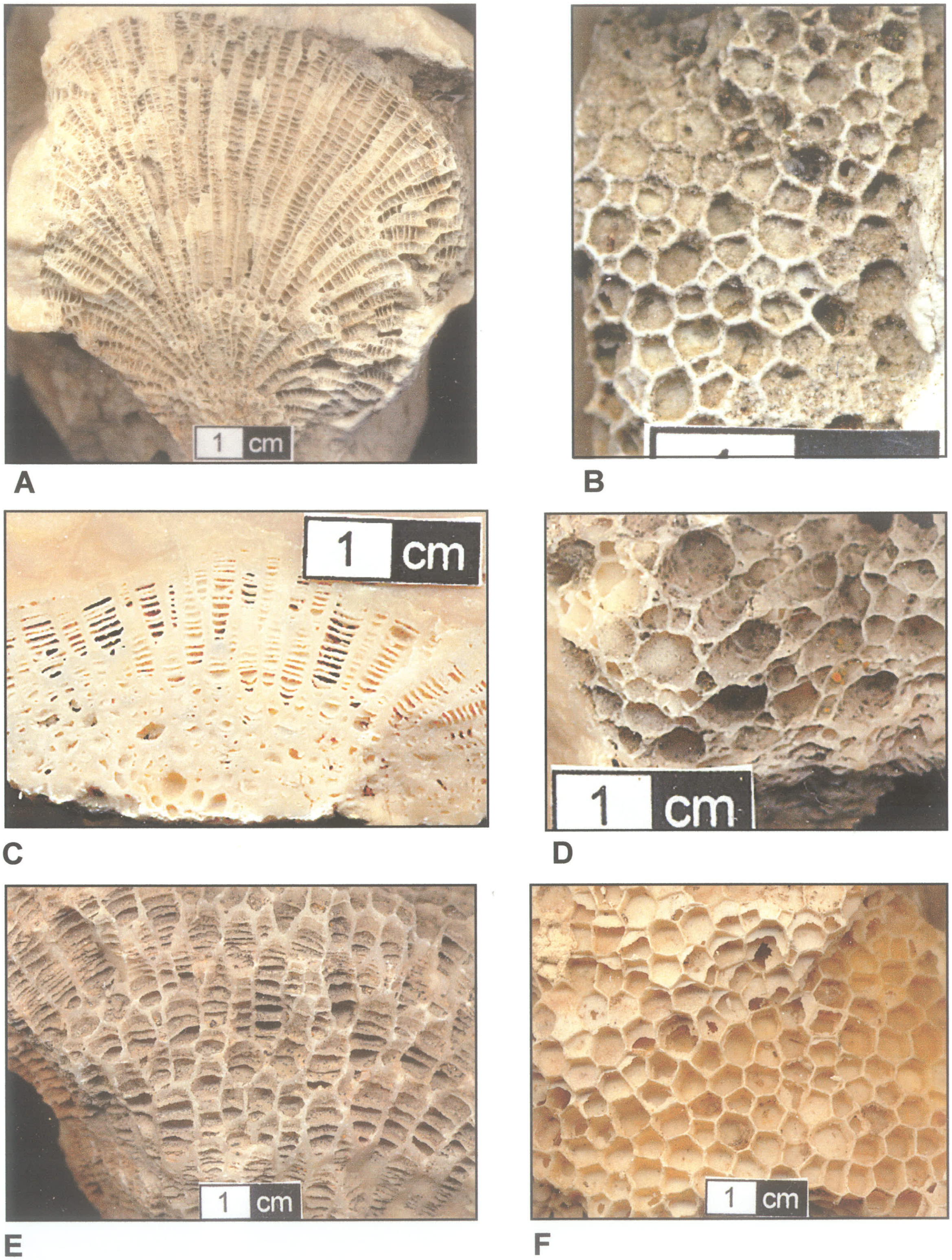


Figure 6.2: Longitudinal and transverse views of favositid corals found within the Lundar Quarry (scale bar = 1 cm). A, B) *Favosites niagarensis lundarensis*. C, D) *Favosites niagarensis inaequalis*. E, F) *Favosites gothlandicus*.

Coralla of this species exhibit all growth forms used to categorize shape in this study. The quarry at Lundar is the type locality for this subspecies (Stearn 1956). *Favosites niagarensis lundarensis* occurs both as free-living forms and within the coenostea of the three prevalent types of stromatoporoids (CY, PI, and CP).

Favosites niagarensis inaequalis Stearn, 1956

The characteristic feature of this subspecies is the inequality of corallite size (Figure 6.2 C, D). Mature corallites attained diameters of 1.8-2.5 mm, whereas immature corallites are 0.5-1.0 mm in diameter. Immature corallites are found throughout the corallum between mature corallites, and are thus not limited to the corallum periphery. Corallite walls are thin and straight. Septa are absent or obscured by recrystallization. Tabulae are straight to slightly convex upward, and spaced approximately 16-18 per 10 mm in mature corallites, and 20-24 per 10 mm in immature corallites. Coralla of this subspecies display all growth forms used for classification in this study, and occur as both free-living colonies and within coenostea of stromatoporoid Type CY. The quarry at Lundar is the type locality for this subspecies (Stearn 1956).

Favosites gothlandicus Lamarck, 1816

This species is characterized by very large, typically uniform corallites, and is thus easily distinguished from other favositid corals found within the Chemahawin Member (Figure 6.2 E, F). Corallites are polygonal and average 4.0 mm in diameter, with a few mature corallites having attained diameters of up to 5.5 mm. Corallites walls are thin and straight. Mural pores are observed within corallites walls in some specimens. Septa are absent or obscured by recrystallization. Tabulae are straight to slightly convex upwards, spaced approximately 12-14 per 10 mm (averaged across a dense and less-dense growth couplet). Growth forms for this species could not be assigned, as all coralla observed in the field and in all collected specimens were incomplete fragments. This coral was recognized by Stearn (1956).

Favosites sp. 1

Only two specimens of this coral were found within stratigraphic samples, though one additional loose specimen was obtained from a rubble pile. The characteristic feature of this species is the presence of very thick (0.4-0.6 mm), straight corallite walls (Figure 6.3 A, B). Corallite size is relatively uniform, with diameters of about 3.0 mm. Septa are absent from this species. Tabulae are convex upwards and spaced approximately 10-14 per 10 mm. All specimens exhibit a domical growth form.

Stearn (1956) recognized the presence of the tabulate coral *Favosites hisingeri* Milne-Edwards and Haime, 1851 within the exposures of the Lundar Quarry. This coral is described as having thick corallite walls (0.2 mm), and a uniform corallite size of approximately 1.4 mm in diameter (Stearn 1956). Additionally, Stearn recorded an average tabulae spacing of about 20 in 10 mm. Also characteristic of *F. hisingeri* are well-developed septal spines. Though it is clear that *Favosites* sp. 1 does not belong to this species, no specimens fitting the description of *F. hisingeri* were obtained from the Lundar Quarry. The two recorded specimens of *Favosites* sp. 1 were classified with unidentifiable tabulate corals for analyses.

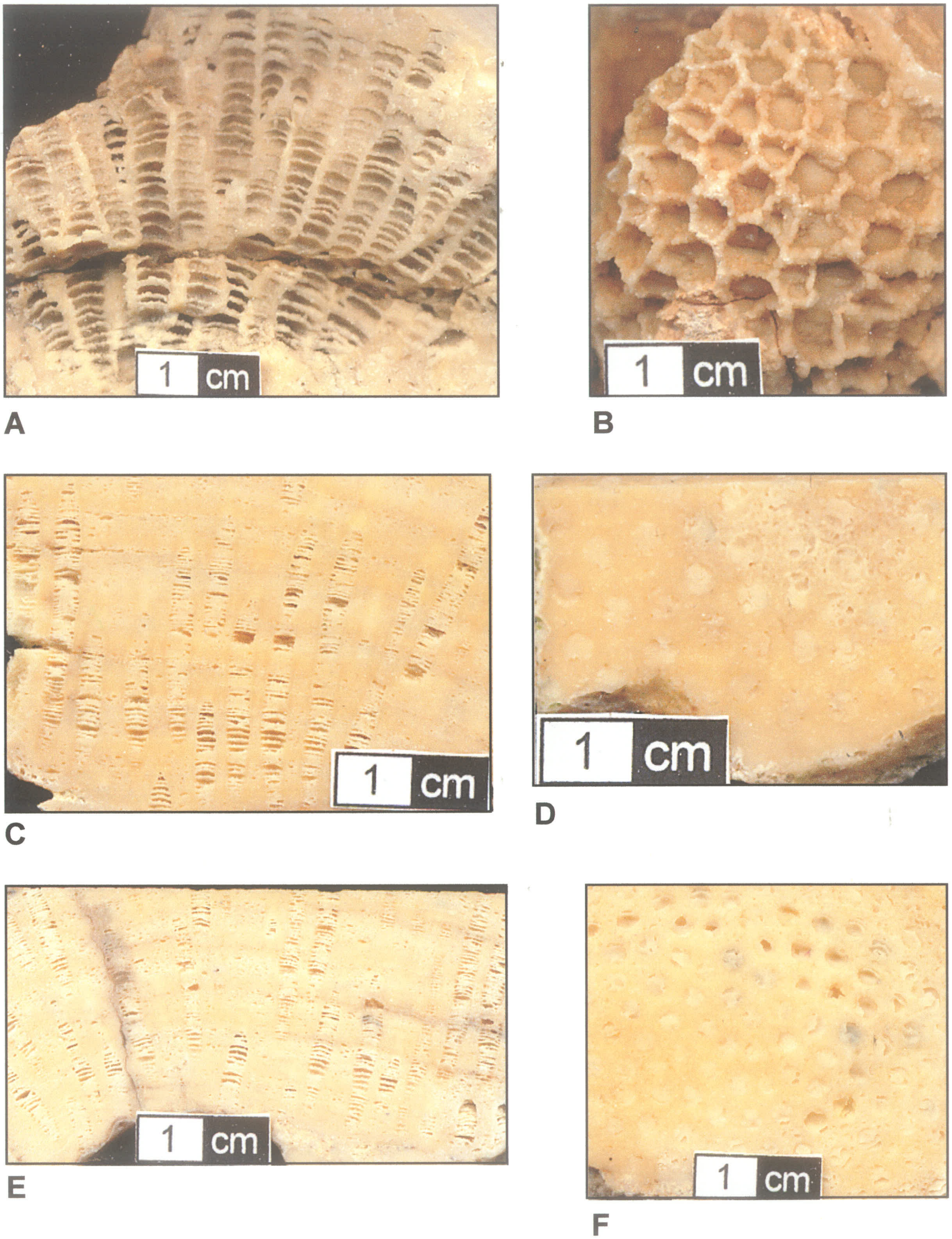


Figure 6.3: Longitudinal and transverse views of tabulate corals found within the Lundar Quarry. A, B) *Favosites* sp. 1. C, D) *Plasmopora* sp. 1. E, F) Proporicae sp. 1.

Plasmopora sp. 1

Only one specimen of this type of coral was found within stratigraphic samples, though two additional loose samples were obtained from a rubble pile. This tabulate coral exhibits a coenenchymal morphology, with common skeletal tissue separating individual corallites (Figure 6.3 C, D). Corallites of this species range in size from 1.0 to 1.4 mm in diameter, and appear crenulate in places with distinct septa. The centres of corallites are approximately 2.0 mm apart. Tabulae are wavy and generally incomplete, with rare complete tabulae displaying distinct vertical spines. Tabulae are planar to convex upward and closely set, with approximately 28-36 per 10 mm. The coenenchymal tissue of this species looks tubular in cross section, and vesicular in longitudinal section. Stearn (1956) did not recognize any corals of this genus from the Chemahawin Member.

Proporicae sp. 1

Though no specimens of this type of coral were found in stratigraphic samples, one loose specimen was obtained from a rubble pile. This second type of tabulate coral with distinct coenenchymal morphology cannot be assigned with confidence to either of the families Plasmoporidae or Proporidae of the superfamily Proporicae. Corallites of this coral range in size from 1.6 to 2.0 mm in diameter, and show slight crenulation (Figure 6.3 E, F). The centres of corallites are 2.2-2.5 mm apart. Tabulae are typically complete, and spaced approximately 32-40 per 10 mm. Coenenchymal tissue of this coral appears tubular in cross section, and exhibits closely spaced vesicles in longitudinal section. Stearn (1956) did not recognize any corals from this superfamily from the Chemahawin Member.

Halysites cf. *catenularius* (Linnaeus, 1767)

This chain coral consists of oval-shaped corallites which average 1.9 mm in long dimension in transverse section (Figure 6.4 A). Corallite walls are relatively thick, up to 0.5 mm. Corallites are separated by small tubules that are 0.3 mm in diameter. Septa are absent from both corallites and tubules. Tabulae are planar to slightly convex upwards, and are spaced approximately 24 per 10 mm. Specimens of this coral are fragmental, consisting of between one and three connected corallites, so growth forms could not be categorized. Stearn (1956) recognized the presence of *Halysites catenularia* (*sic*) in the Chemahawin Member, but due to the thickness of corallite walls in the specimens from Lundar, these corals are assigned to *Halysites* cf. *catenularius* for this study.

Halysites sp. 1

Only a few specimens of this chain coral were found within samples collected from the Lundar Quarry. Aseptate corallites are more circular and smaller in size than in *Halysites* cf. *catenularius.* The average long axis diameter for this species is 1.0 mm (Figure 6.4 B). Only one tubule separating corallites was observed, with a diameter of 0.4 mm. Tabulae could not be observed, as longitudinal sections could not be prepared for this species. Specimens are fragmental, consisting of only a few attached corallites, so corallum morphology could not be determined. Stearn (1956) did not recognize a

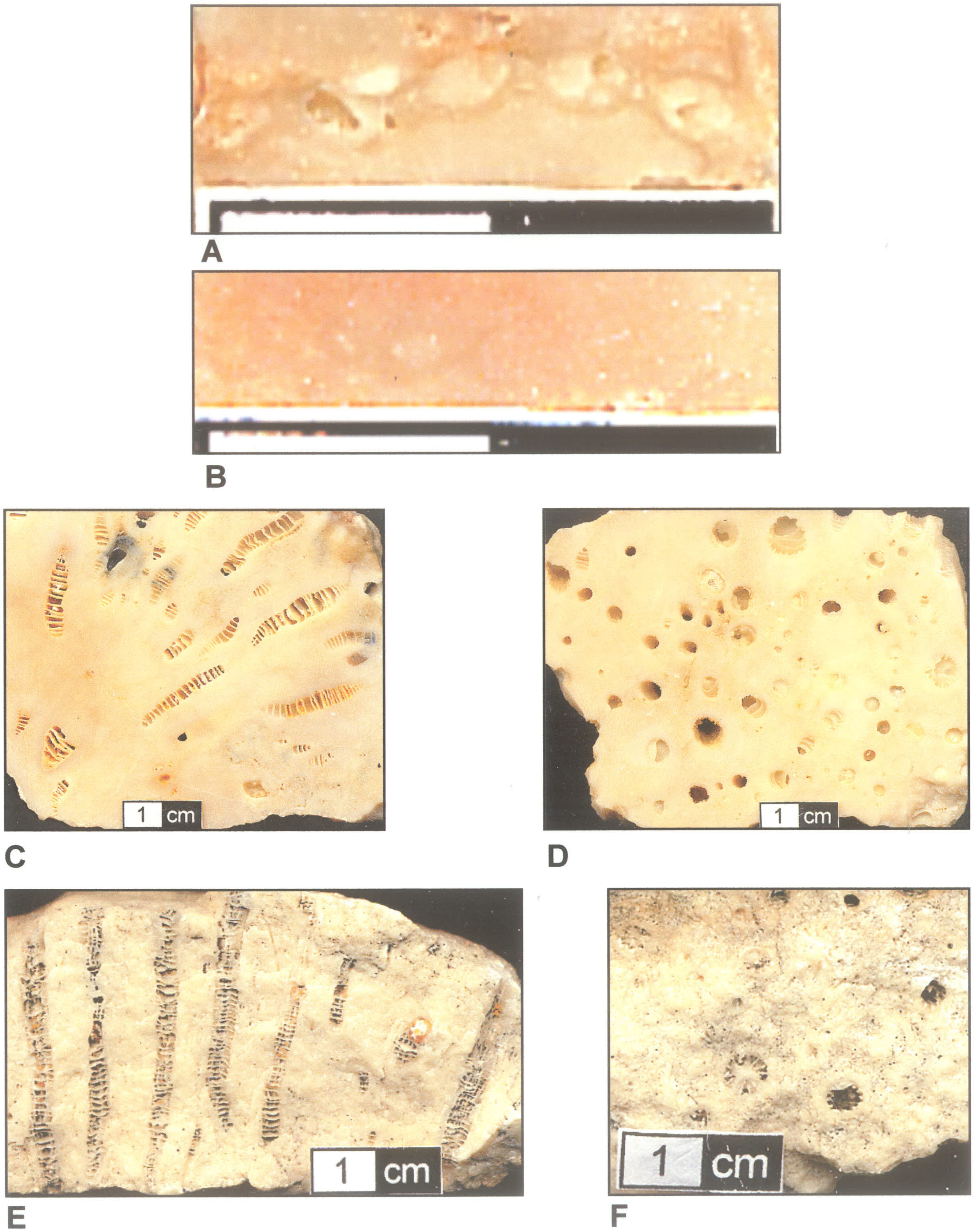


Figure 6.4: Corals found within the Lundar Quarry (scale bar = 1 cm). A) Transverse view of *Halysites* cf. *catenularius*. B) Transverse view of *Halysites* sp. 1. C) Longitudinal, and D) transverse sections of *Pycnostylus guelphensis* within stromatoporoid Type CP. E) Longitudinal, and F) transverse views of *Synamplexoides varioseptatus* within stromatoporoid Type CY.

species of *Halysites* having these characteristics. These specimens are not assigned to a named species in this study because of insufficient data for comparison.

6.3 Colonial Rugose Corals

Pycnostylus guelphensis Whiteaves, 1884

This fasciculate coral only occurs within the coenostea of the three main types of stromatoporoids (CY, PI, CP) of the Chemahawin Member (Figure 6.4 C, D). Corallites are cylindrical to slightly curved and grew approximately parallel to one another, though they branch from the base of the corallum. Corallites are not connected by lateral processes. Septa are amplexoid, attaining their greatest length on the upper surfaces of tabulae, but shorten or disappear between tabulae (Hill 1981). Septa are thin and short, extending approximately 0.5 mm towards the centres of corallites. Corallite diameters are highly variable depending on the level of maturity, ranging in size from 0.7 to 6.5 mm, with an average of 3.5 mm for mature corallites. Tabulae are complete and planar, and spaced approximately 13-17 per 10 mm.

Synamplexoides varioseptatus Stearn, 1956

This coral is abundant within the Lundar Quarry, commonly found within the coenostea of the three main types of stromatoporoids (CY, PI, CP). Coralla are fasciculate, with corallites parallel to one another, typically separated by several millimetres (Figure 6.4 E, F). Corallites are cylindrical to gently expanding, and range in diameter from 0.8 to 3.2 mm, with rare specimens exhibiting corallites of up to 5.5 mm in diameter. Septa are amplexoid and can extend half way to the central axis of corallites.

In mature corallites, tabulae are planar to undulatory and crowded 22-28 per 10 mm. The Lundar Quarry is the type locality for this species (Stearn 1956). Hill (1981) did not accept *Synamplexoides* as a distinct genus, and attempted to place it within *Pycnostylus* or *Palaeophyllum*. However, in view of her uncertainty, *Synamplexoides* is here retained as a separate genus.

6.4 Solitary Rugose Corals

Amplexoides sp. A of Stearn, 1956

This is the most common solitary rugose coral within the Lundar Quarry. Coralla are typically cylindrical to gently expanding trochoid forms. Amplexoid septa are thin and very short, generally projecting only 1-2 mm in from the wall (Figure 6.5 A, B). Where intact, the outer wall is typically thick, between 0.7 and 0.9 mm. Coralla range in diameter from 4 to 23 mm, and attained lengths of up to 85 mm. Tabulae are thin and spaced about 8-10 per 10 mm.

Stearn (1956) recognized *Amplexoides* sp. A within the Chemahawin Member, though his descriptions emphasize small coralla with diameters averaging 10 mm. It is possible that larger specimens observed during the present study belong to a separate species, but they have been included in the same taxon based on the nature of the short, amplexoid septa.

Dinophyllum lundarense Stearn, 1956

This coral is characterized by long major septa which extend to the central axis of the corallum and swirl into the axial structure (Figure 6.5 C, D). Septa are thick near the

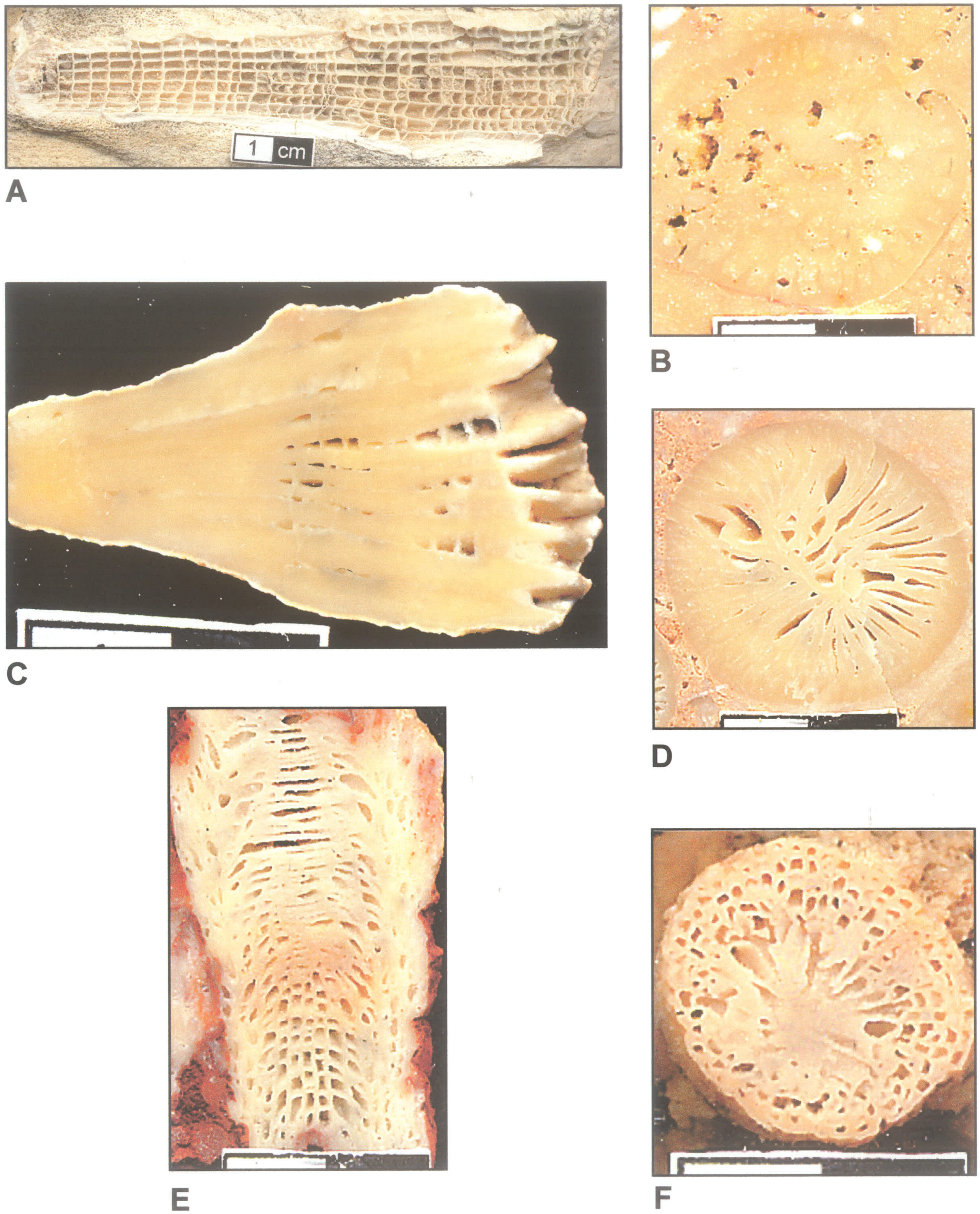


Figure 6.5: Longitudinal and transverse views of solitary rugose corals found within the Lundar Quarry (scale bar = 1 cm; N.B. longitudinal views in A and C are oriented sideways, with calice toward the right). A, B) *Amplexoides* sp. A. C, D) *Dinophyllum lundarense*. E, F) *Cystiphyllum* cf. *niagarensis*.

wall, and thin towards the central axis. Coralla are trochoid to ceratoid, and often slightly curved. Corallum size of this species ranges from 5 to 29 mm in diameter. Lengths of coralla could not be determined, as most coralla are broken fragments. Tabulae are convex upwards and closely spaced. The number of major septa ranges from 40 to 52. The Lundar Quarry is the type locality for this species (Stearn 1956).

Cystiphyllum cf. *niagarensis* (Hall, 1852)

This solitary rugose coral is characterized by an abundance of cyst-like dissepiments which line the inside of the corallum walls (Figure 6.5 E, F). Dissepiments are arranged in an overlapping pattern, as larger, younger dissepiments occur toward the centre of the corallum, and smaller, older structures are situated close to the outer wall. Septa are long, extending almost to the centre of coralla. Complete tabulae are thin and slightly convex upwards. Tabulae spacing is irregular, ranging from 20 to 28 per 10 mm. This species generally exhibits a cylindrical corallum, with diameters ranging from 5 to 22 mm. Coralla occur only as fragments, so the lengths of specimens could not be measured accurately. Septal grooves can be seen on the outer wall. Coarse rugae give a "stacked cup" appearance to the exterior. Stearn (1956) recognized the presence of *Cystiphyllum* within the Lundar Quarry, and his identification of this coral as *Cystiphyllum* cf. *niagarensis* is followed in the present study.

6.5 Other Biologic Components

Echinoderm columnals are generally disarticulated and found scattered within the fossiliferous facies of the Chemahawin Member. Columnals range from 0.5 to 3.0 mm in diameter. Though composed entirely of diagenetic dolomite, in both hand sample and thin section, columnals retained perfect calcite cleavage. Taxonomic identification cannot be conducted on these skeletal fragments, however, as diagnostic structures such as holdfasts and calices are required.

Additionally, external molds of several small brachiopod shells were recovered from various locations within the Lundar Quarry. These shells possess a short to moderately wide hingeline, small beak, and well-defined plications. Classification of these brachiopods is not possible based on the available material and its state of preservation.

Three gastropods have also been recovered from the Lundar Quarry. Two specimens of trochospirally coiled gastropods were found; one as a poorly preserved internal mold, the other as an infilled, thin-shelled form. The third specimen is a fragment of a large whorl. Additionally, broken thin shelly material was observed, which likely represents mollusc fragments.

Microfossil extraction from various hand samples representing unfossiliferous facies from the Lundar Quarry revealed the presence of conodont elements. Two genera were recognized: *Panderodus*, a pelagic genus which ranges from Ordovician to Devonian; and *Oulodus*, an Ordovician to Silurian genus typically associated with shallow-water conditions (Ed Dobrzanski, personal communication 2005). In addition, several hexactinellid sponge spicules and fragments of calcareous algae were recovered (Ed Dobrzanski, personal communication 2005).

Chapter 7: Facies within the Lundar Quarry

7.1 Facies Descriptions

Four facies have been recognized in the portion of the Chemahawin Member exposed within the Lundar Quarry, each distinguished by a distinct suite of biological and sedimentological characteristics (Table 7.1). Thus, facies may be considered as both lithofacies and biofacies, each showing a range of variability. Classification of carbonate rocks follows Dunham (1962) as modified by Embry and Klovan (1972). Porosity classification follows Choquette and Pray (1970). Estimation of abundances was conducted by visual comparison using a modal composition chart. Colour descriptions are derived from the "Geological Society of America Rock-Color Chart".

7.1.1 Facies 1

Facies 1 can be classified as a stromatoporoid-coral floatstone with a skeletal wackestone matrix, which ranges in colour from very pale yellow orange to moderate yellowish and greyish orange (Figure 7.1 A). Within this facies, macrofossils account for 30-60% of hand sample surface area, with matrix accounting for 40-65%, and porosity ranging from 0-10%. Porosity is typically interskeletal or vuggy in this facies, with a few examples of mouldic porosity as a result of dissolved body fossils. Localized needle-like and cubic evaporite crystal molds are found in isolated patches within the matrix of this facies at study sites O and K (see Figure 5.1). Though these evaporites are not distributed throughout this facies, the limited quantity and extent of these molds do not justify a separate facies assignment.

Stromatoporoids are abundant within this facies, accounting for up to 50% of hand sample surfaces. The sizes of coenostea are highly variable, from approximately 15-35

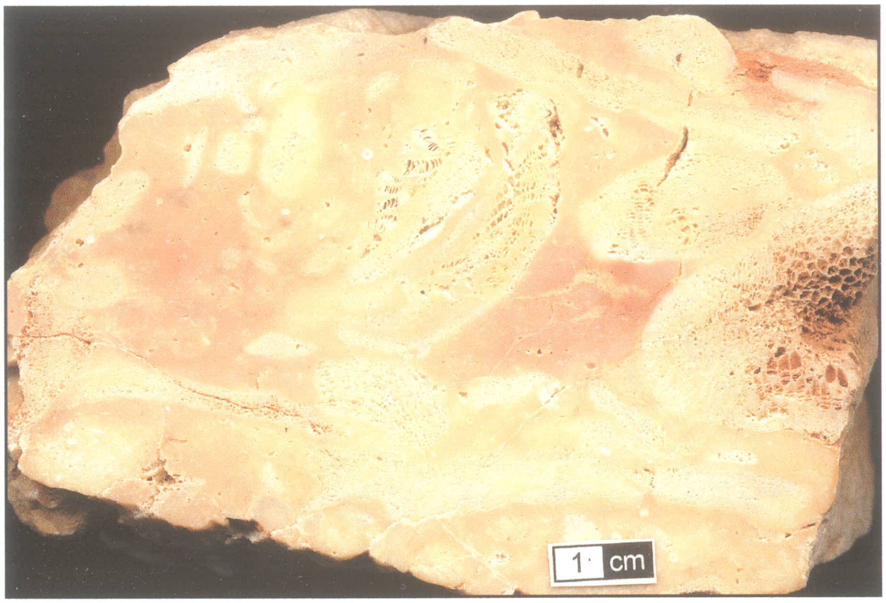
Table 7.1: Diagnostic characteristics of all facies observed within the Lundar Quarry.

Facies	Diagnostic Characteristics

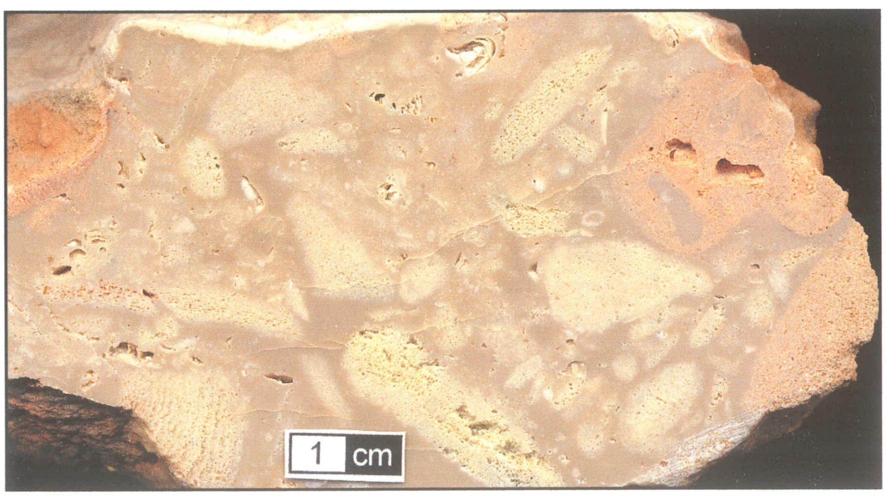
Facies 1
Stromatoporoid-Coral Floatstone w/ wackestone matrix
	- macrofossils – 30-60% of hand-sample surface area
	  - stromatoporoids dominant
	    - skeletons large (> 80 mm width)
	  - corals abundant
	- contains all taxa identified in Chemahawin Member
	- matrix – abundant echinoderm debris, bioclastic debris

Facies 2
Stromatoporoid Floatstone w/ wackestone matrix
	- macrofossils – 45-60% of hand-sample surface area
	  - stromatoporoids dominant
	    - tabular forms dominant, small (10-40 mm width)
	  - corals rare
	- matrix – some echinoderm debris, bioclastic debris

Facies 3 Bioturbated, Laminated Mudstone-Wackestone	- macrofossils – 0-10% of hand-sample surface area - poorly preserved stromatoporoid fragments - evidence for extensive bioturbation - matrix – few echinoderm columnals, bioclastic debris
Facies 4 Laminated Mudstone-Wackestone	- macrofossils absent - alternating laminae of mudstone and mudstone-wackestone - minor bioturbation of laminae



A



B

Figure 7.1: Polished vertical sections of hand samples representing typical examples of facies found within the Lundar Quarry. A) Facies 1, exhibiting the diversity of fauna found in this lithology. B) Facies 2, displaying abundant small stromatoporoid fragments as the dominant faunal constituent.

mm to greater than 80 mm in width. The growth forms of coenostea are also variable. Tabular and irregular forms are most common, though a few domical forms were observed; all forms are smooth-margined. At least 50% of all stromatoporoids are fragmented, which may account for the large proportion of coenostea classified as having irregular forms. Though stromatoporoid coenostea are generally randomly oriented, in some samples up to 30% of individuals occur with the long axis horizontal (see Figure 7.1 A). All types of stromatoporoids identified in the Lundar Quarry are present within this facies.

Corals account for approximately 5-15% of hand sample surfaces, including both colonial and solitary forms. Favositid tabulates account for the majority of corals present within this facies, including all species identified within the Lundar Quarry. Favositids are found both as free-living forms, and in symbiotic association with stromatoporoids. Approximately half of the coralla are crushed and fragmented; where coralla are intact, domical and tabular forms dominate. Symbiotic colony shapes appear to have been influenced by competition with stromatoporoid tissue, so these coralla are commonly classified as irregular growth forms. Other tabulate corals present in this facies are both species of *Halysites*, which only occur as small fragments of a few corallites, and a few specimens belonging to the superfamily Proporicae. Colonial rugose corals are also present, with *Pyncostylus guelphensis* occurring only in symbiotic association with stromatoporoids, and *Synamplexoides varioseptatus* occurring both within coenostea and as free-living forms. All genera of solitary rugose corals identified within the Lundar Quarry are found within this facies, though *Amplexoides* sp. A occurs in greater abundance than other species. Coralla are found both complete and as fragments, and range in size from less than 10 mm to greater than 25 mm in diameter. Abrasion of the outer wall is evident in several specimens.

The matrix of this facies is composed of very fine, crystalline dolomite, ranging in colour from very pale yellowish orange to greyish orange and moderate orange pink. The matrix consists of 35-50% bioclasts, predominately echinoderm columnals, small stromatoporoid coenostea and fragments, and coral fragments. Echinoderm columnals range in size from 0.5 mm up to 6.0 mm in diameter, with an average diameter of 1.5 mm. The distribution and the degree of articulation of echinoderm columnals are variable at different locations within the quarry. The maximum length of articulated echinoderm stem segments is 16.0 mm.

7.1.2 Facies 2

Facies 2 is a stromatoporoid floatstone with a skeletal wackestone matrix, and ranges in colour from pale greyish orange pink to pale yellowish brown, with intermittent staining to pale reddish brown (Figure 7.1 B). Macrofossils comprise approximately 45-65% of hand sample surface area, with matrix accounting for 25-45%, and porosity is generally 1-15%. Porosity is typically interskeletal and vuggy, with a few samples exhibiting mouldic porosity as a result of dissolved fossil fragments.

Stromatoporoids are the dominant fossil within this facies, comprising 35-60% of hand sample surface area. The dominant forms of stromatoporoid coenostea are tabular, with width:height ratios of about 4:1 to 6:1, and irregular forms. Randomly oriented coenostea imply that these organisms were not preserved in life position (see Figure 7.1 B). Complete coenostea are smooth-margined, and have width measurements of between 10 and 40 mm. Rare large coenostea of greater than 80 mm width are found within this facies, typically exhibiting tabular growth forms in irregular shapes. The irregular form has been hypothesized to be the result of encrusting a relatively hard or stable irregular substrate surface (Figure 7.2). The principal three types of stromatoporoids are present within this facies.

Colonial corals are rare in this facies, constituting less than 10% of most hand sample surfaces. Tabulate coral diversity is low, as only two species have been positively identified: *Favosites niagarensis lundarensis*, and *Favosites* sp. 1. The coral *F. niagarensis lundarensis* occurs both as symbiotic and free-living forms. While most coralla are fragmented, complete coralla are typically domical and randomly oriented. The colonial rugosan *Synamplexoides varioseptatus* only occurs in symbiotic association with stromatoporoids in this facies. No solitary rugose corals were documented from hand specimens for this facies.

The matrix consists of very fine, crystalline dolomite. The colour is variable, from pale yellowish brown, greyish orange to greyish orange pink, and stained pale reddish brown. Stromatoporoid and coral fragments and echinoderm columnals comprise about 15-35% of the matrix. Echinoderm columnals are largely disarticulated in this facies, and occur as clusters within the matrix. Columnals average 0.5 mm diameter, though a few specimens are as large as 3.0 mm diameter.

7.1.3 Facies 3

Facies 3 is can be classified as a bioturbated, laminated mudstone to wackestone (Figure 7.3 A). Samples of this facies vary in colour from pale yellowish brown to light brown, and fossils within this facies may be stained moderate orange pink to pale reddish brown. Macrofossil fragments account for 0-10% of hand sample surfaces, with matrix

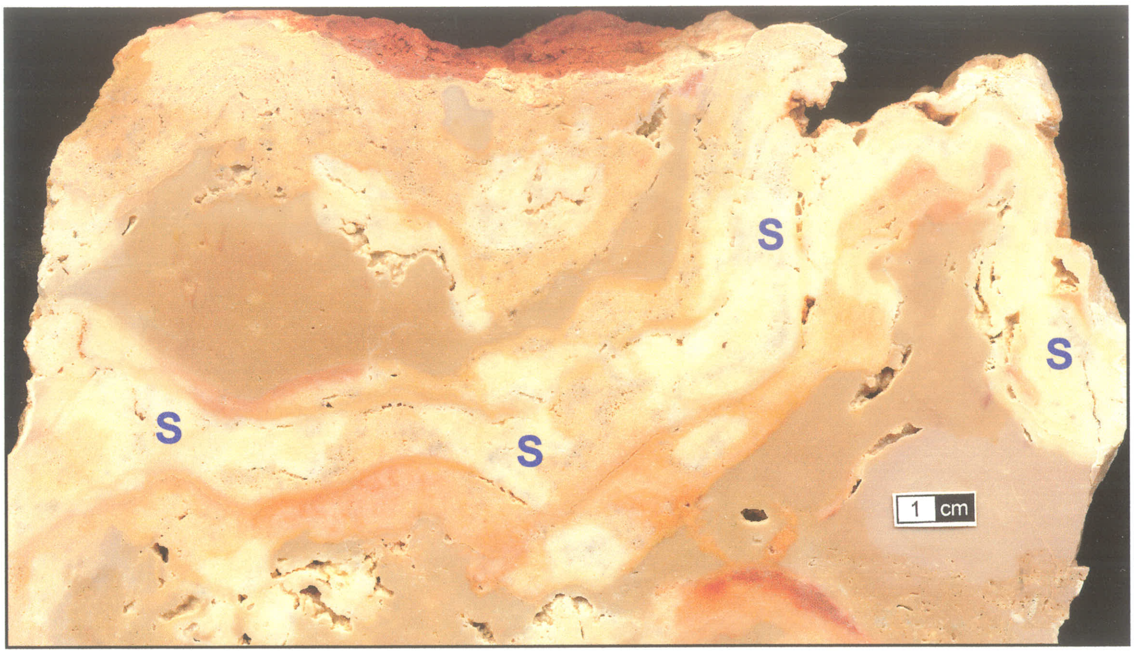


Figure 7.2: Polished vertical section of a facies 2 hand sample showing tabular stromatoporoid (S) classified as an irregular form due to evidence for encrustation of a hard or stable, irregular substrate surface.

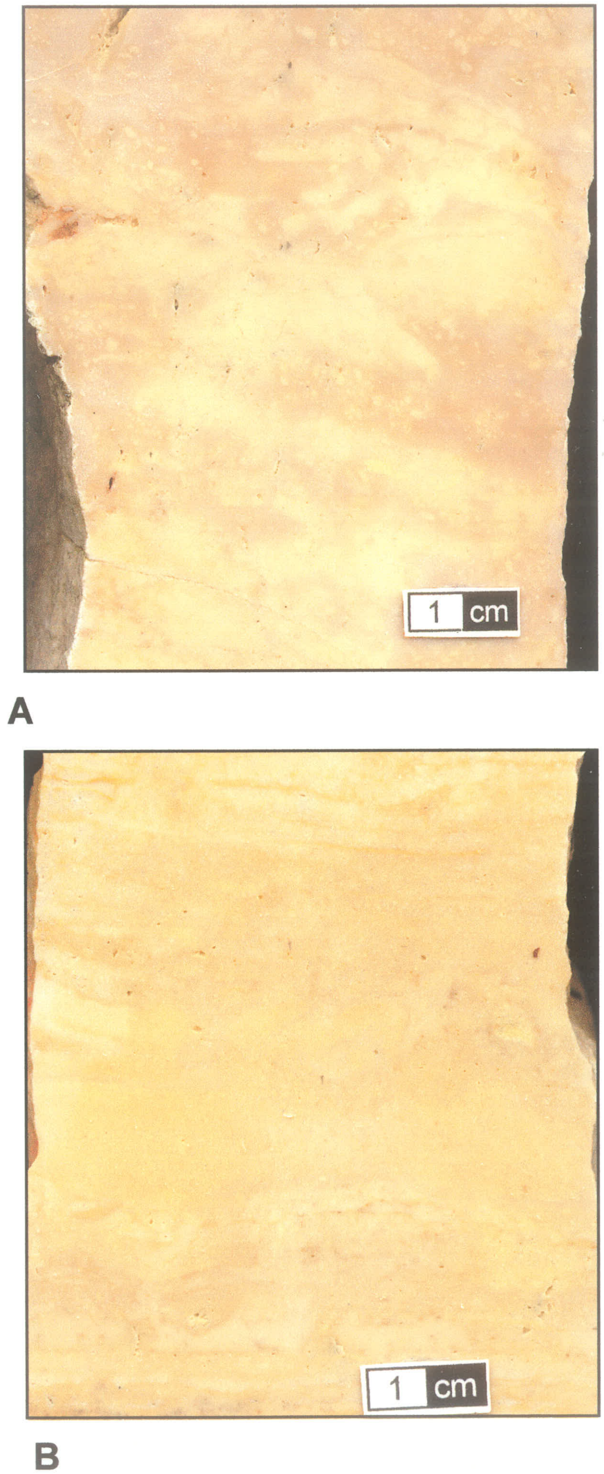


Figure 7.3: Polished vertical sections of hand samples representing typical examples of facies found within the Lundar Quarry. A) Facies 3, characterized by mudstones that show evidence of disturbance of beds, likely due to bioturbation. B) Facies 4, displaying laminated dolomitic mudstones with little evidence for disturbance of laminae.

accounting for 85-100%, and porosity is limited to less than 5%. Porosity is generally represented as small vugs or interskeletal space.

Stromatoporoid coenosteum fragments account for the majority of recognizable fossils in this facies, and most are poorly preserved. Thus, taxonomic identification was not possible. Corals are absent or unrecognizable in this facies. The characteristic feature of this facies is bioturbation, which has extensively disturbed the laminae.

The matrix ranges in colour from pale yellowish brown to pale light brown. The matrix may be subdivided into two classes based on bioclastic content, with either 0% bioclasts present, representing a mudstone, or approximately 20% bioclasts present, representing a wackestone. Echinoderm columnals account for approximately 70% of bioclasts present within the matrix. Columnals are generally very small in this facies, typically less than 0.5 mm in diameter, and are completely disarticulated.

Microfossil analysis of hand samples representing this facies revealed the presence of conodont elements, fragments of calcareous algae, and hexactinellid sponge spicules.

7.1.4 Facies 4

Facies 4 consists of alternating continuous to discontinuous layers or planar laminae of pale to moderate yellowish brown dolomitic mudstone and very pale orange to greyish orange, slightly coarser grained dolomitic mudstone to wackestone (Figure 7.3 B). Porosity is less than 1% within the darker, finer grained mudstones, whereas porosity can be as great as 5% within the paler mud- to wackestones. Body fossils are absent from this facies, though varying degrees of bioturbation disturb laminae. There does not appear to be an obvious stratigraphic trend in the degree of bioturbation.

Microfossil analysis of hand samples representing this facies revealed the presence of conodont elements, as well as common, angular to subrounded quartz grains of less than 250 μm (Ed Dobrzanski, personal communication 2005). These quartz grains are likely eolian in origin, as there is no other evidence to suggest close proximity to a shoreline.

7.2 Facies Interpretations

A general interpretation of facies and their sedimentary components is presented here. A further discussion of the relationships between facies and the interpreted paleoenvironmental conditions is presented in Chapter 14.

Facies 1 contains abundant stromatoporoids and corals typical of Silurian reefs, as well as evidence of complex interactions between organisms (see Chapter 9). Thus, facies 1 is interpreted to represent a reefal facies within the Chemahawin Member (see 7.4 for further discussion).

Facies 2 also represents favourable conditions for some reef-building fauna, as stromatoporoids are abundant within this facies. The limited abundance of corals in this facies, however, and the lack of observed encrusting relationships, suggest that conditions were not suitable for reef building. Sedimentation rates were likely low, as the dominantly tabular stromatoporoids would otherwise have been rapidly smothered.

Facies 3 consists of muddy, laminated sediments which were likely deposited in a relatively quiet-water setting. Bioturbation of the laminae, and the presence of a few stromatoporoid skeletal fragments, suggest that conditions were still relatively favourable to some macrofauna. The lack of abundant fauna, however, suggests that conditions were more restricted than those of facies 2.

Facies 4 represents the most restricted conditions, as the laminated muds remained relatively undisturbed, and macrofossils are absent.

7.3 Distribution of Facies

At most study sites, exposed strata do not display obvious bedding features. Within the southwest corner of the Lundar Quarry, however, exposed bedding surfaces were measured to be approximately horizontal. Due to the relatively small size of the Lundar Quarry, the insignificant regional dip of 0.16 degrees toward the southwest was not apparent in the exposed strata. As well, there is no evidence for structural deformation of the strata (Figure 7.4). Thus, time lines within the quarry are inferred to be generally horizontal and parallel to the water level, and data from equivalent heights above water level are comparable chronostratigraphically.

At the majority of study sites within the quarry, strata represent facies 1 throughout the entire height of exposure. In the southwest portion of the quarry, however, facies 1 only occurs along the very top of the exposure at the southernmost sites, onlapping facies 2 to the west (Figure 7.5). A similar relationship is observed between facies 2, 3, and 4. Thus, the southwest corner provides insight into lateral relationships among facies. Additionally, strata exposed at site Q represent facies 4 from water level up to the highest exposure near the top of the quarry. The occurrence of different facies at the same time-equivalent stratigraphic levels within the quarry suggests that facies were gradually advancing westward in the area of the southwest corner. These lateral facies changes are unlikely to be the result of relative sea-level fluctuation, as the short distances between study sites in the southwest corner would suggest very little

Figure 7.4: Exposed quarry face of approximately 2 m vertical extent at site S, parallel to the regional dip of 0.16° toward the southwest (toward left side of image), which shows the approximate horizontal bedding planes within the Lundar Quarry. Image taken facing northwest. Boundaries of facies at this study site indicated by dashed lines.

Figure 7.5: Distribution of facies in the southwest corner of the Lundar Quarry (linear distance from site Y to site R is approximately 20 m). Image was taken facing southwest. Sampled sites outlined and labeled in white (see Figure 5.1 for map view of site locations). Approximate facies divisions based on hand samples indicated by dashed lines. Site Q is located approximately 40 m west along the quarry perimeter, where only facies 4 is exposed from water level up to the highest exposure near the top of the quarry.

difference in water depth. Thus, closely spaced facies exhibiting distinctly different biological components are likely the result of local environmental conditions.

Within the south quarry, Facies 2 is the dominant facies, and occurs near the base of each site. At S.D. site 1, facies 3 occurs at the very top of the quarry, whereas facies 4 is the uppermost facies at the other three sites (see Figure 5.1 for location of S.D. sites). Facies 1 was not observed in the south quarry. Thus, based on the quarries at Lundar, facies are not laterally extensive and have a patchy distribution.

7.4 Reef Facies of the Chemahawin Member

Stearn (1956) classified the Chemahawin Member as a biohermal unit, based on the abundance of *in situ* reef-building organisms. Examination of drill core of this unit, however, revealed that only a few metres of strata may be classified as fossil-rich within the Chemahawin Member (see Chapter 8). Additionally, there is little evidence for significant relief of the buildup in outcrop, and reefal facies 1 is conformable with overlying and underlying strata. Thus, classification of the organic buildup within the Chemahawin Member as a bioherm is likely inappropriate. Facies 1 within the Lundar Quarry likely represents a biostrome near the top of the Chemahawin Member. Though neither ancient cements nor binding algal components were recognized in thin section, encrusting relationships were recognized between macrofauna, and dense packing of fossils suggests some structural rigidity. Stromatoporoids were the dominant reef-building organisms within the Chemahawin biostrome, while corals were subordinate. Echinoderms and shelly organisms were reef-dwellers, and did not contribute to the construction of the buildup. The low-diversity faunal assemblage of Facies 2 within the

Lundar Quarry likely represents a period of initial colonization of previously unsuitable substrate.

Chapter 8: Subsurface Analysis

8.1 Drill Core Analysis

A major effort to better understand the relationships between Lower Paleozoic units in the Interlake region of Manitoba prompted the drilling of numerous exploratory holes by the Manitoba Mines Branch in 1969. Cores obtained from two of these holes were examined for this study in order to relate surface exposures to the subsurface geology, including lateral extensions of units below the surface, and contacts between units.

Two cores obtained from locations in close proximity to the Lundar Quarry were examined for this study (Appendix C). The first was drilled at the Lundar Quarry (M-08-69); the precise location with respect to the sites shown in Figure 5.1 is unknown. This core contains the contact of the Cedar Lake Formation with the underlying East Arm Formation. The second is from the nearby Mulvihill West quarry (M-06-69), which includes the upper unconformable contact of the Chemahawin Member with the Devonian Ashern Formation (see Figures 1.2, 8.1). Although the final total depth of the Lundar Quarry North core is more than 55 m, only strata above a red, argillaceous interval at about 42 m depth were included in this study. This red interval corresponds to the position within this core where Cowan (1971) identified the v marker bed. The v marker has been placed within the East Arm Formation of Stearn (1956; Cowan 1971; Johnson and Lescinsky 1986; see Figure 1.3). Examination of the core down to this marker bed ensured a complete assessment of the entire Cedar Lake Formation and the upper portion of the East Arm Formation for this study. These cores were both previously logged by H. R. McCabe (logs provided by Manitoba Geological Survey), whose descriptions were used as a guide for this study.

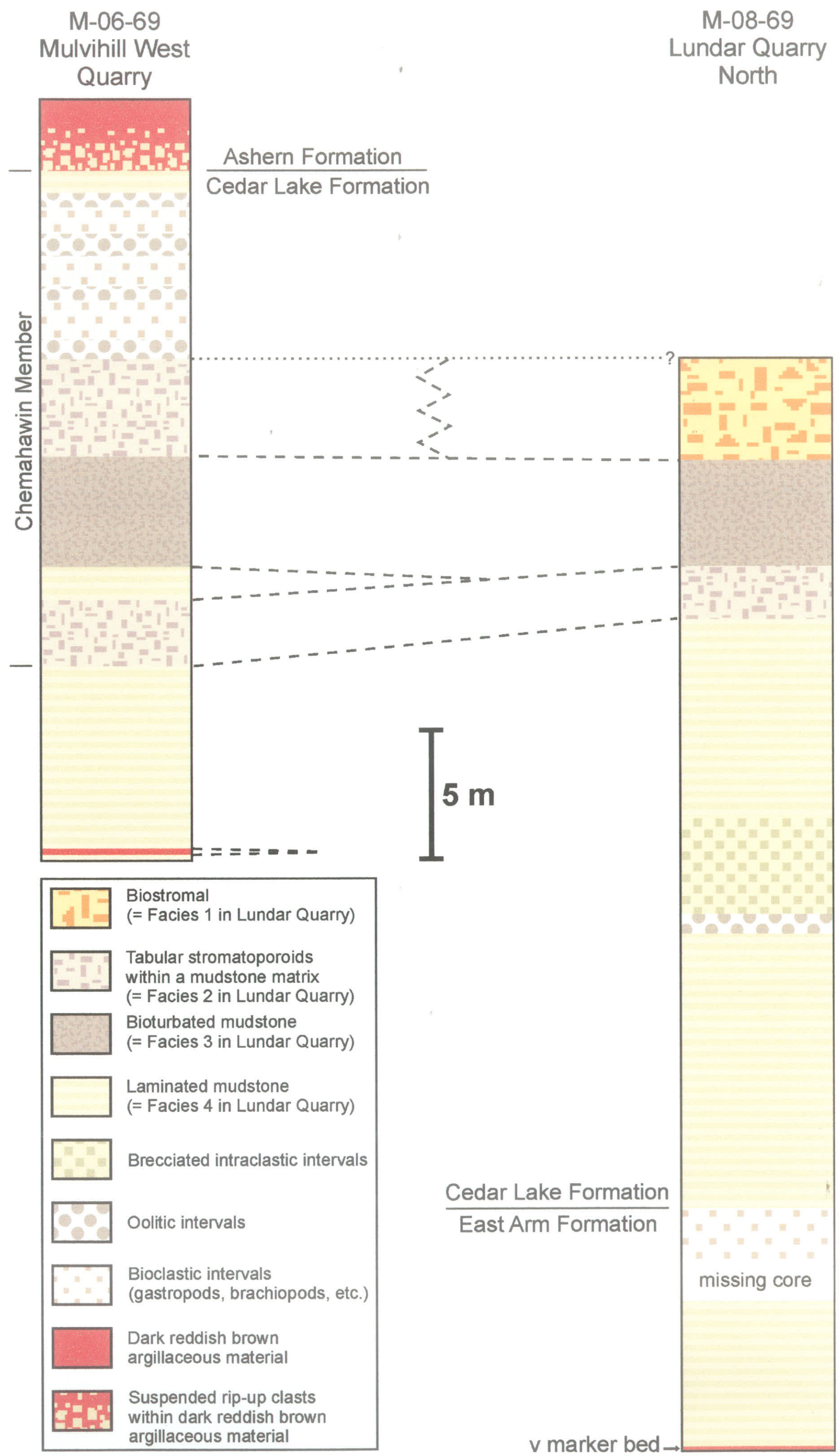


Figure 8.1: Correlation of the Mulvihill West Quarry and Lundar Quarry North drill cores. The top of the Lundar Quarry North core corresponds to the bedrock surface in the vicinity of Lundar Quarry. See text for explanation of evidence used to correlate units.

8.2 Lundar Quarry North (M-08-69)

Examination of drill core obtained from the Lundar Quarry revealed facies in the subsurface similar to those seen in outcrop. The uppermost portion of the core represents biostromal facies 1, with diverse and abundant stromatoporoid and coral fossils, echinoderm columnals, and vuggy porosity (Figure 8.1). Facies 1 extends down nearly 4 m below the bedrock surface and is replaced abruptly by facies 3, a 4-m-thick, tight unit lacking body fossils but displaying evidence of bioturbation. Two metres of strata below facies 3 are analogous to facies 2, with abundant small, tabular stromatoporoids suspended within a brownish grey, tight matrix. Below this interval is over 30 m of massive to finely laminated, tight, microcrystalline dolostone essentially devoid of fossils, which represents facies 4. This interval includes brecciated intraclasts from 19 m to 22 m depth (Figure 8.2 B), underlain by a 50-cm-thick oolitic dolostone bed. Only one other interval of notable fossil content is present within this core, almost 10 m above the presumed v marker in the East Arm Formation. This interval contains echinoderm columnals, brachiopod shell fragments, gastropod steinkerns, and unrecognizable bioclastic debris, which may represent the fauna of the upper East Arm Formation (see Stearn 1956). Over a metre of core is missing from below this interval, so the stratigraphic extent of these fossils is unknown. Below the missing interval of core, very pale, tight, microcrystalline dolostone extends down to dark brownish red rubble at about 42 m depth. This 15-cm red interval is presumed to represent the argillaceous v marker in the East Arm Formation (Figure 8.2 A).

Figure 8.2: Unique features within subsurface cores (scale bars in centimetres). A) The 15-cm interval of dark reddish brown rubble between 42.29 and 42.44 m (138'9"-139'3") in the Lundar Quarry North core is in striking contrast with the overlying pale dolomitic interval. This red interval is presumed to represent the v marker bed in the East Arm Formation. B) Example of brecciated intraclasts of finely laminated dolostone within the Lundar core between 19 and 22 m. C) Interval of dark reddish brown Ashern Formation (Devonian) from the Mulvihill West Quarry core between 1.85 and 2.34 m, containing pale gray rip-up clasts from the underlying unit, which is considered to represent the uppermost portion of the Chemahawin Member of the Cedar Lake Formation (Silurian).

8.3 Mulvihill West Quarry (M-06-69)

Within the core from the Mulvihill West quarry, more than 2 m of the Devonian Ashern Formation overlie the Cedar Lake Formation (see Figure 8.1). The Ashern Formation is characterized by dark reddish brown, argillaceous, microcrystalline dolostone with little porosity. The base of this homogeneous interval includes light yellowish grey, rip-up clasts derived from the underlying strata, which are considered to represent the uppermost portion of the Silurian Chemahawin Member (Figure 8.2 C). The finely laminated, tight, unfossiliferous dolomitic mudstones of the yellowish grey interval at the top of the Chemahawin Member are characteristic of facies 4. The highest occurrence of fossils within the Mulvihill West Quarry core occurs at around 3.5 m depth, where gastropod steinkerns, brachiopods, and unrecognizable bioclasts account for approximately 10% of rock volume. Thin beds of oolitic dolostone occur throughout the bioclastic interval. A facies 2 faunal assemblage is found below this interval, containing predominantly small, tabular stromatoporoids and few colonial corals. This 4-m-thick interval represents the maximum biotic development in this core, with 30-50% fossils by rock volume, which is in striking contrast with the underlying bioturbated interval representing facies 3, which extends to a depth of 18 m. An interval of pale, chalky dolostone is found below facies 3, and is assumed to have been deposited under similar conditions as facies 4. Underlying strata likely represent a second interval of facies 2, as small stromatoporoids, accounting for 25-40% of rock volume, increase with depth within a greyish matrix. A second interval of pale, chalky dolostone is found in the lowermost 10 m of core, with a 20-cm layer of laminated pale red and green clays near the base of the cored strata.

8.4 Correlation and Interpretations

At Lundar, located a few kilometers east of the Silurian-Devonian contact, the top of the Chemahawin Member is missing, likely removed by erosion. Estimates of the thickness of missing strata in this area were determined using the extrapolated position of the Silurian-Devonian contact on geologic maps, the southwestward regional dip of 2.8 m per kilometre (Beyzs and McCabe 1996), and the local topography near Lundar (Energy, Mines and Resources Canada topographic map 62 J/9, Edition 3, 1:50000).

The elevation of the stratigraphic horizon represented by the bedrock surface at the Lundar Quarry and the top of the Lundar Quarry North core, is approximately 262 m (Manitoba Industry, Economic Development, and Mines (IEDM) Branch). Measuring in a southwest direction from the Lundar Quarry, the Silurian-Devonian contact of Stearn (1956, Supplementary Map 1) is approximately 3.5 km away. Using the regional dip, over a distance of 3.5 km there is a calculated drop of 9.8 m for the stratigraphic horizon. The elevation of the top of the Chemahawin Member at the Silurian-Devonian contact was estimated from the topographic map to be approximately 255 m. Thus, there is a difference of 7 m in elevation between these two sites. Subtracting the difference in elevation from the projected position of the stratigraphic horizon leaves a difference of 2.8 m, which can be interpreted as the amount of Chemahawin Member strata likely missing from the top of the Lundar Quarry.

In contrast, using the Silurian-Devonian contact on the geologic map of Corkery (1994), the measured distance from the Lundar Quarry southwestward to the unconformity is 10 km. Using the regional dip, there is a drop of 28 m for the stratigraphic horizon. The estimated elevation at the Silurian-Devonian contact of Corkery (1994) is approximately 249 m. The difference between the elevation at Lundar

(262 m) and at the Silurian-Devonian contact is 13 m. Subtracting this value from the projected position of the stratigraphic horizon reveals that an estimated 15 m of Chemahawin Member strata are missing at Lundar.

Thus, between 3 m and 15 m of Chemahwin Member strata below the Silurian-Devonian contact are estimated to be missing at the Lundar Quarry. The Silurian-Devonian contact and upper Chemahawin Member are preserved in the Mulvihill West core. Based on stratigraphic correlation of the Lundar Quarry North and Mulvihill West Quarry cores by Cowan (1971, Figure 2), approximately 6 m of strata are missing from the top of the Lundar Quarry North core, assuming minimal relief on the Devonian unconformity. This is within the independently estimated range of 3-15 m described above.

As facies 1 is absent from the Mulvihill West core, direct correlation of this facies is not possible between the two cores. At approximately 8 m below the Silurian-Devonian contact, however, an interval of facies 2 represents the maximum biotic development within the Mulvihill core. Similarly, facies 1 at the top of the Lundar Quarry North core represents maximum biotic development. Thus, based on faunal content of these lithologies, and the estimated amount of strata likely missing from the top of the Lundar Quarry North core, this interval of facies 2 in the Mulvihill West core can be correlated to facies 1 at the top of the Lundar Quarry North core (see Figure 8.1). This correlation also places the underlying intervals of facies 3, 2, and 4 at approximately the same stratigraphic positions in the two cores (Figure 8.1). Thus, the stratigraphic successions in the two cores are comparable. The red layer near the base of the Mulvihill West core, however, is absent at the corresponding position within the Lundar Quarry North core. Based on subsurface work by Cowan (1971), the Cedar Lake Formation maintains relatively uniform thickness throughout the Interlake area, so it is unlikely that the red layer at the base of the Mulvihill West Quarry core correlates with the v marker bed of the Lundar Quarry North core. Thus, this layer was likely a local feature, and does not represent a major, basin-wide marker bed, such as the v marker.

According to Stearn (1956), the top of the East Arm Formation is characterized by the presence of abundant brachiopods. Within the core from Lundar, a bioclastic interval containing brachiopods and gastropod steinkerns was recognized a few metres above the v marker bed. Thus, the contact between the East Arm and Cedar Lake formations is likely at the top of this bioclastic interval, which is approximately 7.5 m above the v marker (Figure 8.1). The East Arm Formation is estimated to be between 12 m and 15 m thick (Stearn 1956; Johnson and Lescinsky 1986), which would place the v marker near the middle of the formation.

Based on the correlation of cores, in the vicinity of Lundar and Mulvihill, the Cedar Lake Formation is estimated to be approximately 42.5 m thick. Johnson and Lescinsky (1986), referring to Cowan (1971), stated that the Cedar Lake Formation was about 50 m thick. Cowan, however, used the v marker as the base of the Cedar Lake Formation in his stratigraphic scheme. Thus, this discrepancy accounts for the additional 7.5 m of thickness reported by Johnson and Lescinsky (1986), as 50 m of strata are present from the base of the Devonian to the v marker based on the correlation in the present study.

The strata within the Lundar Quarry North core represent an overall deepening upward succession of facies. The lower 30 m of cored strata, including the upper East Arm and lower Cedar Lake formations, are characteristic of shallow water, restricted conditions. Laminated mudstones at the base of the Cedar Lake Formation may represent the stromatolitic dolostones of the Cross Lake Member (Stearn 1956). These strata are overlain by oolitic and intraclastic intervals, which suggest higher energy conditions within the environment.

In the Interlake area, Cowan (1971) reported that the Chemahawin Member is 25-39 ft (7.6-11.9 m) thick. In this study, the core obtained from Mulvihill West Quarry reveals 11.27 m of strata from the top of the Cedar Lake Formation to the base of the upper facies 2 interval, which may therefore represent the base of the Chemahawin Member, according to Cowan (1971). It seems reasonable, however, also to include the lower interval of facies 2 within the Chemahawin Member, as it represents the same Chemahawin lithology. Thus, for the present study, the base of the Chemahawin Member is located at the lower boundary of the lower facies 2 interval within the Mulvihill West Quarry. The Chemahawin Member represents somewhat deeper conditions than the lower Cedar Lake Formation, with the gradual introduction of fauna to the full-scale development of a biostromal unit near the top of the core. This sequence is consistent with the interpreted transgressive episode of the Cedar Lake Formation, which started after the latest interval of subaerial exposure in the East Arm Formation, represented by the v marker bed (see Figure 1.3; Johnson and Lescinsky 1986).

Within the Mulvihill West core, strata above the upper facies 2 interval, which has been correlated to the facies 1 interval at the top of the Lundar Quarry, represent a gradual shallowing of facies. Oolitic intervals and bioclastic units characterized by shallow-water fauna, and the uppermost laminated dolomitic mudstones, lie above the level of maximum biotic development. Thus, this transition likely represents the suggested regressive episode which occurred at the close of Cedar Lake deposition (Johnson and Lescinsky 1986).

Chapter 9: Faunal Relationships

9.1 Introduction

Both modern and ancient reef communities commonly exhibit complex relationships among fauna. These interactions can be the result of competition for limited space and nutrients within the reef, symbiotic intergrowths, or the result of live organisms using dead skeletons as a viable substrate (Fagerstrom et al. 2000). Competition within a reef will result in dense-packing of organisms, as each species attempts to achieve dominance over other taxa (Fagerstrom et al. 2000). All organisms require similar resources, often resulting in intense interspecific competition. How different species acquire and use the available resources reflects the survival and competitive strategies of each organism (Fagerstrom et al. 2000). Often, one species will outcompete others and continue to thrive in the environment. In order for competitors to maintain a population within that environment, they must adapt their life habits to reduce competition (Wood 1999). Thus, species coexisting within the same environment will have more restricted niches than if those species were living separately (Wood 1999). Symbiotic relationships may or may not be competitive in nature, and this may be recorded as interactions of skeletal tissue between the host and symbiont organisms. As the relationships between organisms typically cannot be directly observed for ancient communities, evidence to suggest biological interactions during life must be derived from the fossil record.

9.2 Methods

As all taxa present within the Chemahawin Member are found within facies 1, and facies 1 is found at the majority of sites within the Lundar Quarry, only faunal relationships in this facies are considered for this analysis. As different numbers of specimens are observed at each locality within the quarry, direct comparison of absolute abundances is inappropriate for recognizing dominant species. Thus, the relative abundances of species for each faunal group were compared in order to recognize dominant species within the unit. Additionally, the diversity of tabulate corals present within the Chemahawin Member was considered in order to understand how these corals could have coexisted in the same environment while competing for similar resources. Colonial rugose corals were not considered for this analysis, as they are commonly found within the coenostea of stromatoporoids, and thus their distribution and abundances at each locality may be influenced by that of the host. In order to analyze symbiotic relationships, the distributions of symbiotic corals were compared with host stromatoporoid types in order to recognize evidence for host selection by the corals. As well, evidence for organisms growing directly on other skeletons was analyzed, as encrusting relationships may suggest the presence of a biologically controlled framework. Encrustation provides a binding component to the biostrome framework, which is apparently lacking in the form of cementation or algal binding within the Chemahawin biostrome.

9.3 Competitive Relationships

9.3.1 Diversity

Diversity has been defined as the proportional abundances of species present within a study area (Dodd and Stanton 1990). Examining the relative abundances of species or growth forms within each faunal group allows for direct comparison of faunal proportions, regardless of the number of specimens examined at different sites. The diversity of taxa at each locality may provide insight into the competitive relationships which led to the dominance of certain species over others.

Within the Lundar Quarry, stromatoporoid Type CY is dominant in the stromatoporoid-coral fauna, accounting for 44% of all specimens, and over 60% of all stromatoporoids present in the unit (Table 9.1). Thus, stromatoporoid Type CY was likely the best-suited taxon for the conditions within the paleoenvironment. Stromatoporoids most commonly exhibit tabular growth forms in this unit. Statistical analysis of stromatoporoid growth forms for each type of stromatoporoid did not reveal any significant differences among taxa (Appendix E-1). Thus, the morphologic plasticity of all types of stromatoporoids within the Chemahawin Member was similar, suggesting that the dominance of stromatoporoid Type CY cannot be attributed to a related genetic advantage for success within the environment. In contrast to growth forms, the relative abundances of specimens in the various coenosteum size categories for each type of stromatoporoid revealed a significant relationship (Appendix E-2). Though stromatoporoid Type CP is not abundant within the quarry, it tended to grow larger skeletons, as 35% of coenostea are larger than 50 mm wide. The differences in coenosteum sizes among stromatoporoid types may be the result of inherent genetic control, or conditions within the environment which limited the sizes of other stromatoporoids.

Favosites niagarensis lundarensis is the most common coral found within the Chemahawin Member, accounting for 45% of all colonial corals present (Table 9.2).

Table 9.1: Absolute abundance of stromatoporoid specimens and their proportion with respect to all specimens of stromatoporoids and corals recorded in hand sample analysis for facies 1 (N = 710). Locations of localities are shown in Figure 5.1. Abbreviations are as follows:

# = Number of specimens
Strome = All stromatoporoids
% Pop. = Proportion with respect to N
SW cor. = Southwest corner
CY = Stromatoporoid Type CY
PI = Stromatoporoid Type PI
CP = Stromatoporoid Type CP
VC/Un = Stromatoporoid Type VP and/or unidentified specimens
Rel. Ab. = Proportion of stromatoporoid types relative to the total number of stromatoporoid specimens (n = 503)

Locality	# Strome	% Pop.	# CY	% Pop.	# PI	% Pop.	# CP	% Pop.	# VC/Un	% Pop.
D-W	108	15.21%	68	9.58%	30	4.23%	8	1.13%	0 / 2	0.28%
H	55	7.75%	35	4.93%	20	2.82%	0	0.00%	0	0.00%
J-X	120	16.90%	83	11.69%	23	3.24%	12	1.69%	1 / 1	0.28%
K	51	7.18%	21	2.96%	15	2.11%	15	2.11%	0	0.00%
L	37	5.21%	9	1.27%	16	2.25%	12	1.69%	0	0.00%
O	46	6.48%	24	3.38%	12	1.69%	11	1.55%	0	0.00%
SW cor.	86	12.11%	70	9.86%	13	1.83%	3	0.42%	0	0.00%
Overall	**503**	**70.85%**	**309**	**43.52%**	**129**	**18.17%**	**61**	**8.59%**	**4**	**0.56%**
Rel. Ab.			**61.43%**		**25.65%**		**12.13%**		**0.80%**	

Table 9.2: Absolute abundance of colonial coral specimens and the proportions of the most common species with respect to all colonial coral specimens recorded in hand sample analysis for facies 1 (N = 151). Locations of localities are shown in Figure 5.1. Abbreviations are as follows:

= Number of specimens
Col. Corals = All colonial corals
% Pop. = Proportion with respect to N
SW cor. = Southwest corner

Lund. = *Favosites niagarensis lundarensis*
Inaeq. = *Favosites niagarensis inaequalis*
Goth. = *Favosites gothlandicus*
Col. Rug. = All colonial rugose corals

Locality	# Col. Corals	# Lund.	% Pop.	# Inaeq.	% Pop.	# Goth.	% Pop.	# Col. Rug.	% Pop.
D-W	45	23	51.11%	4	8.89%	1	2.22%	10	22.22%
H	22	8	36.36%	2	9.09%	0	0.00%	7	31.82%
J-X	37	15	40.54%	6	16.22%	2	5.41%	8	21.62%
K	4	3	75.00%	1	25.00%	0	0.00%	0	0.00%
L	10	5	50.00%	1	10.00%	0	0.00%	4	40.00%
O	11	4	36.36%	0	0.00%	0	0.00%	5	45.45%
SW cor.	22	11	50.00%	4	18.18%	2	9.09%	5	22.73%
Overall	**151**	**69**	**45.70%**	**18**	**11.92%**	**5**	**3.31%**	**39**	**25.83%**

Over 50% of all specimens of this coral are found within the coenostea of stromatoporoids. The ability to enter into such relationships, and to maintain relatively high populations on a variety of substrates, suggests that this species was likely a successful competitor for available substrate and space within the biostrome structure.

The solitary rugose coral *Amplexoides* sp. A is the most abundant solitary coral within the Chemahawin Member, with more than double the number of specimens recorded for other species (Table 9.3). The majority of specimens, however, are smaller than 6 mm in diameter, whereas a greater proportion of specimens of *Dinophyllum lundarense* and *Cystiphyllum* cf. *niagarensis* achieved larger sizes. This difference in corallite size may be the result of genetic differences among species, or some factor of the environment which limited corallum sizes of this coral.

9.3.2 Niche Partitioning

Coexistence of coral species with different corallite sizes may suggest niche partitioning, in which different organisms with similar requirements are able to live in the same environment without competing by partitioning available resources (Watkins 2000). Niche partitioning can be regarded as an outcome of interspecific competition under conditions of limited resources (Watkins 2000). Copper and Grawbarger (1978) were the first to suggest niche partitioning among major groups of corals to explain the high diversity of an Ordovician coral carpet located on Manitoulin Island, Ontario. Prey size has been correlated with polyp size in modern scleractinian corals (Sebens and Johnson 1991), and polyp size is related to corallite size (Watkins 2000). Species with smaller polyps, and therefore smaller corallites, may have required smaller food particles than

Table 9.3: Absolute abundance of solitary rugose coral specimens and the proportion of each species with respect to all solitary rugose coral specimens recorded in hand sample analysis for facies 1 (N = 58). Solitary corals for which taxonomic identification was not possible are included in the total number of solitary corals at each locality. Locations of localities are shown in Figure 5.1. Abbreviations are as follows:

= Number of specimens
Sol. Rug. = All solitary rugose corals
% Pop. = Proportion with respect to N
SW cor. = Southwest corner

Amplex. = *Amplexoides* sp. A
Dino. = *Dinophyllum lundarense*
Cysti. = *Cystiphyllum* cf. *lundarensis*

Locality	# Sol. Rug.	# Amplex.	% Pop.	# Dino.	% Pop.	# Cysti.	% Pop.
D-W	10	5	50.00%	3	30.00%	1	10.00%
H	6	2	33.33%	0	0.00%	1	16.67%
J-X	14	6	42.86%	3	21.43%	1	7.14%
K	4	1	25.00%	2	50.00%	1	25.00%
L	14	8	57.14%	2	14.29%	3	21.43%
O	2	1	50.00%	1	50.00%	0	0.00%
SW cor.	8	5	62.50%	2	25.00%	0	0.00%
Overall	**58**	**28**	**48.28%**	**13**	**22.41%**	**7**	**12.07%**

those captured by the polyps of corals with larger corallites (Watkins 2000). Corals possessing similar sizes of corallites, however, may have fed on the same-sized particles, and thus competition may have been intense. In such situations, the more competitive species would have likely eclipsed the weaker contender and dominated the microhabitat.

Porter (2003) recognized the co-existence of two species belonging to the same genus of colonial rugose coral within the Ordovician Red River Formation of southern Manitoba, and suggested that this represents niche partitioning among species. A similar phenomenon is observed within the Chemahawin Member, as the four species of the cerioid genus *Favosites* present within the Lundar Quarry show no significant overlap of mature corallite diameters (Figure 9.1). Non-overlapping niches of these species suggest differential feeding habits which reduced competition between species, permitting occupation of the same microenvironments. Lower abundances of corals with larger corallites within this unit may be a function of a limited amount of larger prey within the environment, whereas smaller prey were likely more abundant, allowing corals with smaller corallites to dominate.

In addition, there is no significant overlap of mature corallite sizes between the two species of coenenchymal corals (*Plasmopora* sp. 1 and Proporicae sp. 1), nor between the two species of cateniform corals (*Halysites* cf. *catenuarius* and *Halysites* sp. 1; Figure 9.1). Thus, members of the same group of corals may have reduced competition between species by possessing different feeding habits. Between members of the three different groups of corals, however, there is significant overlap of mature corallite sizes (between *F. niagarensis lundarensis, Plasmopora* sp. 1, and *Halysites* sp. 1, and between *F. niagarensis inaequalis*, Proporicae sp. 1, and *Halysites* cf.

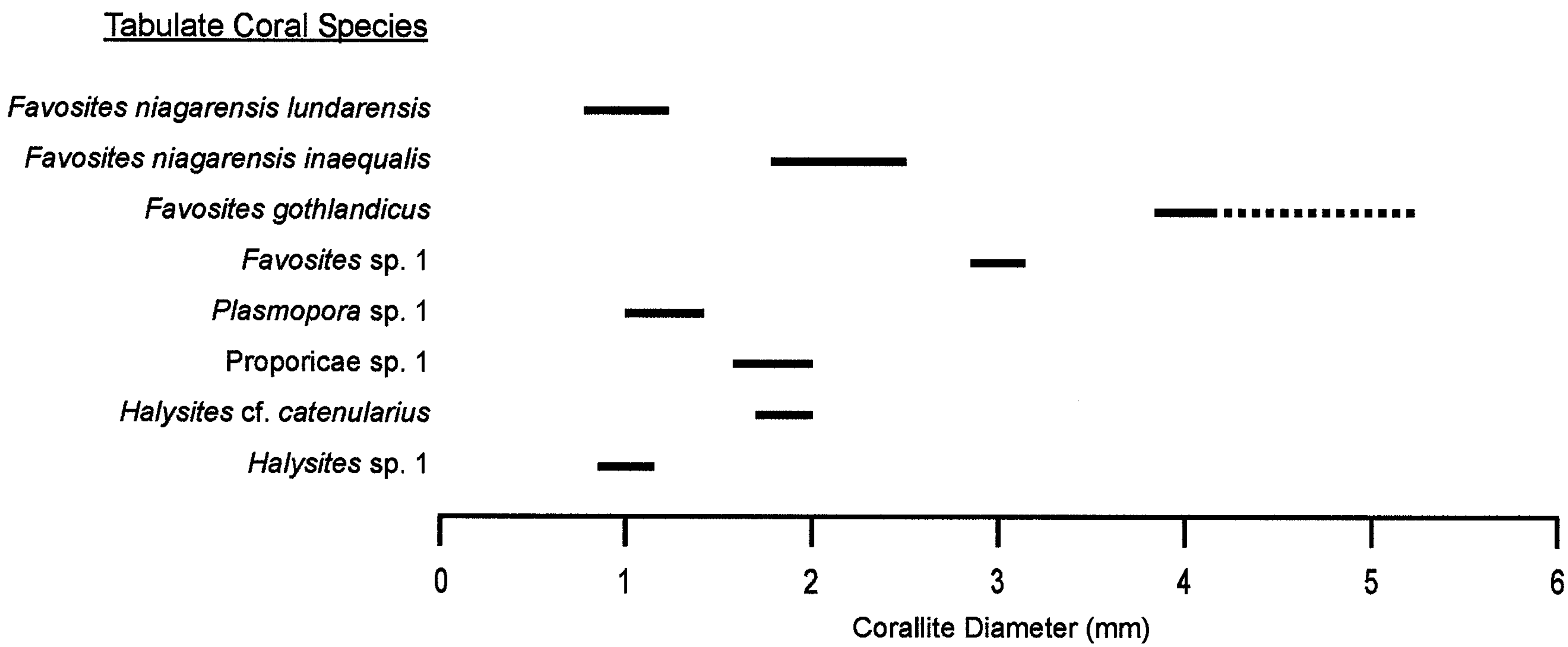


Figure 9.1: Ranges of mature corallite diameters for each species of tabulate coral found within the Lundar Quarry. Dashed line indicates the maximum corallite sizes observed for *Favosites gothlandicus*.

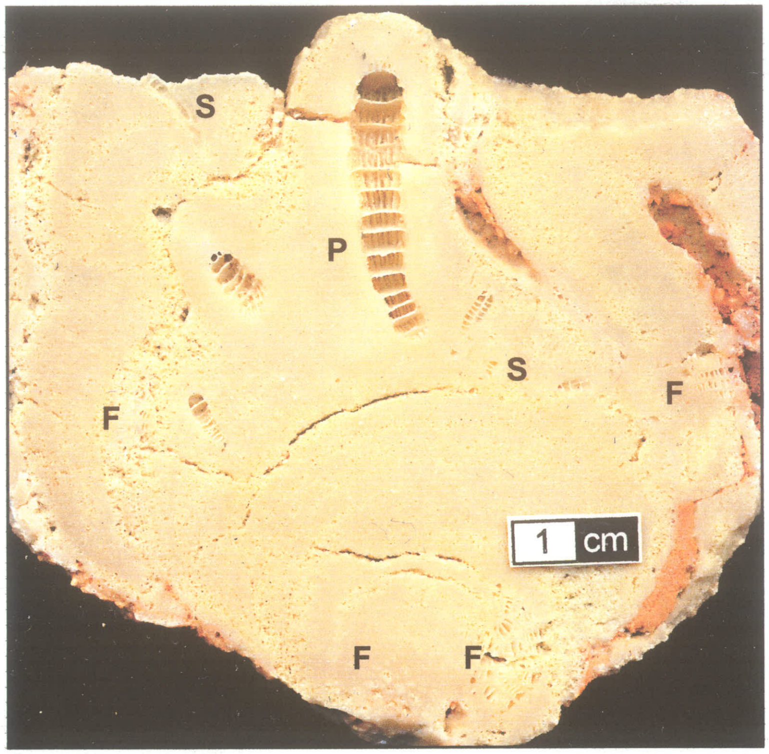
catenularius; Figure 9.1). It is possible that, although these corals may have utilized the same size of food resources, each group may have selected different types of resources within the same size class. This may have allowed the different groups to co-exist within the same microenvironment without competition.

A formal statement regarding the required size difference of corallites for niche partitioning has not been made. Data collected by Copper and Grawbarger (1978), however, included corals with corallite sizes that differed by ratios of 1.6 to 1.8. Thus, this may represent the minimal necessary difference between corallite sizes of coexisting taxa of similar body plan. It is noteworthy that ratios between average corallite diameters of species of *Favosites* in the present study range between 1.4 and 2.2.

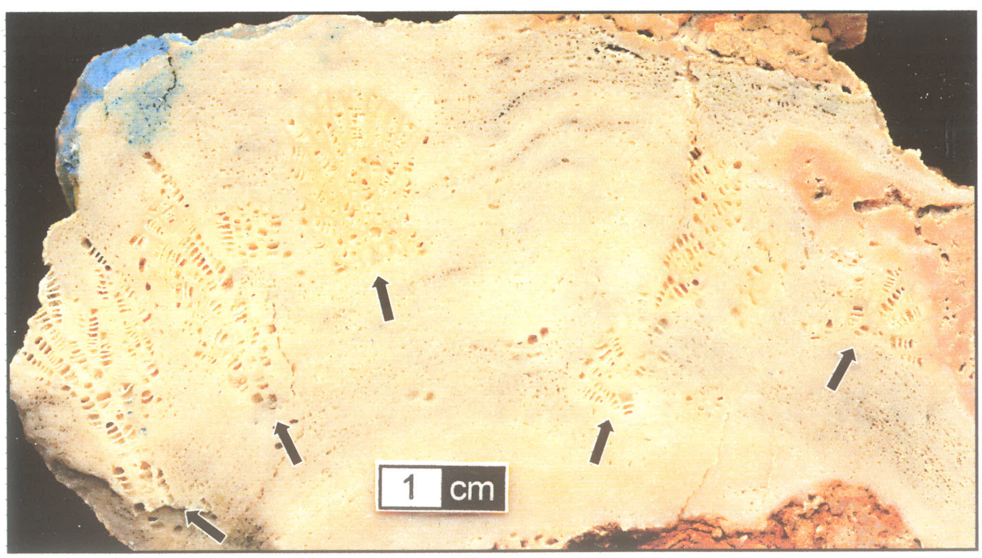
Thus, the Chemahawin biostrome was inhabited by a low-diversity suite of tabulate corals which may have had specialized feeding habits that permitted cohabitation of the same microenvironments within and around the structure. The limited abundances of most tabulate coral species catalogued in this study, however, did not permit a thorough investigation of niche partitioning.

9.4 Symbiotic Associations

The occurrence of colonial coral skeletons within the skeletal tissue of stromatoporoid fossils is common within facies 1 of the Chemahawin Member, as more than 10% of stromatoporoid specimens contain one or more coral within the coenosteum (Figure 9.2). Such relationships between fauna are still poorly understood, as little information can be obtained regarding the soft tissue communication between organisms (Kershaw 1987). Careful examination of the relationships between skeletons, however,



A



B

Figure 9.2: Longitudinal polished sections of stromatoporoid skeletons hosting corals in symbiotic association obtained from the Lundar Quarry. A) Multiple associations of tabulate and rugose corals within the skeleton of Stromatoporoid Type CP (F = *Favosites niagarensis lundarensis*; P = *Pycnostylus guelphensis*; S = *Synamplexoides varioseptatus*). B) Multiple coralla of *Favosites niagarensis lundarensis* (arrows) living in symbiotic association with Stromatoporoid Type CY.

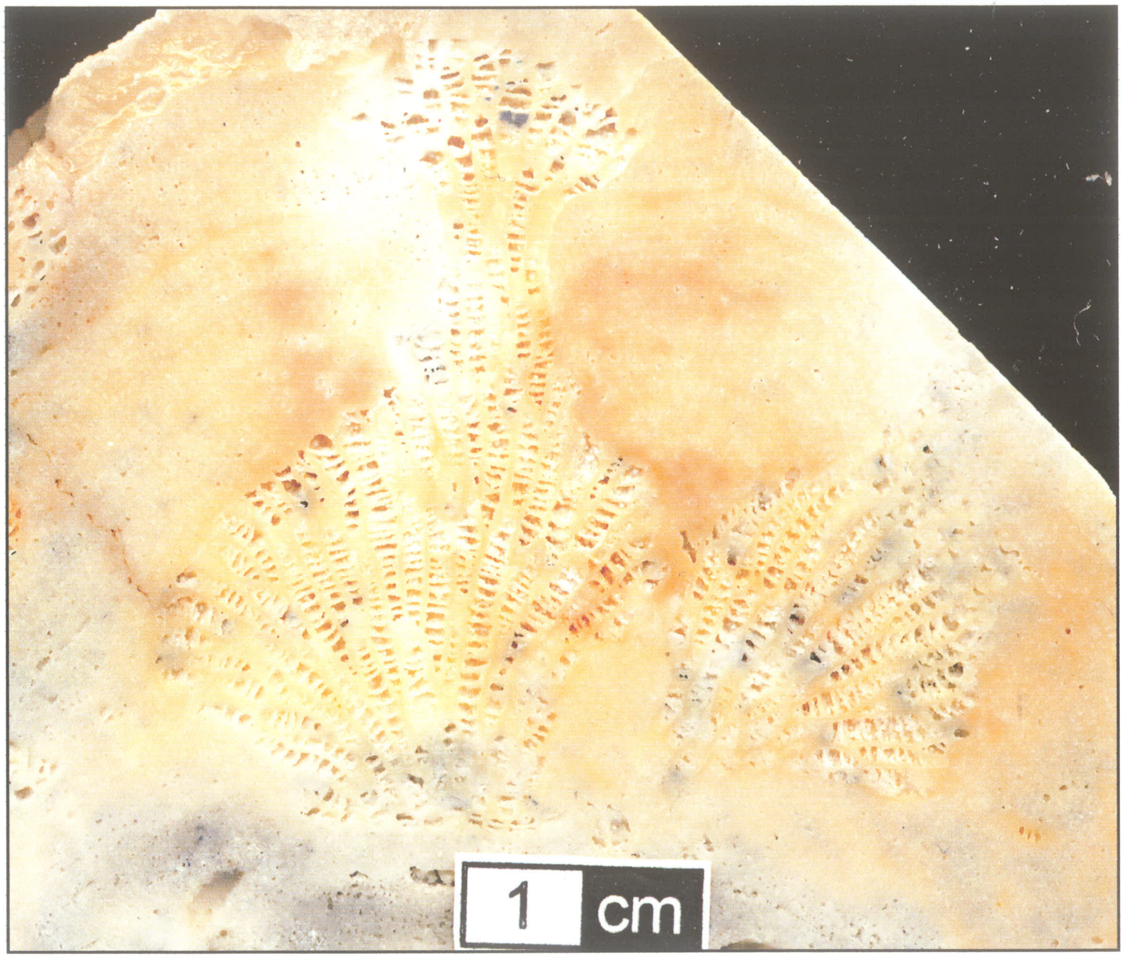
can provide evidence for symbiotic associations between organisms. Corals of the Chemahawin Member appear to have initiated on growth surfaces of stromatoporoids, possibly at sites of partial mortality. Both organisms continued to growth vertically, with the growth orientation of these corals being similar to that of the stromatoporoids. In most cases, the stromatoporoid eventually enclosed the coral skeleton. This likely followed the death of the coral, as Gao and Copper (1997) determined that Silurian stromatoporoids had considerably slower growth rates (0.8-1.3 mm/yr) than tabulate and colonial rugose corals (2-9 mm/yr, and 4.3-27.2 mm/yr, respectively). Thus, it is unlikely that the corals were overwhelmed by the stromatoporoids and thereby incorporated within coenostea. Therefore, this evidence suggests that these organisms were living together in symbiotic association. Although host stromatoporoids appear to have neither benefited nor been impaired by the relationship, symbiosis may have provided some protection for delicate organisms from biological or physical disturbance (Wood 1999). Thus, small tabulate corals or fasciculate colonial rugose corals may have required protection from higher energy conditions, as there is little evidence for bioturbation or predation within facies 1.

Tabulate corals within the Lundar Quarry most commonly exhibit irregular and domical growth forms. The abundance of irregular forms, however, may be a result of the high number of *Favosites niagarensis lundarensis* that inhabit stromatoporoid skeletons, which could have influenced the growth form. The majority of irregular corals fall within the size 1 category, which may also be a function of symbiotic association with stromatoporoids. Symbiotic corals must keep up with the growth rates of the stromatoporoid or risk being overgrown, which would result in shorter life spans.

Tabulate corals with tabular growth forms are not commonly found in symbiotic association with stromatoporoids, as a tabulate form could completely cover the stromatoporoid growth surface, thus killing the host. Correspondingly, two-thirds of observed domico-columnar forms of *F. niagarensis lundarensis* are found within the skeletons of stromatoporoids. This growth form would have allowed for both the coral and stromatoporoid to maintain normal growth simultaneously. Several specimens of *F. niagarensis lundarensis* found in symbiotic association with stromatoporoids show evidence of partial mortality of the growth surface near the edges of the colony, with sustained growth near the centre (Figure 9.3). This feature is likely evidence for partial mortality of the polyps near the extremities of the colony. Typically, corals were able to recover from the partial mortality and resume lateral growth at a higher level within the stromatoporoid skeleton.

The colonial rugosan *Pycnostylus guelphensis* is only found in symbiotic relationship with stromatoporoids, the majority of which are larger, domical and irregular forms (see Figure 9.2 A). Due to its larger corallite sizes, it is likely that *P. guelphensis* preferentially occupied larger stromatoporoids, which provided greater accommodation space for upward growth of the coral than tabular forms. Similarly, symbiotic tabulate corals are most commonly found within stromatoporoid coenostea of greater than 15 mm width. It is also noteworthy that only tabulate colonies smaller than 20 mm width are found in symbiotic relations with stromatoporoids, suggesting that larger corals may have been unsuitable given the accommodation space available from stromatoporoids.

Stromatoporoid Type CY is the most common host for symbiotic associations with colonial corals. This is likely a function, however, of the dominance of this type of



<u>Figure 9.3:</u> Longitudinal polished section of a specimen of Stromatoporoid Type CP that hosts two coralla of *Favosites niagarensis lundarensis* within the skeleton. The larger coral on the left shows evidence of partial mortality at the colony edges. Sustained growth near the centre of the colony allowed the coral to survive and resume lateral growth at a higher level within the stromatoporoid skeleton.

stromatoporoid within the unit. Statistical analysis comparing the type of stromatoporoids which contain one or more symbiotic tabulate coral revealed no preference for inhabiting any particular type of stromatoporoid (Appendix E-3). In contrast, statistical analysis revealed that the proportion of colonial rugosans occurring in symbiotic relationship with each type of stromatoporoid varies among types (Appendix E-4). Stromatoporoid Type CP hosted the greatest proportion of colonial rugosans, as compared with other types. This is likely evidence for host selection by the symbiotic coral.

No definable trend was recognized for the preference of symbiotic corals to inhabit particular stromatoporoid growth forms. The initiation and termination of coral colonies within the stromatoporoid skeleton can often be associated with well-developed laminae, which indicate periods of slow vertical growth (Kershaw 1998). The majority of symbiotic corals observed in the present study, however, were not associated with major laminae.

Stromatoporoids were capable of hosting multiple symbiotic corals within their skeletons (see Figure 9.2). Specimens of the three major types of stromatoporoids all show examples of multiple symbiotic relationships. Commonly, multiple colonies of *Favosites niagarensis lundarensis* are found within a single skeleton, often in association with one or more rugosan colonies (Figure 9.2). As both species of colonial rugose coral found within this unit exhibit fasciculate growth within the skeleton of stromatoporoids, it is difficult to determine the number of coralla present. Thus, multiple specimens of the same species could not be recognized within the same skeleton. Such complex relationships likely reflect extreme competition for space within the biostrome.

9.5 Encrusting Relationships

Fossils which were either draped over or wrapped around other fossils, or found with the basal portion of the skeleton more than 50% in contact with another fossil with no apparent sediment between, were considered to represent encrusting relationships. Though dolomitization likely obscured many such features, several complex overgrowths and encrusting relationships have been observed.

Criteria for recognizing biological interactions (see Fagerstrom et al. 2000), such as those seen between favositid corals in symbiotic relationships with stromatoporoids (see Figure 9.3), were not observed for encrusting relationships. Thus, the encrusting relationships within this unit are not considered to be true biological interactions, but rather taphonomic feedback, as the live organisms are assumed to have encrusted dead skeletons.

The results of this analysis can be seen in Table 9.4. A total of 38 encrusting relationships were observed in hand samples (Figure 9.4). Approximately two-thirds of observed encrusters are stromatoporoids, with stromatoporoid Type CY as the principal encruster, though the coral *Favosites niagarensis lundarensis* was also dominant. Comparisons among localities revealed that localities H and J-X show the greatest abundances of encrusting relationships with regard to the total sample area, with 400 and 328 relationships per square metre, respectively. The northern portion of the quarry showed the lowest frequency of encrusting relationships, with a total of only one stromatoporoid found encrusting another at localities O, L, and K combined.

The evidence for encrusting relationships in facies 1 strengthens the argument for the presence of a biostrome within the Lundar Quarry. Though limited numbers of such

Table 9.4: Encrusting relationships by locality for facies 1. The types of encrusting taxa are listed according to the faunal group used for attachment. The total sample area for each locality was calculated based on the total number of 20 cm^2 detailed areas analyzed in hand sample for this study. Abbreviations are as follows:

Total Freq. = total frequency of each type of encrusting relationship
encrust/m^2 = total number of encrusting relationships per square metre

Encrusting Relationships								
Type / Encrusters	Total Freq.	D-W	H	J-X	K	L	O	SW corner
Stromatoporoids	**25**	**4**	**5**	**13**	**0**	**0**	**1**	**3**
On Stromatoporoid	16	3	3	7	0	0	1	2
Type CY on Type CY	4	1		1				2
Type PI on Type CY	2	1		1				
Type PI on Type PI	7	1	3	3				
Type CP on Type CY	1						1	
Type CP on Type CP	1			1				
Type VP on Type CY	1			1				
On *Favosites*	7	1	2	5	0	0	0	0
Type CY on *F. niag. lundarensis*	2		1	2				
Type PI on *F. niag. lundarensis*	1			1				
Type CY on *F. niag. inaequalis*	2	1		1				
Type PI on *F. niag. inaequalis*	2		1	1				
On Solitary Coral	1	0	0	0	0	0	0	1
Type CY on *Dinophyllum lundarense*	1							1
On Other Fauna	1	0	0	1	0	0	0	0
Type CY on Echinoderm Columnal	1			1				
Colonial Corals	**13**	**2**	**3**	**6**	**0**	**0**	**0**	**2**
On Stromatoporoid	12	1	3	6	0	0	0	2
F. niag. lundarensis on Type CY	5		2	3				
F. niag. lundarensis on Type PI	2	1	1					
F. niag. lundarensis on Type VP	1			1				
F. niag. inaequalis on Type CY	1							1
Synamplexoides varioseptatus on Type CY	3			2				1
On Solitary Coral	1	1	0	0	0	0	0	0
F. niag. lundarensis on *Amplexoides* sp. A	1	1						
Totals	**38**	**6**	**8**	**19**	**0**	**0**	**1**	**5**
Sample Area (m^2)	0.222	0.052	0.020	0.058	0.018	0.026	0.020	0.028
# encrust/m^2	171.17	115.38	400.00	327.59	0.00	0.00	50.00	178.57

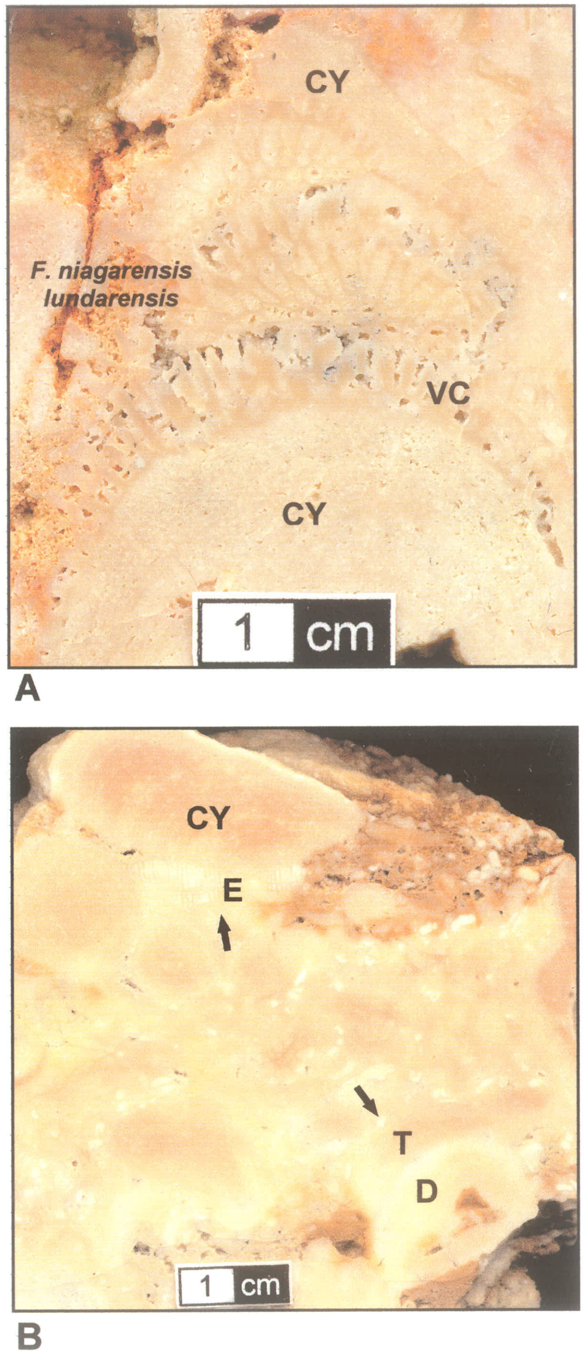


Figure 9.4: Longitudinal polished sections of examples of encrusting relationships observed within samples of facies 1 obtained from the Lundar Quarry. A) Multiple encrusting relationships: Stromatoporoid Type CY is encrusted by Type VC, which is encrusted by *Favosites niagarensis lundarensis*, which is encrusted by a second Type CY. B) Two examples of encrusting relationships: top arrow shows Stromatoporoid Type CY encrusting an articulated segment of echinoderm columnals (E); bottom arrow points to two specimens of Stromatoporoid Type PI, with a tabular form (T) encrusting a domical form (D).

relationships were observed in hand sample, the presence of basal attachment by stromatoporoids to other skeletons suggests the possibility of vertical development of the biostrome above the surrounding seafloor. Basal attachment by stromatoporoids and colonial corals to other skeletons would have provided some structural rigidity to the biostrome, which is lacking in the form of calcareous algae or cementation. Since the majority of stromatoporoid and coral specimens within the Chemahawin Member did not initiate growth on a hard substrate, the presence of encrusting relationships suggests competition for space within a crowded biostrome.

Chapter 10: Spatial Analysis

10.1 Spatial Trends within the Lundar Quarry

In order to understand the paleoenvironmental conditions that prevailed during deposition of the Chemahawin Member, it is important to analyze the lateral distribution of fauna. Faunal distributions are controlled to some degree by the physical environment (Schneider and Ausich 2002). Different species or growth forms may have preferentially occupied different positions within and around the biostrome where both environmental conditions and competition with other organisms were more favourable. Thus, recognition of spatial heterogeneity within the dataset may provide evidence for different microenvironmental conditions present at different positions within and around the biostrome. As well, interpreting the suite of fauna at each locality may aid in understanding the paleoecology of species or growth forms.

10.2 Spatial Analysis Methods

As fossils occur in great abundance only in facies 1 and 2, and facies 1 is the only unit exposed at the majority of study sites within the quarry, it is appropriate to compare faunal distributions among all sites for this facies. Additionally, all fauna represented within the Lundar Quarry are present within facies 1, so the lateral distribution of all fauna may be compared. Raw data were combined for all stratigraphic samples at each site representing facies 1. Within the southwest corner, facies 1 is exposed only along the top of the quarry, so data from the few collected samples were combined to generate a larger dataset. As well, data for other closely spaced sites were combined in order to achieve sufficient numbers for statistic analysis. Thus, the study areas compared in this analysis are localities D-W, H, J-X, K, L, O, and the southwest corner (see Figure 5.1).

Cluster analysis was conducted on abundance data for stromatoporoid and coral taxa at each locality within the Lundar Quarry (Appendix F; Figure 10.1). Two clusters were recognized within the data set, representing the northern localities (K, L, and O) and the southern localities (D-W, H, J-X, and southwest corner; see Figure 5.1). As well, patterns observed within the data revealed similarities among the southern localities, which are in contrast with those of the northern localities (see subsequent sections). Although data from the southwest corner were considered to be similar to the other southern localities, the limited amount of stratigraphic exposure at this location, as well as details observed within the data, resulted in consideration of the southwest corner separately (see Figure 5.1). Thus, based on cluster analysis and the distribution patterns of stromatoporoids and corals, three zones were recognized: the northern zone, the southern zone, and the southwest corner (see Figure 5.1).

Combined data in localities and zones contain unequal numbers of hand samples studied for this analysis, so direct comparison would be inappropriate. Thus, data for each locality were considered in terms of the numbers of specimens recorded per square metre, calculated by adding the number of 20 cm^2 areas studied on hand samples examined for each locality and converting to square metres (Tables 10.1, 10.2, and 10.3). As well, the average size index for taxa in each category was calculated for each locality in order to better understand biovolume as it relates to the faunal density of the unit.

A few unidentifiable specimens were observed within facies 1, but were not included for this analysis. As well, the single specimen of stromatoporoid Type VC occurs within facies 1; this was excluded from the data when comparing stromatoporoids

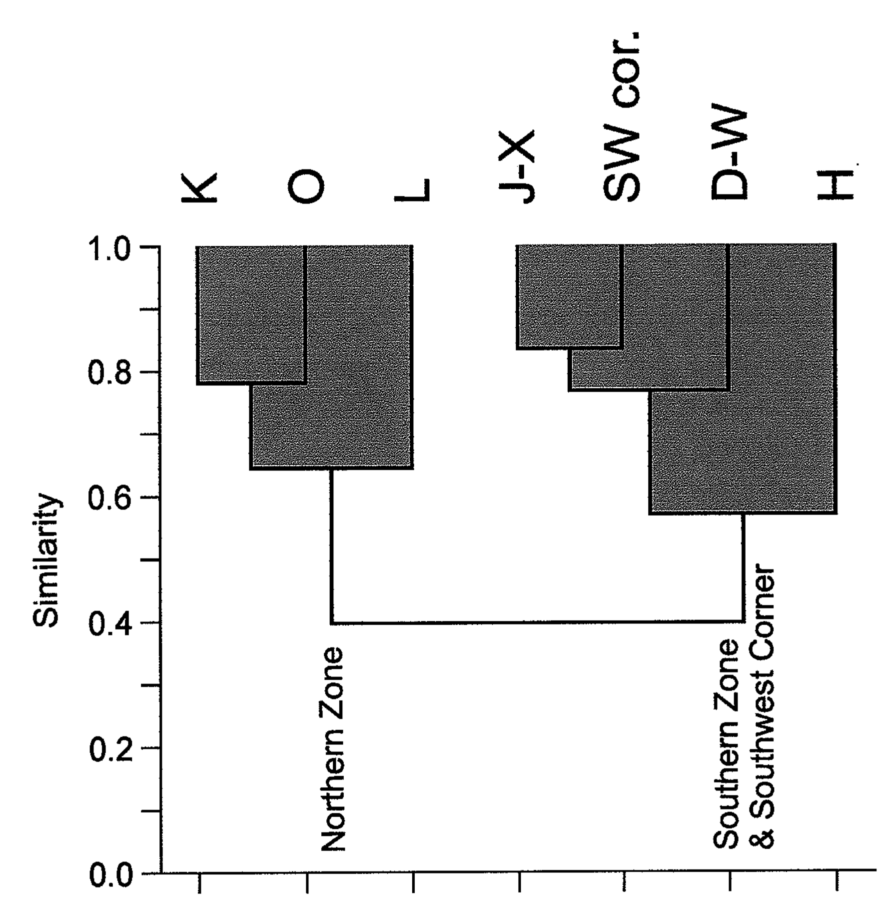


Figure 10.1: Cluster analysis hierarchical dendrogram for the abundances of stromatoporoid and coral taxa within facies 1 at each locality within the Lundar Quarry. This analysis revealed the presence of two clusters of localities: the northern localities (K, L, and O) and southern localities (D-W, H, J-X, and southwest corner). Based on this test and the distribution patterns of stromatoporoids and corals, three zones were recognized: the northern zone, the southern zone, and the southwest corner (see Figure 5.1).

Table 10.1: Abundances of stromatoporoids within facies 1 at each locality within the Lundar Quarry. The total numbers of hand samples examined from each locality for this analysis were tallied. The total area studied was calculated based on the number of 20 cm^2 hand sample detailed study areas examined from each locality. The number of specimens per square metre was calculated by dividing the total number of specimens at each locality by the total area (m^2) studied in hand sample for each locality. Average size indices were calculated based on the average of the assigned size classes for specimens at each locality. Southern zone includes localities D-W, H, and J-X; northern zone includes localities K, L, and O. Abbreviations are as follows:

Stromes = All types of stromatoporoids
Type CY = Stromatoporoid Type CY
Type PI = Stromatoporoid Type PI
Type CP = Stromatoporoid Type CP

Locality	# Samples	Area (m^2)	# Stromes	Stromes/ m^2	Avg. Size Index	# Type CY	Type CY/ m^2	Avg. Size Index	# Type PI	Type PI/ m^2	Avg. Size Index	# Type CP	Type CP/ m^2	Avg. Size Index
D-W	26	0.052	108	2076.92	1.815	68	1307.69	1.838	30	576.92	1.767	8	153.85	2.429
H	10	0.020	55	2750.00	1.891	35	1750.00	2.053	20	1000.00	1.706	0	0.00	0.000
J-X	29	0.058	120	2068.97	1.933	83	1431.03	1.831	23	396.55	1.913	12	206.90	2.583
K	9	0.018	51	2833.33	1.765	21	1166.67	1.810	15	833.33	1.800	15	833.33	1.667
L	13	0.026	37	1423.08	2.162	9	346.15	2.000	16	615.38	2.063	12	461.54	2.417
O	10	0.020	46	2300.00	1.870	24	1200.00	1.826	12	600.00	1.833	11	550.00	2.000
SW corner	14	0.028	86	3071.43	1.709	70	2500.00	1.657	13	464.29	1.846	3	107.14	2.333
Overall	111	0.222	503	2265.77	1.859	309	1391.89	1.824	129	581.08	1.841	61	274.78	2.183

Table 10.2: Abundances of tabulate corals within facies 1 at each locality within the Lundar Quarry. The number of specimens per square metre was calculated by dividing the total number of specimens at each locality by the total area (m^2) studied in hand sample for each locality (see Table 10.1). Average size indices were calculated based on the average of the assigned size classes for specimens at each locality. Size indices could not be calculated for *Favosites gothlandicus* or chain corals, as both were only present as fragments within the Lundar Quarry. Southern zone includes localities D-W, H, and J-X; northern zone includes localities K, L, and O. Abbreviations are as follows:

Tabs. = All identifiable tabulate corals
Lund = *Favosites niagarensis lundarensis*
Inaeq = *Favosites niagarensis inaequalis*
Goth = *Favosites gothlandicus*
Haly = both species of *Halysites*
Prop = both members of the superfamily Proporicae

Locality	# Tabs.	# Tabs./ m^2	# Lund	# Lund/ m^2	Avg. Size Index	# Inaeq	# Inaeq/ m^2	Avg. Size Index	# Goth	# Goth/ m^2	# Haly	# Haly/ m^2	# Prop	# Prop/ m^2	Avg. Size Index
D-W	35	673.08	23	442.31	1.130	4	76.92	1.500	1	19.23	7	134.62	0	0.00	0.00
H	15	750.00	8	400.00	1.125	2	100.00	2.000	0	0.00	5	250.00	0	0.00	0.00
J-X	29	500.00	15	258.62	1.467	6	103.45	1.800	2	34.48	6	103.45	0	0.00	0.00
K	4	222.22	3	166.67	1.333	1	55.56	1.000	0	0.00	0	0.00	0	0.00	0.00
L	6	230.77	5	192.31	1.600	1	38.46	2.000	0	0.00	0	0.00	0	0.00	0.00
O	5	250.00	4	200.00	2.333	0	0.00	0.000	0	0.00	0	0.00	1	50.00	3.000
SW corner	17	607.14	11	392.86	1.455	4	142.86	2.000	2	71.43	0	0.00	0	0.00	0.00
Overall	111	500.00	69	310.81	1.353	18	81.08	1.778	5	22.52	18	81.08	1	4.50	3.000

Table 10.3: Abundances of both colonial and solitary rugose corals within facies 1 at each locality within the Lundar Quarry. The number of specimens per square metre was calculated by dividing the total number of specimens at each locality by the total area (m^2) studied in hand sample for each locality (see Table 10.1). Average size indices were calculated for solitary corals based on the average of the assigned size classes for specimens at each locality. Size indices could not be calculated for colonial rugose corals, as these corals were commonly found in symbiotic association with stromatoporoids, so true colony sizes could not be measured. Southern zone includes localities D-W, H, and J-X; northern zone includes localities K, L, and O. Abbreviations are as follows:

Col. Rug. = All colonial rugosans
Syn = *Synamplexoides varioseptatus*
Pycno = *Pycnostylus guelphensis*
Sols. = All solitary rugosans
Amp = *Amplexoides* sp. A
Dino = *Dinophyllum lundarense*
Cysti = *Cystiphyllum* cf. *niagarensis*

Locality	# Col. Rug.	#Col.Rug./ m^2	# Syn	# Syn/ m^2	# Pycno	# Pycno/ m^2	# Sols.	# Sols./ m^2	Avg. Size Index	# Amp	# Amp/ m^2	Avg. Size Index	# Dino	# Dino/ m^2	Avg. Size Index	# Cysti	# Cysti/ m^2	Avg. Size Index
D-W	10	192.31	7	134.62	3	57.69	10	192.31	2.000	5	96.15	1.600	3	57.69	2.333	1	19.23	2.000
H	7	350.00	6	300.00	1	50.00	6	300.00	1.667	2	100.00	1.000	0	0.00	0.000	1	50.00	3.000
J-X	8	137.93	6	103.45	2	34.48	14	241.38	2.143	6	103.45	1.833	3	51.72	2.333	1	17.40	3.000
K	0	0.00	0	0.00	0	0.00	4	222.22	1.750	1	55.56	1.000	2	111.11	2.000	1	55.56	2.000
L	4	153.85	3	115.38	1	38.46	14	538.46	1.357	8	307.69	1.125	2	76.92	1.500	3	115.38	1.667
O	5	250.00	4	200.00	1	50.00	2	100.00	1.000	1	50.00	1.000	1	50.00	1.000	0	0.00	0.000
SW corner	5	178.57	5	178.57	0	0.00	8	285.71	1.875	5	178.57	1.400	2	71.43	3.000	0	0.00	0.000
Overall	39	175.68	31	139.64	8	36.04	58	261.26	1.724	28	126.13	1.393	13	58.56	2.231	7	31.53	2.143

among localities. Due to the low numbers of chain corals present within the Chemahawin Member, both identified species are considered together in order to generate more significant results. In addition, the amount of echinoderm debris was estimated from hand samples in order to recognize trends in abundance and degree of articulation between localities.

Statistical analyses of spatial fossil distributions were conducted for stromatoporoid types and growth forms, as well as for the sizes of solitary rugosan coralla. Abundances of other faunal groups were insufficient to permit statistical tests, but observed distribution patterns will be discussed for colonial corals and solitary coral species.

10.3 Observations

10.3.1 Distribution Patterns of Corals

The distribution of corals around the quarry reveals several notable trends. The density of solitary rugose corals is greatest at locality L, nearly double that of any other locality within the quarry (Table 10.3). These corals are generally smaller within the northern zone, however, as statistical analysis revealed a significant difference in the proportion of solitary coral sizes (Appendix E-6). The diameters of solitary coralla are greatest to the south; the northern zone did not contain any solitary corals with a diameter of greater than 10 mm, and at locality O, only solitary corals with a diameter of less than 6 mm were present. The most abundant coral at each sampled locality is *Amplexoides* sp. A, with the exception of locality K, which shows a dominance of *Dinophyllum lundarense.* The rugosan *Cystiphyllum* cf. *niagarensis* does not occur in great abundance within the quarry, but is notably absent from locality O and the southwest corner.

Solitary corals are relatively abundant within the southwest corner, and possess corallite diameters of 6-10 mm on average.

Data for colonial corals reveal that localities of the northern zone contain fewer tabulate and colonial rugose corals as compared to the southern zone (Tables 10.2, 10.3). The average density of tabulate corals in the southern zone is 608 specimens per square metre, nearly three times the average in the north. Chain corals are absent from localities of the northern zone and the southwest corner. The density of these corals is greatest at locality H, nearly double that of any other southern locality. The abundances of *Favosites niagarensis inaequalis* and *F. gothlandicus* are highest in the southwest corner of the quarry. The colonial rugosan *Pycnostylus guelphensis* is notably absent from the southwest corner, though the faunal density of *Synamplexoides varioseptatus* is among the highest in the quarry. At locality K, both species of colonial rugose coral are absent.

In terms of tabulate coral growth forms, the southern zone contains the lowest proportion of tabular morphologies as compared to other shapes in this zone (Table 10.4). In the northern zone, domical and tabular growth forms are equally dominant, with the exception of locality O, where domical shapes are most common (80%). No other obvious trends were noted for tabulate growth forms.

10.3.2 Stromatoporoid Distributions

Statistical analysis among all localities revealed a significant relationship between the proportion of stromatoporoid types at each locality, and geographic position within the quarry (Appendix E-5; Table 10.5). Localities of the southern zone exhibit distinctly different proportions of stromatoporoid types in comparison with those in the northern zone. Localities H and J-X were shown to have similar proportions of stromatoporoid

Table 10.4: Relative abundances and percent frequency of growth forms for both stromatoporoids and tabulate corals within facies 1 at each locality within the Lundar Quarry. Southern zone includes localities D-W, H, and J-X; northern zone includes localities K, L, and O. Abbreviations are as follows:

Strome = Total number of all stromatoporoids
% = Percent frequency of particular growth form relative to the total number of specimens
Tabulate Corals incl. = All tabulate corals for which the growth form could be distinguished
D.-C. = domico-columnar growth form

Locality	Stromatoporoids							Tabulate Corals								
	# Strome	Tabular	% Tab.	Domical	% Dom.	Irregular	% Irr.	# Tabulate Corals incl.	Tabular	% Tab.	Domical	% Dom.	D.-C.	% D.-C.	Irregular	% Irr.
D-W	108	74	68.52%	11	10.19%	23	21.30%	27	5	18.52%	8	29.63%	1	3.70%	13	48.15%
H	55	20	36.36%	20	36.36%	15	27.27%	11	1	9.09%	2	18.18%	0	0.00%	8	72.73%
J-X	120	71	59.17%	25	20.83%	24	20.00%	24	2	8.33%	8	33.33%	5	20.83%	9	37.50%
K	51	36	70.59%	6	11.76%	9	17.65%	4	1	25.00%	1	25.00%	0	0.00%	2	50.00%
L	37	22	59.46%	6	16.22%	9	24.32%	6	2	33.33%	2	33.33%	1	16.67%	1	16.67%
O	46	27	58.70%	10	21.74%	9	19.57%	5	0	0.00%	4	80.00%	0	0.00%	1	20.00%
SW corner	86	63	73.26%	16	18.60%	7	8.14%	18	2	11.11%	8	44.44%	4	22.22%	4	22.22%
Overall	503	313	62.23%	94	18.69%	96	19.09%	95	13	13.68%	33	34.74%	11	11.58%	38	40.00%

Table 10.5: Comparison of stromatoporoid type and growth form relative to the estimated percentage of echinoderm debris present within facies 1 at each locality within the Lundar Quarry. Stromatoporoid Type VC and unidentifiable stromatoporoids were included in the total number of stromatoporoids at each locality. Southern zone includes localities D-W, H, and J-X; northern zone includes localities K, L, and O. Abbreviations are as follows:

Total # Stromes = Abundance of all stromatoporoids at each locality
% Strome Type = Percent frequency of each stromatoporoid type
% Strome Growth Form = Percent frequency of each stromatoporoid growth form
Crinoids Avg. % = Average percentage of matrix consisting of echinoderm debris
CY = Stromatoporoid Type CY
PI = Stromatoporoid Type PI
CP = Stromatoporoid Type CP

Locality	Total #	% Strome Type						% Strome Growth Form						Crinoids
	Stromes	CY	% CY	PI	% PI	CP	% CP	Tabular	% Tab.	Domical	% Dom.	Irregular	% Irr.	Avg. %
D-W	108	68	62.96%	30	27.78%	8	7.41%	74	68.52%	11	10.19%	23	21.30%	2.22%
H	55	35	63.64%	20	36.36%	0	0.00%	20	36.36%	20	36.36%	15	27.27%	7.91%
J-X	120	83	69.17%	23	19.17%	12	10.00%	71	59.17%	25	20.83%	24	20.00%	2.97%
K	51	21	41.18%	15	29.41%	15	29.41%	36	70.59%	6	11.76%	9	17.65%	0.78%
L	37	9	24.32%	16	43.24%	12	32.43%	22	59.46%	6	16.22%	9	24.32%	1.78%
O	46	24	52.17%	12	26.09%	11	23.91%	27	58.70%	10	21.74%	9	19.57%	3.60%
SW corner	86	70	81.40%	13	15.12%	3	3.49%	63	73.26%	16	18.60%	7	8.14%	1.29%

types to locality D-W. As well, the proportions at localities L and O are similar to those of locality K (Table 10.5). In the northern portion of the quarry, localities K, L, and O contain the lowest relative abundances of stromatoporoid Type CY (41%, 25%, and 52%, respectively) compared to localities within the southern zone. As well, localities of the northern zone contain significantly higher proportions of stromatoporoid Type CP (30%, 43%, and 24%, respectively) than in the south. Thus, there are statistically different proportions of stromatoporoids in the southern and northern zones. The distribution of species in the southwest corner was significantly different from that at most other localities within the quarry. Thus, this locality is characterized by a third distribution pattern, which could not be statistically related to the northern and southern zones of the quarry. The observed distribution of stromatoporoid types in the southwest corner, however, is most similar to that of locality J-X of the southern zone, as both locations contain abundant specimens of stromatoporoid Type CY and low proportions of the other types.

The spatial distributions of stromatoporoid types within the Lundar Quarry also revealed important patterns. Excluding locality D-W, there is an observed increase in the abundance of stromatoporoid Type CP from the southeast to the northwest: from 0% at locality H, to 3.49% in the southwest corner, followed by locality J-X (7.76%), O (23.91%), K (29.41%), and L (32.43%; Figure 10.2). Thus, in addition to the recognition of three zones within the quarry, there is evidence for a faunal gradient involving a progressive increase in stromatoporoid Type CP from the southeast to the northwest within the Lundar Quarry.

When examining faunal density, the southwest corner contains the greatest number of stromatoporoids per square metre, and has the lowest average size class index

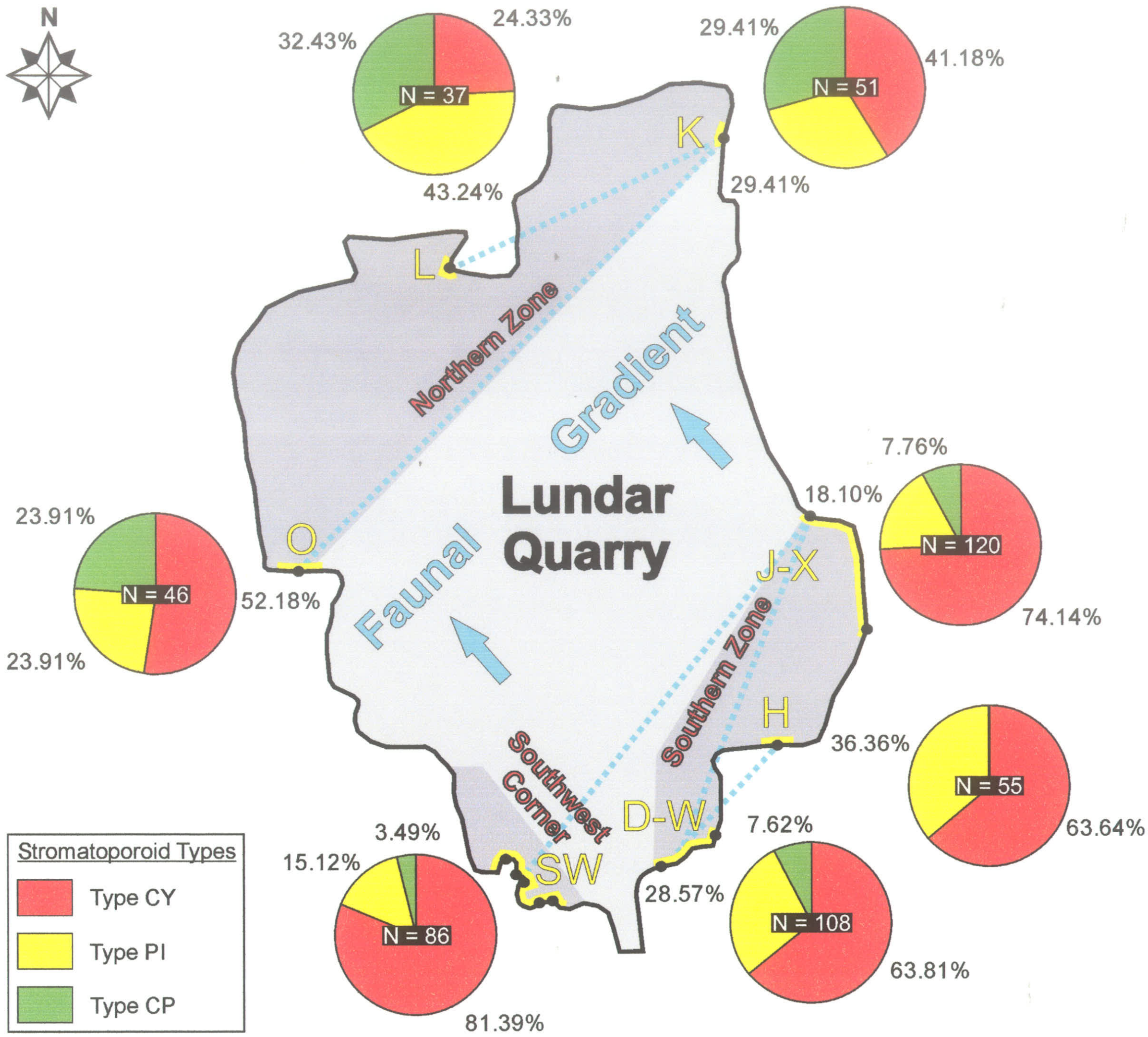


Figure 10.2: Observed faunal gradient within the Lundar Quarry. Yellow lines and text represent localities used for this analysis. Pie charts represent the relative abundances of stromatoporoid types within facies 1 at each locality (N = total abundance of stromatoporoid specimens for each locality). Blue dotted lines connect localities with proportions of stromatoporoid types that are statistically indistinguishable. Thus, the localities of the southern zone are similar to each other, and significantly different from the localities of the northern zone. As well, the proportions in the southwest corner are significantly related to locality J-X, though this relation should be interpreted with caution due to limited numbers in some classes. There is a northwestward faunal gradient, as the proportions of stromatoporoid Type CP increase in this direction relative to the other two types of stromatoporoids.

in the quarry (see Table 10.1). As well, this locality shows a distinct dominance of stromatoporoid Type CY as compared with other types. Interestingly, stromatoporoid Type CY has a very low average size index at this locality, but stromatoporoid Type PI and Type CP maintain moderate sizes.

When comparing the proportions of stromatoporoid growth forms among localities, it was determined that a statistically significant relationship exists between coenosteal shape distributions and location (Appendix E-7; Figure 10.3). Tabular growth forms are the dominant coenosteal shape at all localities with the exception of locality H, which shows the highest proportion of domical forms in the quarry (36%; see Table 10.4). Locality H exhibits a significantly different distribution of shapes when compared with the other localities of the southern zone, as well as the southwest corner, and locality K of the northern zone. Though the distribution of growth forms at locality H is not significantly different from those at localities L and O of the northern zone, locality H is the only location to show a dominance of domical forms. Interestingly, the southwest corner contains the highest proportion of tabular stromatoporoids (73%).

The average size indices of stromatoporoids were compared between localities in order to recognize trends in coenosteum size by locality. Comparison between individual species and for all stromatoporoids at each locality did not reveal any noticeable trends in size. The size index for stromatoporoids in the southwest corner, however, is the lowest in the quarry (see Table 10.1).

10.3.3 Spatial Faunal Relationships

The abundances of colonial rugose corals *Synamplexoides varioseptatus* and *Pycnostylus guelphensis* are greater for the southern zone than for the northern zone (see

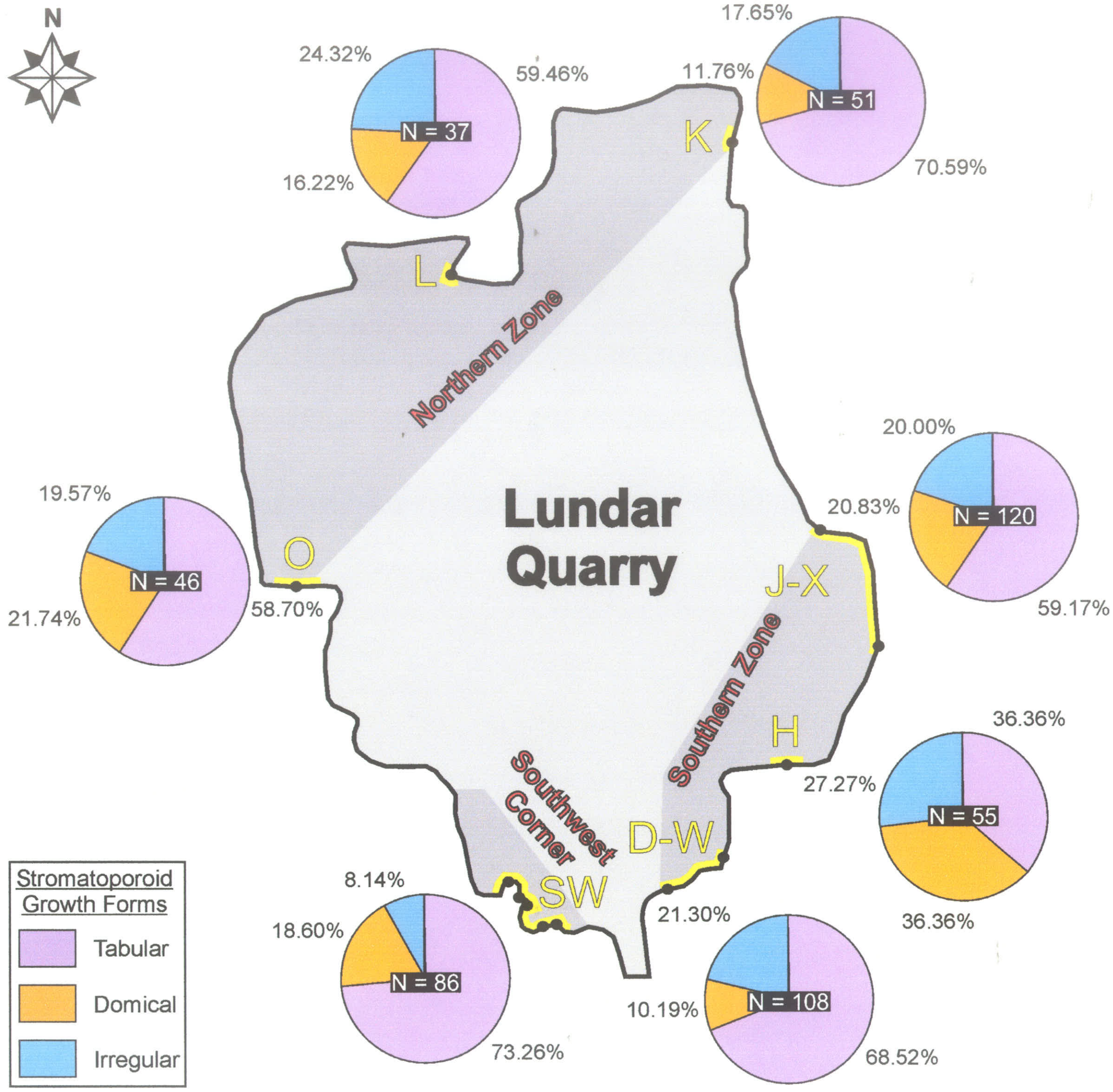


Figure 10.3: Abundances of stromatoporoid growth forms within facies 1 at localities within the Lundar Quarry. Yellow lines and text represent localities used for this analysis. Pie charts represent the relative abundances of stromatoporoid growth forms at each locality (N = total abundance of stromatoporoid specimens for each locality).

Table 10.3). As well, several specimens of *S. varioseptatus* were found as free-living forms in the south; these forms were absent in the northern zone. However, since these corals are most often found in symbiotic association with stromatoporoids, their distribution is likely controlled by that of the host organism. In order to truly assess the distribution of colonial rugose corals, it was important to first note whether each coral showed preferences to a particular species or growth form of stromatoporoids. Statistical analysis of the proportion of colonial rugose corals found in symbiotic association with stromatoporoids revealed a preference for inhabiting stromatoporoid Type CP (see Chapter 9). As previously mentioned, localities of the northern zone contain the highest proportion of stromatoporoid Type CP specimens (see Table 10.1). The highest proportion of *S. varioseptatus* specimens found in association with stromatoporoid Type CP occurred within the northern zone (Table 10.6). *Pycnostylus guelphensis* alone is most commonly found in association with stromatoporoid Type CY. As this stromatoporoid occurs in the greatest proportions within the southern sites, it is understandable why *P. guelphensis* is most common in the southern zone.

As *Favosites niagarensis lundarensis* is the only tabulate coral found in high abundance in the Chemahawin Member, both as free-living and symbiotic forms, the distribution of this coral was assessed. The proportion of *F. niagarensis lundarensis* occurring in symbiotic association with stromatoporoids was considerably greater in the northern zone (Table 10.6). Interestingly, *F. niagarensis lundarensis* is commonly found in symbiotic association with stromatoporoid Type CY in the southern zone, whereas stromatoporoid Type PI is the principal host in the north.

Even though localities within the northern zone contain the fewest colonial corals, these study sites include the highest percentages of corals in symbiotic association with

Table 10.6: Percentages of colonial corals found in symbiotic association with stromatoporoids, and the relationships between symbiotic colonial corals and host stromatoporoid type within facies 1 in the southern and northern zones of the Lundar Quarry. As *Favosites niagarensis lundarensis* is the only tabulate coral found in high abundance in the Chemahawin Member, this is the only tabulate coral considered. *Pycnostylus guelphensis* is only found in symbiotic association, so for this species, the percentage of specimens in symbiotic association with stromatoporoids is 100% in both zones. Abbreviations are as follows:

TOT. = Total number of specimens
SA = Total number of specimens in symbiotic association with stromatoporoids
% SA = Percentage of specimens in symbiotic association with stromatoporoids
% in CY = Percentage of specimens in symbiotic association with stromatoporoid Type CY
% in PI = Percentage of specimens in symbiotic association with stromatoporoid Type PI
% in CP = Percentage of specimens in symbiotic association with stromatoporoid Type CP

	Favosites niagarensis lundarensis						***Synamplexoides varioseptatus***						***Pycnostylus guelphensis***			
Zone	**TOT.**	**SA**	**% SA**	**% in CY**	**% in PI**	**% in CP**	**TOT.**	**SA**	**% SA**	**% in CY**	**% in PI**	**% in CP**	**TOT.**	**% in CY**	**% in PI**	**% in CP**
Southern	46	24	52.2%	75%	8.3%	16.7%	19	12	63.2%	58.3%	16.7%	25%	6	66.7%	16.7%	16.7%
Northern	12	8	66.7%	25%	62.5%	8.3%	7	7	100%	57.1%	0%	42.9%	2	0%	50%	50%

stromatoporoids. Locality D-W, however, exhibits the greatest number of symbiotic corals per stromatoporoid specimen.

An interesting and important relationship was noted between the amounts of echinoderm debris present at each locality and the distribution of stromatoporoid types (see Table 10.5). It was observed that with increasing percentages of echinoderm debris within the matrix at a locality, there is an observed general decrease in the proportion of stromatoporoid Type CP relative to other species. At locality H, which has the greatest average percentage of echinoderm debris (7.91%), stromatoporoid Type CP is absent. In contrast, localities K and L show among the lowest percentages of debris present, and have the highest proportions of stromatoporoid Type CP. Additionally, a relationship exists between the percentage of echinoderm debris and stromatoporoid growth form. A higher proportion of debris is associated with an increase in the proportion of domical growth forms, with locality H having the greatest amount of debris and the highest proportion of domical stromatoporoids (see Table 10.5).

10.4 Interpretations

It is likely that the lower abundances of colonial rugose corals within the northern zone are a result of a less favourable microenvironment. All colonial rugose corals in the northern portion of the quarry are found in symbiotic relationships with stromatoporoids. In this area, stromatoporoid Type CP contains the highest proportion of symbiotic *Synamplexoides varioseptatus* relative to any other stromatoporoid species. A limited number of *Pycnostylus guelphensis* are found in the north, as these corals favoured stromatoporoid Type CY, which is relatively rare in the northern portion of the quarry. Consequently, *P. guelphensis* from this zone resorted to symbiotic relationships with less preferable host species. It seems that these delicate colonial rugose corals were likely not well suited to the environmental conditions of this area, so they required stability and protection afforded by stromatoporoids, even if their preferred host was rare.

Additionally, a higher proportion of symbiotic relationships of other corals occurs in the northern portion of the quarry. The proportion of *Favosites niagarensis lundarensis* coralla found inside stromatoporoid coenostea is significantly greater to the north. Though the largest proportion of *F. niagarensis lundarensis* is found within stromatoporoid Type CY in the Lundar Quarry, the low relative abundance of this stromatoporoid species in the north is the likely cause for a shift in host preference to stromatoporoid Type PI. This further suggests that conditions in the northern portion of the quarry were likely unfavourable, so this favositid must also have required some protection, regardless of host preferences.

As all chain corals within the Chemahawin Member are represented by fragments, their distribution within the quarry is likely not a representation of their occurrence in life, but rather their response to hydraulic energy as sedimentary particles. It is assumed, however, that transportation of fossil material was limited to within the range of their original microenvironment of habitation (Kidwell and Brenchley 1996). Thus, though ecological interpretations of chain coral distribution may not be appropriate, consideration of their distribution will be included. The lack of evidence for chain corals in the northern zone and the southwest corner suggests their absence from these microenvironments during life. Lee and Elias (1991) suggested that the structure of these corals would be best suited for areas subject to influxes of sediment during high energy events in the environment, as they are capable of shedding sediment into voids between chains of corallites to prevent smothering. Thus, the southern zone, especially locality H, may represent a higher energy environment, or an area frequently subject to higher energy events, than at other positions within the biostrome.

The distribution of stromatoporoids within the quarry suggests that different environmental conditions prevailed at different positions within the biostrome. Locality H shows the greatest proportion of domical stromatoporoids. In general, stable, domical growth forms are common within the reef-core facies of buildups, where moderately intense energy conditions prevail (Riding 2002). An abundance of domical stromatoporoids in reef-core facies has also been reported in Early Silurian reef structures, such as in the buildups of the Chicotte Formation, Anticosti Island (Brunton and Copper 1994). Thus, applied to this study, this evidence may further support the indication of slightly higher energy conditions at locality H. The absence of stromatoporoid Type CP at this locality may indicate that it was intolerant of higher energy conditions.

Though stromatoporoid Type CY is the dominant faunal constituent within the overall unit, the observed faunal gradient within the quarry suggests that this type is not uniformly distributed within the biostrome. It is likely that the limited thickness of facies 1 strata exposed at the top of the southwest corner indicates that this facies was established later at this locality than elsewhere in the quarry. The high proportion of stromatoporoid Type CY in the southwest corner may suggest that this stromatoporoid was one of the first to colonize new substrate.

The relative abundance of small, tabular stromatoporoids in the southwest corner is further evidence for later establishment of the biostrome at this locality. The abundance of small, tabular stromatoporoids in facies 2, which underlies facies 1 in the southwest corner, was interpreted to represent the initial colonization of previously unsuitable substrate (see Chapter 7). Thus, the faunal assemblage of facies 1 at this locality may represent the early stages of development of the biostromal facies.

A relationship likely exists between the abundance of echinoderm debris present in the matrix and the level of hydraulic energy at each locality. It is well known that the echinoderm skeleton consists of calcite components held together by soft tissue, and easily disarticulates after death of the organism. Crinoids were common reef dwellers in the Paleozoic, and mid-Silurian crinoids were well adapted to reefs subject to high turbulence (Fagerstrom 1987). Thus, it is interpreted for this study that abundances of crinoid debris indicate higher energy conditions. It appears that stromatoporoid Type CP was least capable of withstanding higher energy conditions, as the proportions of this species are low in areas of abundant echinoderm debris. This is especially true for locality H, which shows the highest average percentage of debris and a complete absence of stromatoporoid Type CP. Thus, this may be further evidence to suggest higher energy conditions near locality H. In contrast, locality L has a low percentage of debris, and has the highest proportion of size 3 stromatoporoids (> 50 mm). It was suggested by Kershaw (1998) that lower energy settings may have been conducive for stromatoporoid growth, allowing them to attain larger sizes. The thick vertical elements within the skeleton of stromatoporoid Type CP presumably added strength, allowing it to attain larger sizes under suitable conditions.

Chapter 11: Temporal Analysis

11.1 Temporal Trends within the Lundar Quarry

In order to understand faunal and facies distributions through time, it is important to study vertical changes within the Chemahawin Member. The recognition of temporal processes in the fossil record required sampling at regular vertical intervals at each site in order to achieve a relatively even distribution of data for comparison around the quarry (see Figure 5.2).

It is been well established that both modern and ancient reefs exhibit vertical zonation in terms of community composition, growth forms, and skeleton size (e.g., Brunton and Copper 1994). Ecological succession is related to the different life strategies of organisms as they cope with changing local environmental conditions through time (Dodd and Stanton 1990). As well, vertical succession of facies within reefs has been attributed to changes in water depth over time (Lowenstam 1957). In general, facies succession is related to change in one or more environmental variables, whereas ecological succession within the reef is related to biological changes through time. Thus, small-scale changes in community structure may provide evidence for ecological succession within the Chemahawin Member, and vertical changes in facies may indicate lateral arrangements of different depositional microenvironments through time.

11.2 Ecological Succession

In broad context, ecological succession can be viewed as relatively predictable changes within a community over time. There are two main factors governing succession: biological control, and effects of the physical environment (Odum 1969). Though both factors generally operate at the same time, the degree of physical environmental control is usually considered in many ecological studies (Johnson 1977). Odum (1969, p. 262) defined the term ecological succession as:

> "...an orderly process of community development that is reasonably directional, and therefore, predictable...It results from modification of the physical environment by the community; that is, succession is community-controlled even though the physical environment determines the pattern, the rate of change, and often sets the limits as to how far development can go."

Similarly, Walker and Alberstadt (1975) considered biologically governed factors to be important for ecological succession, such as the gradual alteration of unstable substrate by pioneer organisms. Ecological succession may be recognized in the fossil record by changes in the distribution of fauna through time. Typically, succession is thought of as a long-term process, in which a community goes through a number of stages of increasing diversity, number, and size of fauna (Dodd and Stanton 1990). It is important to note, however, that succession is not a form of community replacement. Johnson (1977) defined community replacement as the substitution of one community for another as a result of periodic and dramatic physical changes within the environment. In contrast, ecological succession operates on shorter time-scales, during intervals of stability between these periodic environmental disturbances (Johnson 1977). The terms "pioneer" and "climax" communities or stages were used by Walker and Alberstadt (1975) to represent the initial and final stages which may be seen in successions. A typical pioneer community consists of a low-diversity assemblage of generalist forms with rapid growth and reproductive rates in order to rapidly colonize newly available substrate. The climax stage occurs after the pioneer community has stabilized the substrate, and mainly consists of a high-diversity assemblage of specialized, large, modular organisms and solitary forms, whose proportions may vary depending on the degree of environmental changes within the environment. Though longer-term succession may be recorded as extinctions and evolutions of species through time, small-scale changes in the proportion of species present at each stratigraphic interval, and the absence or dominance of different species at each interval, may also be present (Walker and Alberstadt 1975). Thus, though little of the Chemahawin Member is exposed for evaluation of ecological succession, small-scale changes of community structure may be observable, both within and among facies.

Additionally, each species of stromatoporoid and tabulate coral within the Chemahawin Member exhibits a variety of growth forms. It is difficult to explain the presence of two different growth forms in coexistence based on either genetics or the physical environment alone. The problem is exacerbated by potential time-averaging and shorter term variation in environmental conditions. Jackson (1979) noted that species which adopt different growth forms may be genetic polymorphs, or phenotypes of the same genotype controlled by environmental conditions. It is generally accepted that morphologic plasticity of a species is the result of a combination of intrinsic (genetic) and extrinsic (environmental) factors. Stearn (1982) stated that too much importance has been placed on the environment of deposition as the controlling factor of growth form, and that morphologic plasticity should be examined at the species level in order to truly understand which factor is dominant. Kershaw (1981) also noted that genetics are important in controlling growth form, as his study in Gotland, Sweden demonstrated that each of the stromatoporoid species, which were present within the same environment, occurs in a variety of forms. However, even Kershaw himself (1990) admitted that there was evidence that some species responded to environmental gradients within the same study area, exhibiting phenotypic plasticity of growth form. Thus, for the present study, it is recognized that genetics limit the range of possible growth forms a species may assume, but the influence of the environment may be discernable by analyzing the relationships between growth forms and environmental indicators. Young and Scrutton (1991) recognized that the range for growth form variation is genetically controlled, although different species may have distinctly different levels of response to conditions within the physical environment. Therefore, paleoenvironmental interpretations of growth form should be considered at the species level. For the present study, however, sample sizes were insufficient for statistical analysis of growth forms at the level of stromatoporoid type or coral species. Thus, to achieve sufficient sample sizes for statistical analysis, growth forms for each faunal group were considered together in order to understand the broad environmental responses of each growth form.

Recognizable vertical changes in the fossil community structure may be observed if the time span of succession is long enough to permit preservation within the slowly accumulating stratigraphic record (Dodd and Stanton 1990). Ecological succession may be interpreted from the fossil record by observed vertical zones of different species compositions, different growth forms of the same organism, or an increase in skeleton size through time. In the present study of the Lundar Quarry, small-scale differences within facies 1 will be considered, as well as the differences in the size, shape, and abundance of fauna between facies 1 and 2.

11.3 Facies Succession

Vertical changes in facies distribution within the quarry may provide evidence for the lateral arrangement of microenvironments through time. Walther's Law states that facies successions which are preserved vertically within rock sequences were once laterally related depositional microenvironments (see Dodd and Stanton 1990).

Typically, vertical facies changes within a unit are considered to be the result of changing relative sea level, though environmental conditions may be different across a reef, as the structure has an influence on the surrounding environment (Braithwaite 1973). Thus, the observed vertical distribution of facies within the Lundar Quarry was considered as temporal patterns in facies succession due to biostromal control on the local environment.

Facies associations were observed in the southwest corner of the main quarry, within the southern quarry, and in drill core, as previously mentioned. In the southwest corner of the Lundar Quarry, there is a vertical transition from laminated sublithographic dolostone (facies 4), through a zone of bioturbation of the laminae (facies 3), followed by the development of a low-diversity assemblage dominated by small, tabular stromatoporoids (facies 2), which is succeeded by the biostromal facies 1 (see Chapter 7). Within the southern quarry, the reverse pattern is observed, as facies 2 is overlain by facies 3 and 4, respectively. In the drill core obtained from the Lundar Quarry, facies associations are similar to that of the main quarry, as facies 1 is the uppermost unit, underlain by strata with progressively less fossil content with depth (see Chapter 8).

The distribution and proportion of fauna within facies 2 were determined by visual analysis only, as fossils were poorly preserved and highly fragmented. Thus, accurate enumeration could not be accomplished. A general discussion will be made, however, on the observed proportions of species and growth forms as compared with those of facies 1.

11.4 Temporal Analysis Methods

As the strata within the quarry are essentially horizontal, it is assumed that hand samples representing stratigraphic intervals of equal distance above water level at different sites are contemporaneous. As previously stated, facies 1 is the only unit exposed at all sampled sites within the quarry that contains all fauna present within the Chemahawin Member, so raw data were collected only for this facies. Within the southwest portion of the Lundar Quarry, facies 1 is exposed only at the uppermost position, so stratigraphic data were limited. Thus, data collected from sites within the southwest corner were not considered for this analysis.

Based on evidence from the spatial data analysis, faunal distributions differ between the southern and northern zones of the quarry (see Chapter 10). Equivalent stratigraphic intervals were combined for localities within the southern and northern zones in order to recognize spatial-temporal faunal trends within facies 1. This allowed for the comparison of temporal trends within the quarry, as well as spatial trends between equivalent stratigraphic intervals of the southern and northern zones.

In order to achieve sufficient sample sizes for statistical analysis, 20-cm intervals were created for each zone, with twelve intervals above water level, and one interval representing rocks obtained from below water level (Figure 11.1). Each hand sample was considered to represent a 10-cm vertical increment at each site; samples were separated into the appropriate interval based on these vertical increments, and data from these samples were combined (see Appendix A, Part 2). Samples situated between two intervals were placed within the interval containing the largest proportion of the 10-cm increment (Appendix A, Part 2). Data from each interval are assumed to be time-averaged, and are considered as a single constituent in order to compare between equivalent intervals between zones (see Kershaw 1990). Again, unidentifiable specimens were not included in this analysis. Also, the single specimen of stromatoporoid VC that occurs within facies 1 was also excluded from analysis.

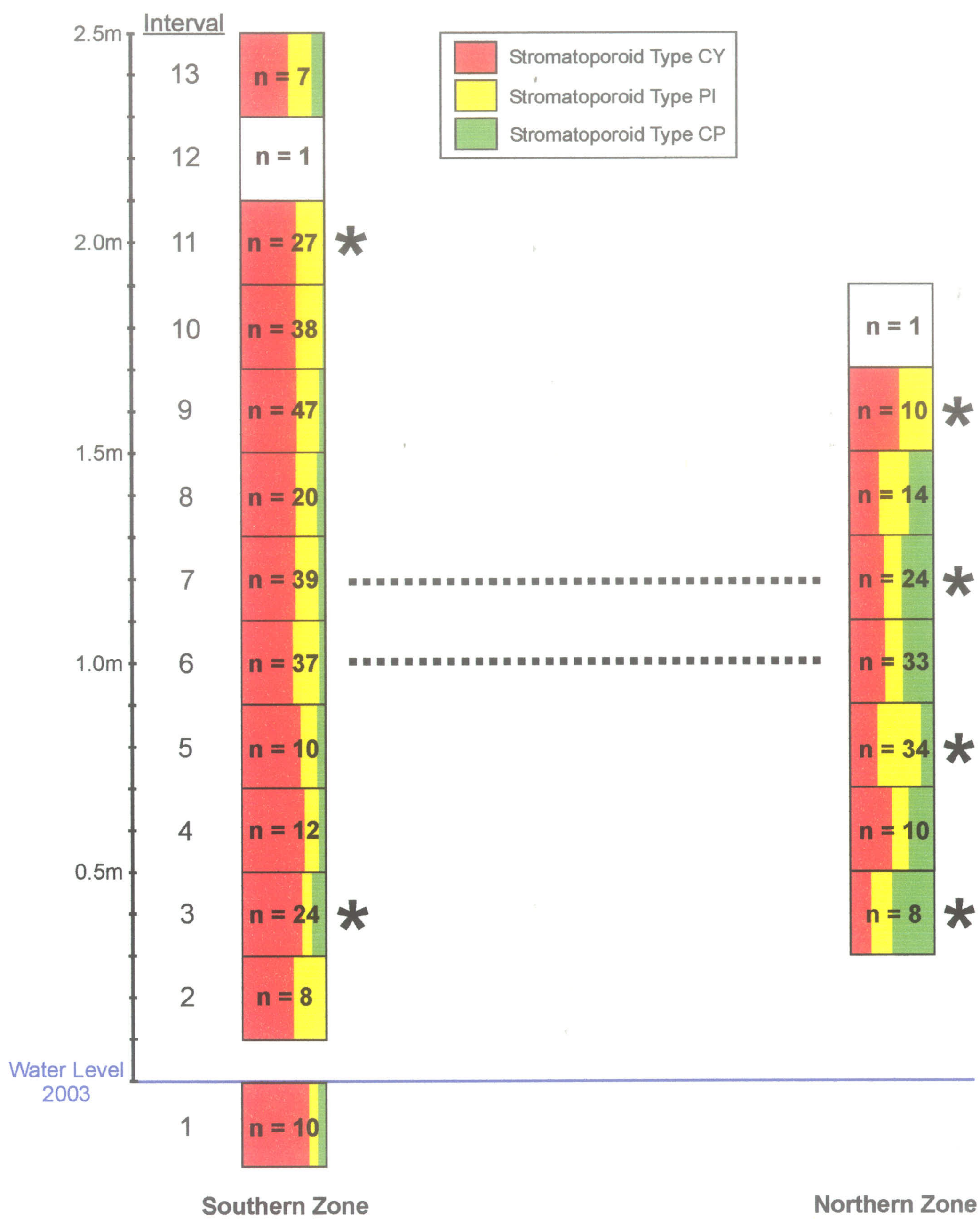


Figure 11.1: Relative abundances of stromatoporoid types within facies 1 in each 20-cm stratigraphic interval within the Lundar Quarry. Intervals are numbered from lowest to highest, with twelve intervals above water level, and one interval representing specimens obtained from below water level (interval 1). Interval numbers apply to both the southern and northern zones; thus, the northern zone is represented only by stratigraphic intervals 3 to 10. The number of stromatoporoid specimens at each interval is indicated within box. Intervals for which only one large stromatoporoid was observed in hand sample were not considered for this analysis. Asterisks indicate intervals for which the distribution of stromatoporoid types is significantly different from at least one other interval within the zone. Dotted lines represent intervals for which the distribution of stromatoporoid types is significantly different from the equivalent interval of the other zone.

Statistical tests were used to compare the relative abundances of fauna between pairs of stratigraphic intervals, for all possible pairs of intervals in a zone. A Chi-square test was applied for comparison of pairs of intervals within each zone to determine if a significant relationship exists between the relative abundances of species, growth forms, and skeleton sizes over the interval of time represented by the quarry exposure. Stratigraphic intervals that did not contain a statistically significant number of specimens were not included in this analysis. Additionally, data within each interval were compared with equivalent intervals between zones in order to recognize any broad temporal-spatial trends. As the vertical exposure in the southern zone is greater than that found in the northern zone, intervals without a stratigraphic equivalent were not included for the spatial-temporal analysis. Each interval within a zone may not have the same number of samples represented, so direct comparison of faunal abundances between intervals was not possible. Therefore, the total number of specimens for each category analyzed in each interval for each zone was divided by the total amount of study area analyzed (m^2) at each interval for all localities within the zone.

11.5 Observations

11.5.1 Succession of Facies

Stromatoporoids within facies 2 possess predominantly tabular growth forms (see Chapter 7). It has been suggested that low-profile forms would be best suited for soupy substrates, as the weight of the skeleton is spread out across a wider base than high-profile forms (Kershaw 1990). It is therefore interpreted that the stromatoporoids adopted a lateral growth strategy in order to prevent sinking into the soupy muds of facies 3 and 2, which are exposed in the southwest corner of the main quarry. As well, low-profile forms are thought to be competitively advantageous for space and food collection, and would not be as vulnerable to current action (Kershaw 1981). Within facies 1, however, there is a greater proportion of domical forms present. It is likely that the development of a more stable substrate by the stromatoporoids of facies 2 allowed organisms to expand their form vertically in order to gain better access to the water column.

Stromatoporoids were capable of attaining considerably larger sizes in facies 1, which is in striking contrast with facies 2, where stromatoporoids are generally less than 30 mm wide. The size of skeletons is typically dependent on the rate of growth and the total life span of the organism (Baarli et al. 1992). It is possible that the tabular stromatoporoids of facies 2 were subject to smothering by the shifting sediments or overturning due to periodic turbulence, resulting in short life spans and small skeleton sizes.

Facies 1 contains abundant colonial and solitary corals, which are limited in abundance or absent within facies 2. Solitary corals are typically suited to muddy substrates, so their absence in facies 2 is difficult to explain. It is likely that other conditions within the environment were responsible for preventing initiation of solitary coral growth. The rarity of corals is likely related to physical disturbance in the environment, causing shifting sediments and overturning of skeletons.

Comparison between facies in the southwest corner of the Lundar Quarry reveals a gradual increase in biotic influence through time in this setting. Facies 4 is characterized by undisturbed beds of carbonate mudstones, whereas the overlying facies 3 contains profuse mottling and disruption of the mudstone layers. The introduction of abundant stromatoporoid skeletons within facies 2, and the complete biostromal assemblage of overlying facies 1, reveals the gradual evolution of this locality through time. The transition from muddy, apparently inhospitable substrates to a fully developed biostromal facies demonstrates the relatively rapid modification of an environment by fauna. Modification of the muddy substrate by pioneer organisms provided new colonization sites via taphonomic feedback, which, in conjunction with intense competition for space within the biostrome, likely prompted the expansion of fauna over previously unsuitable areas.

The distribution of facies within the southwest corner suggests the presence of distinct depositional environments which were in lateral association at different intervals in time. Biostromal facies 1 is exposed through the entire height of exposure at the majority of sites in the quarry, though in the southwest corner, there is evidence that adjacent to the biostrome lay areas which favoured the deposition of carbonate muds with limited biota present. The lateral and vertical transition of facies in the southwest corner suggests the gradual expansion of the biostrome towards the southwest over these muddy areas. Thus, facies succession in the southwest corner of the quarry reveals the lateral relationship between time-equivalent depositional environments that existed during the mid-Early Silurian at this location.

Within the drill cores examined for the present study, the arrangement of facies is similar to that in the southwest corner of the Lundar Quarry, with intervals of maximum biotic development near the top of the cored strata, and laminated mudstones near the base (see Figure 8.1). Although facies 2 is not found directly below facies 1 in the Lundar Quarry North core, an interval of facies 3 underlies facies 1, suggesting biotic working of the substrate prior to macrofaunal establishment. Two intervals of facies 2 are present in the Mulvihill West Quarry core, which suggests cyclic faunal development, possibly as a result of periodic favourable conditions in the environment that allowed fauna to temporarily become established. Above the upper facies 2 interval, which has been correlated with the interval of facies 1 of the Lundar Quarry North core, is a unit of bioclastic debris and oolites representing shallower water conditions. This unit likely represents the regressive episode proposed for the end of Cedar Lake time (see Figure 1.3), and the shallower conditions likely caused the termination of the stromatoporoid-dominated communities near the top of both cores.

The facies arrangement in the south quarry is opposite to that of the southwest corner of the main quarry, with facies 4 near the top of the exposure, underlain by facies 3 and 2, respectively. As previously mentioned, facies 1 is not exposed in the south quarry. It is possible that full biostromal development was not attained in this area due to unfavourable conditions in the microenvironment. Perhaps this distant location was not protected by the biostrome during higher energy events, so the pioneer fauna of facies 2 could not fully develop to biostromal facies 1. Alternatively, the southwestward advancement of the biostrome within the main quarry may have caused more restricted conditions in this area through time, causing a reversion to lagoonal, back-reef conditions.

11.5.2 Relative Abundances of Taxa

Statistical analysis for the relative abundance of stromatoporoid types for each interval, among all intervals in a zone, established that the proportions of stromatoporoid types at some intervals were significantly different from at least one other interval within the zone (Figure 11.1). In the southern zone, a higher proportion of stromatoporoid Type CP at interval 3 compared to interval 11 resulted in a statistically significant difference between these intervals (Appendix E-8, Part 1). In the northern zone, the absence of stromatoporoid Type CP at interval 9 resulted in a significant difference as compared with other intervals (Appendix E-8, Part 2). As well, the proportion of stromatoporoid Type PI is greatest at interval 5, in contrast to interval 7, which contains the lowest proportion of this type. No discernible vertical trends were observed for this data, but it is important to note the variance in the relative abundances of stromatoporoid types over time. Additionally, comparisons among equivalent intervals between zones revealed a significant difference at some intervals (Appendix E-8, Part 3; Figure 11.1). Visual inspection of the data distribution revealed a high relative abundance of stromatoporoid types CP and PI within most intervals of the northern zone, whereas stromatoporoid Type CY is unequivocally dominant in the south.

Statistical comparison of the relative abundances of stromatoporoid growth forms at each interval, among all intervals within the southern zone revealed several intervals that were significantly different from one or more interval in the zone (Appendix E-9, Part 1; Figure 11.2). As well, comparisons between equivalent stratigraphic intervals among zones revealed a statistically significant difference (Appendix E-9, Part 3; Figure 11.2). Among the intervals of the northern zone, however, observed differences in the relative abundances of growth forms were not statistically significant (Appendix E-9, Part 2). Observations of the relative abundances of growth forms between intervals of the southern zone reveal that the difference is related to the proportion of domical forms present, in inverse relation to the dominant tabular form. A cyclic trend for the rise and fall in abundance of domical forms can be seen in Figure 11.2; it appears two periods of time were favourable for this growth form (represented by intervals 1 and 2, and intervals 6, 7, and 8), separated by an interval of less favourable conditions. When examining interval 4 between the two zones, it appears that irregular forms were absent and tabular

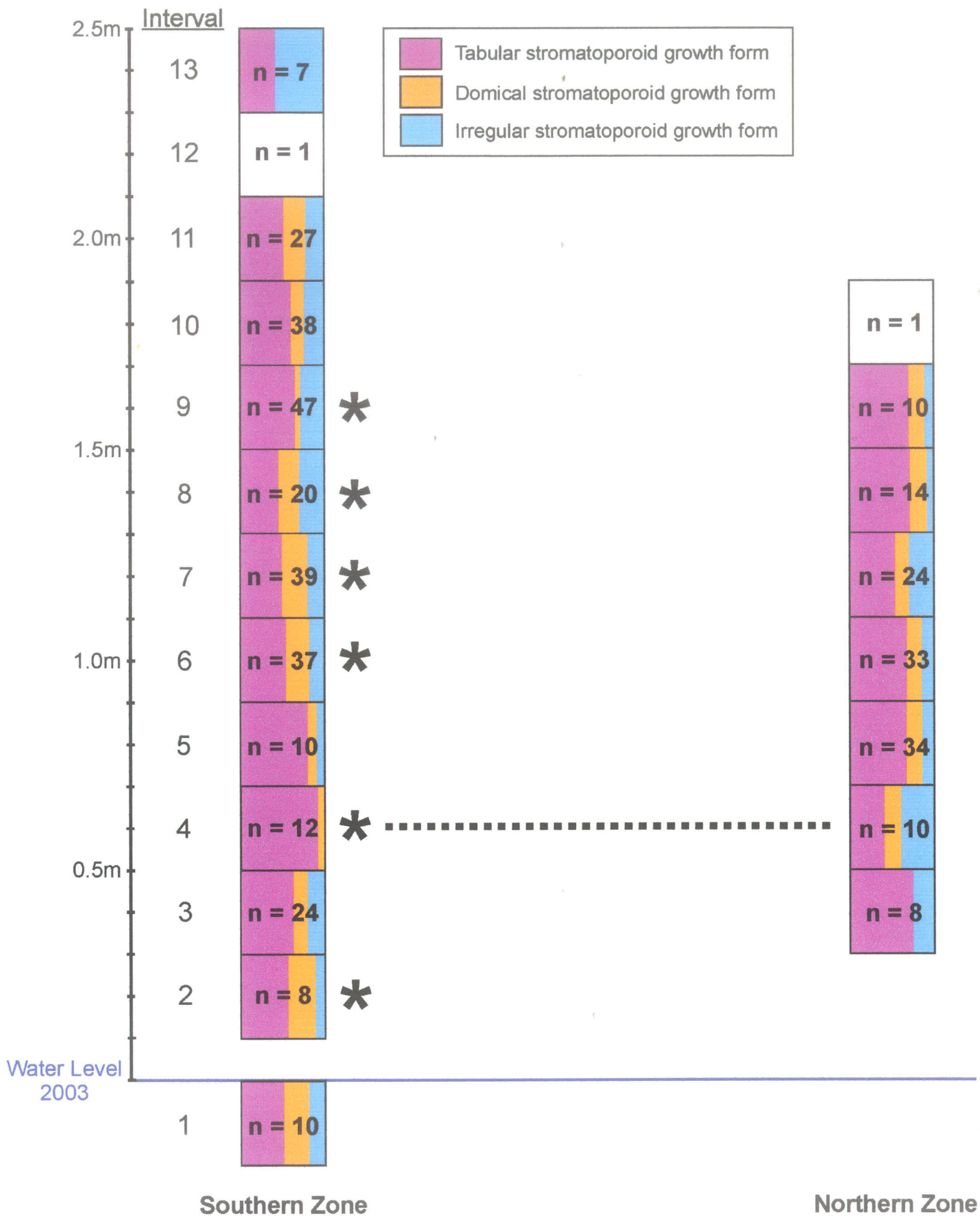


Figure 11.2: Relative abundances of stromatoporoid growth forms within facies 1 at each 20-cm stratigraphic interval within the Lundar Quarry. The number of stromatoporoid specimens in each interval is indicated within box. Intervals for which only one large stromatoporoid was observed in hand sample were not considered for this analysis. Asterisks indicate intervals for which the relative abundances of stromatoporoid growth forms is significantly different from at least one other interval within the zone. Dotted line represents intervals for which the relative abundances of stromatoporoid growth forms is significantly different from the equivalent interval in the other zone.

forms were almost exclusive at this time in the southern zone, whereas irregular forms were co-dominant in the north. In general, however, it appears that the conditions which affected the proportion of stromatoporoid growth forms to the south were either not prevalent or did not affect growth form to the same degree in the northern zone.

Though tabulates are the dominant coral group within the quarry, the numbers of specimens at each interval were too small for statistical analysis. An attempt was made nonetheless to compare the relative abundances of tabulate coral growth forms with stromatoporoid shapes at each interval in each zone. This comparison, however, did not reveal any recognizable trends.

11.5.3 Faunal Density

Histograms were generated for the number of specimens per square metre for each species or faunal group at each interval, for each zone, in order to observe the density of corals relative to stromatoporoids between intervals of each zone, and among equivalent intervals between zones (Figures 11.3, 11.4).

When comparing the faunal density among intervals in each zone, several notable trends were observed. In the southern zone, interval 1 shows a much higher density of stromatoporoids than corals, and tabulate and solitary rugose corals are equally abundant (Figure 11.3). At interval 2, however, both tabulate and solitary corals started to increase in abundance relative to stromatoporoids. Higher up at interval 5, colonial corals declined drastically, though solitary rugose corals remained in relatively high abundance, and were the dominant corals during this time interval. The conditions that negatively affected corals at this interval apparently also had a strong impact on stromatoporoids, which also show a dramatic decrease in numbers for this interval. Following this time

Southern Zone

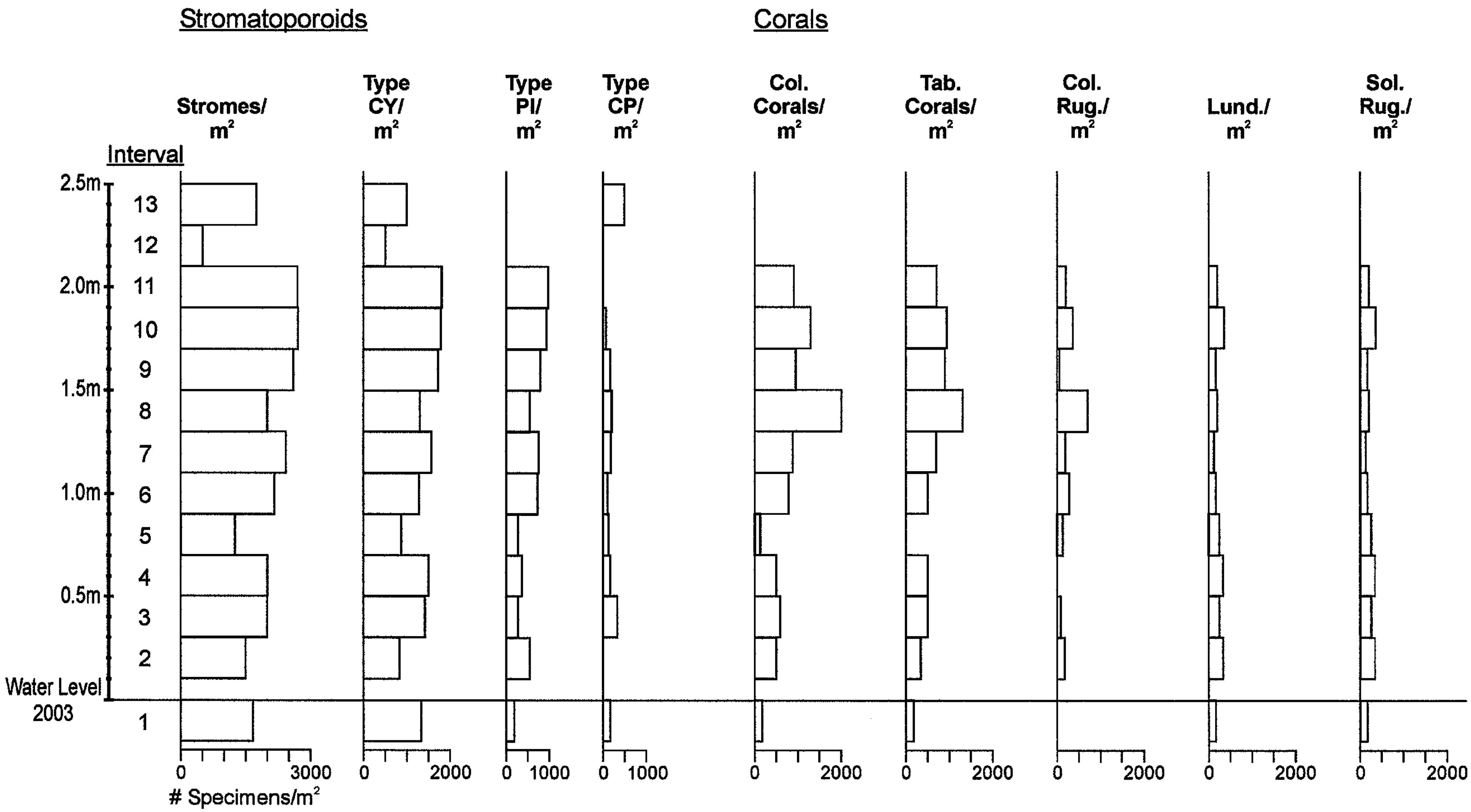


Figure 11.3: Histograms for the southern zone depicting the number of specimens per square metre for major groups of fauna found within facies 1 in the Lundar Quarry. Stromes = all stromatoporoids; Col. Corals = all colonial corals; Tab. Corals = all tabulate corals; Lund. = all specimens of *Favosites niagarensis lundarensis*; Sol. Rug. = all solitary rugose corals.

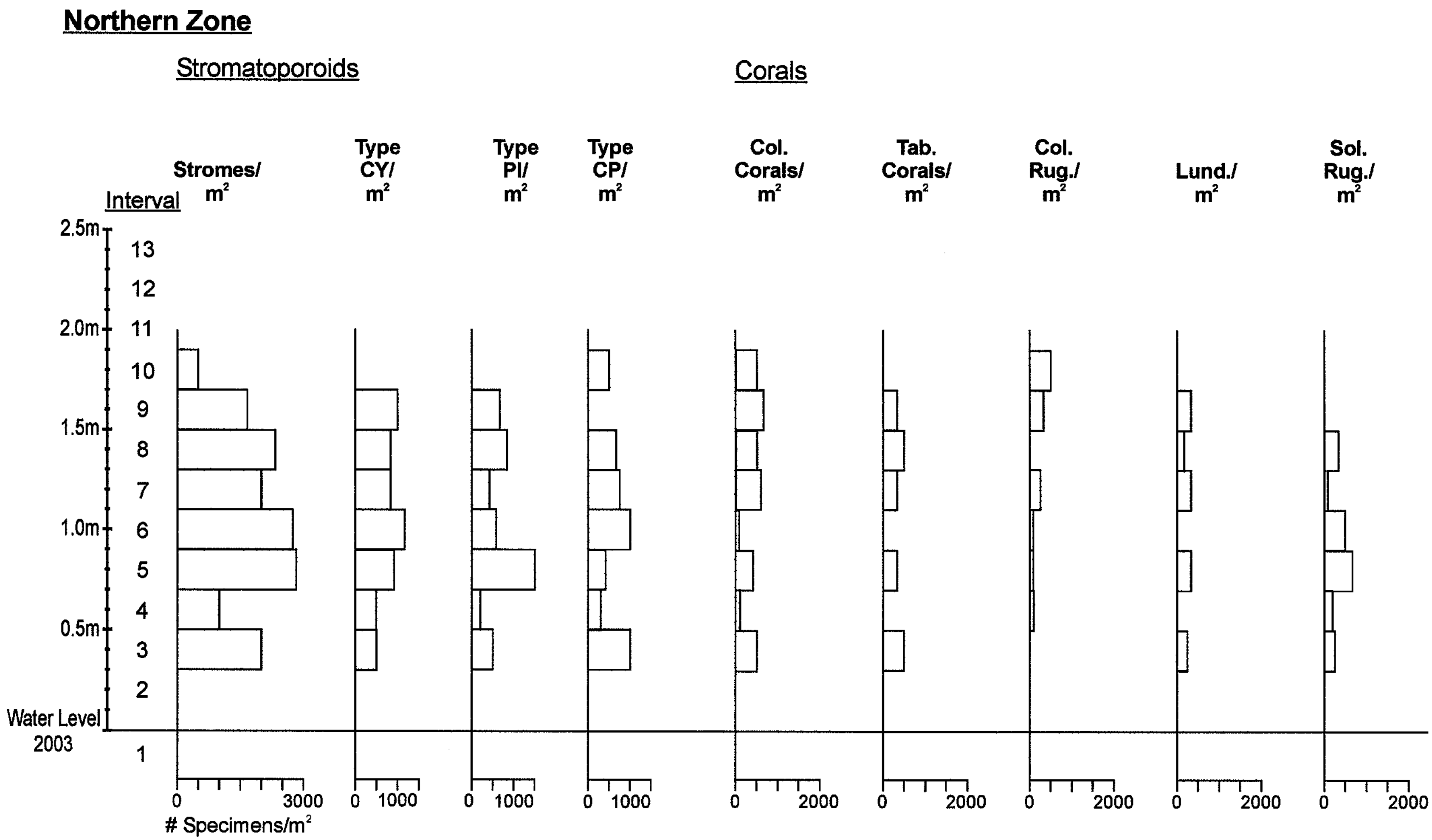


Figure 11.4: Histograms for the northern zone depicting the number of specimens per square metre for major groups of fauna found within facies 1 in the Lundar Quarry. Stromes = all stromatoporoids; Col. Corals = all colonial corals; Tab. Corals = all tabulate corals; Lund. = all specimens of *Favosites niagarensis lundarensis*; Sol. Rug. = all solitary rugose corals.

period, both colonial corals and stromatoporoids generally increased in number. At interval 8, coral density matched that of stromatoporoids. Although solitary rugose corals maintained relatively stable numbers throughout the section, both tabulate and colonial rugose corals peaked at this interval. For stromatoporoids, both types CY and PI suffered the greatest negative impact during this interval, while Type CP maintained low abundances. The density of corals gradually tapers off after interval 8, while stromatoporoids regained exclusive dominance.

Within the northern zone, stromatoporoids are dominant, as coral density remains low throughout the section (Figure 11.4). Stromatoporoid Type CP is the dominant type at interval 3, and colonial rugose corals are absent. Both stromatoporoids and corals show a dramatic increase in abundance at interval 5. Stromatoporoid Type PI far outnumbered the other stromatoporoid types present at this interval, and solitary rugose corals also saw a peak in dominance among the corals present. At interval 6, solitary corals remained in abundance, though colonial corals saw a drastic decline. Though total stromatoporoid density remained high, Stromatoporoid Type PI declined in numbers, replaced by an increase in the abundance of Type CP. Above this interval, stromatoporoid density and species proportions remained relatively static. Colonial rugose corals slowly began to increase in density up the section, whereas solitary corals began a stepwise decline, and tabulate coral abundance remained comparatively stable.

Comparison of equivalent intervals between zones for each of the faunal groups also reveals several interesting trends (Figures 11.3, 11.4). Within interval 5, there is a distinct decline in stromatoporoid density in the southern zone, whereas the northern zone shows a peak in abundance. Also, the dominant stromatoporoid in the northern zone is Type PI, whereas Type CY is the most abundant in the south. Corals show a similar correlation at the same interval, as the southern zone shows very low numbers relative to a peak in the north, though solitary rugosans are the dominant coral in both zones. At interval 6, stromatoporoid Type CP is abundant in the northern zone, whereas abundance of this type is suppressed in the south. During the same interval, colonial corals re-emerge as the dominant form in the southern zone, while solitary corals remain dominant to the north. Through the remaining intervals, stromatoporoids maintain similar abundances and proportions of stromatoporoid types. Colonial corals, however, show a significant peak at interval 8 in the southern zone, which is not seen in the north. As well, this interval marks the peak of colonial rugose coral density for the southern zone, whereas these corals are completely absent in the north.

In order to examine temporal trends in coral colony size, a standardized size classification system was employed to represent the average size class of colonies. Tabulate corals were used for this assessment, as these are the only colonial corals for which colony size could be accurately measured. Figure 11.5 displays the average size class indices for tabulate corals within each interval, for all intervals in each zone. Though the average size indices are based on a small number of specimens within each interval, the general trends observed may still be useful for speculative interpretation. In the northern zone, the size of tabulate coral colonies gradually increases up through the section, and thus through time. A similar, though less pronounced, trend can be observed for the southern zone; lower intervals mostly exhibit small size indices, and towards the middle and top of the section colonies are slightly larger on average.

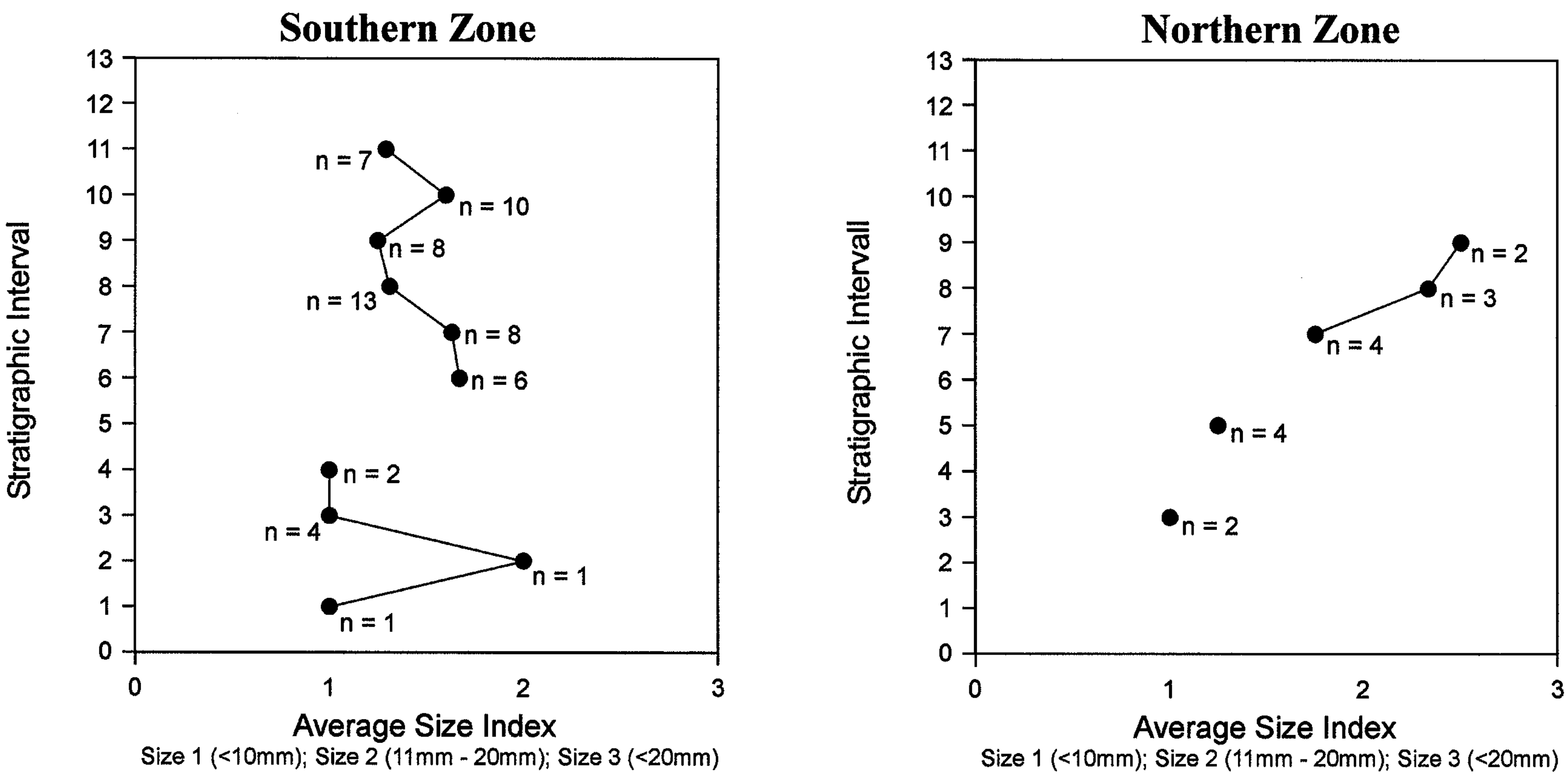


Figure 11.5: Scatter plots of the average size class indices for tabulate corals in facies 1 within each stratigraphic interval, for all intervals in each zone (n = number of specimens at each interval). Intervals for which tabulate corals are absent were excluded. Also, unidentifiable specimens were not included.

11.6 Interpretations

The arrangement of facies in the southwest corner of the Lundar Quarry suggests that this area represents relatively new biostromal expansion onto previously less-favourable substrate. At this locality, facies 1 is only represented by a thin layer near the top of the quarry, directly overlying facies 2. The fauna of facies 2 consists predominantly of small, tabular stromatoporoids and a low diversity of corals, which suggests less favourable conditions than were present during the formation of facies 1. It is possible that the fauna of facies 2 indicates the initiation of substrate colonization by a low-diversity suite of stromatoporoids. The preferential tabular growth form of these stromatoporoids was likely best suited for colonizing the muddy sediments of facies 3 without sinking into the soupy substrate. The slightly higher proportion of tabular stromatoporoids in facies 1 in the southwest corner compared to that at localities within the southern and northern zones likely represents the early stages of biostrome development (see Chapter 10). Gradual stabilization of the substrate allowed these stromatoporoids to slowly achieve larger sizes and alternate growth forms, and as well, the other fauna of facies 1 could be introduced. Thus, the limited exposure of facies 1 at the top of the southwest corner represents the initiation of this facies, where tabular stromatoporoids were still the preferred form to cope with semi-stable sediments. Additionally, the stromatoporoids of the southwest corner are smaller on average when compared to other localities within the quarry, which suggests that conditions were not yet ideal to attain very large skeletons. Thus, facies 2 may represent a pioneer community which created a more suitable environment for successive colonizers by stabilizing the carbonate muds from being eroded and held in suspension. Facies 1 likely represents the climax community of ecological succession.

The absence of facies 1 in the south quarry suggests that biostromal development was patchy in the vicinity of the Lundar Quarry. As previously mentioned, facies 4 is exposed near the top of the south quarry, underlain by facies 3 and 2, respectively (see Chapter 7). It is likely that the fauna of facies 2 attempted to colonize this area, but the southwestward progradation of biostromal facies 1 in the main quarry likely created a lagoonal, back-reef environment in this area. The lack of full-scale development of facies 1 within the Mulvihill West Quarry core also suggests patchy biostromal distribution in the Interlake area. Although conditions were apparently favourable for potential biostrome development, localized factors, such as substrate conditions, nutrient availability, or vulnerability to storms, must have influenced the distribution of biostromes.

At interval 5 within facies 1 in the southern zone of the Lundar Quarry, stromatoporoids and colonial corals decrease substantially in abundance (see Figure 11.3). In the northern zone, however, stromatoporoids, particularly Type PI, solitary corals, and to a lesser extent colonial corals, show peaks in abundance (see Figure 11.4). Thus, environmental conditions within the southern zone were apparently less favourable to the reef-building fauna during this interval, compared to the northern zone, where conditions were particularly favourable. Therefore, substantially different environmental conditions existed across the biostrome itself.

Within facies 1, small-scale ecological succession is interpreted within the biostrome. Although there are stratigraphic fluctuations in the abundances of fauna, there appears to be a general upward increase in the abundance of colonial corals, with a corresponding decrease for solitary rugose corals (see Figures 11.3, 11.4). Ecological succession within reefs generally results in an increase in the abundance of specialist, clonal organisms during community development, replacing generalist, aclonal forms (Wood 1999). Thus, the observed inverse relationship for colonial and solitary corals may reflect ecological succession within the biostrome. The observed trends for the size of tabulate coral colonies may help support this hypothesis. Within both the southern and northern zones, there is a general trend towards larger colony size through time. This may suggest that colonies were able to grow in a more stable environment, unlike earlier forms, which would have been subject to the environmental stress of the newly available substrate.

Climax stages of reef development are often dominated by one specialized taxon, which is especially true for most stromatoporoid-dominated assemblages, which have one species more common than others (Kershaw 1998). Thus, the gradual increase in the abundance of stromatoporoid Type CY up-section in the southern zone likely represents the development of a climax stage within the biostrome. Due to the limited amount of exposure, however, this climax stage is not evident in the northern zone.

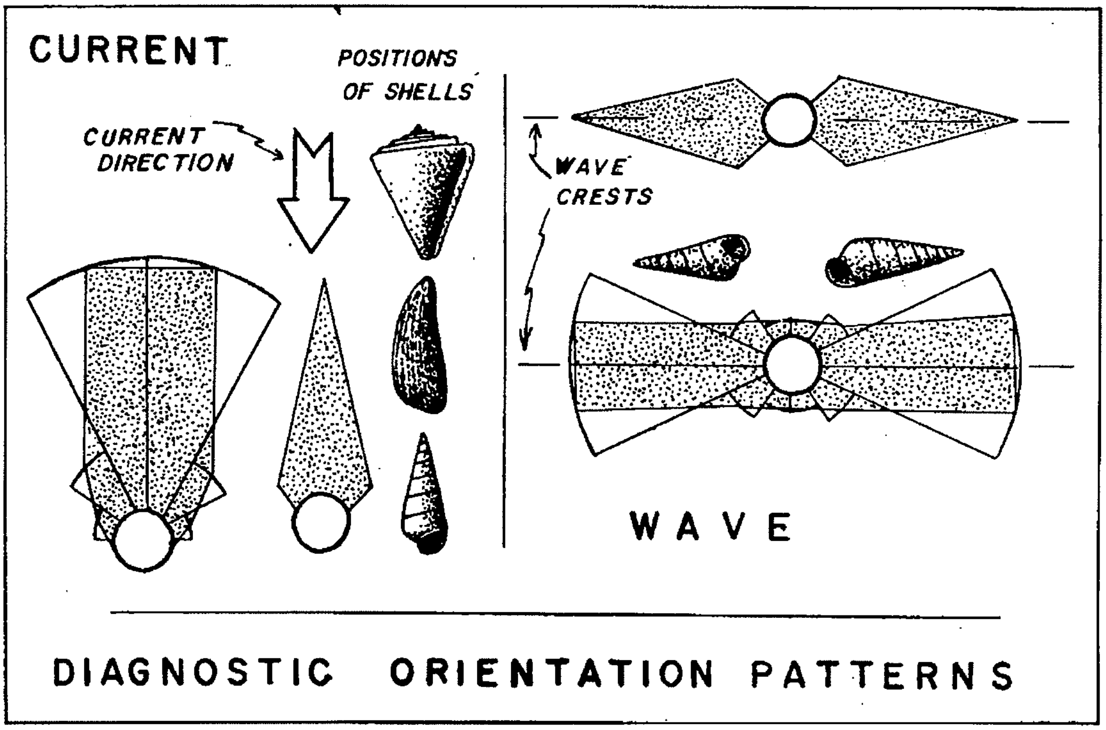
Thus, vertical zonation of the biostrome of facies 1 represents small-scale changes in community composition through time, which suggests ecological succession. This orderly process is likely related to the gradual establishment of a biostrome, from initiation to culmination. Diversity of fauna increased through time, peaked, and began a slow decline near the top of the exposure at Lundar. The strata exposed at the southwest corner reveal the successive stages that occurred in the environment around the biostrome as it progressively expanded over previously unsuitable substrate.

Chapter 12: Paleocurrent Analysis

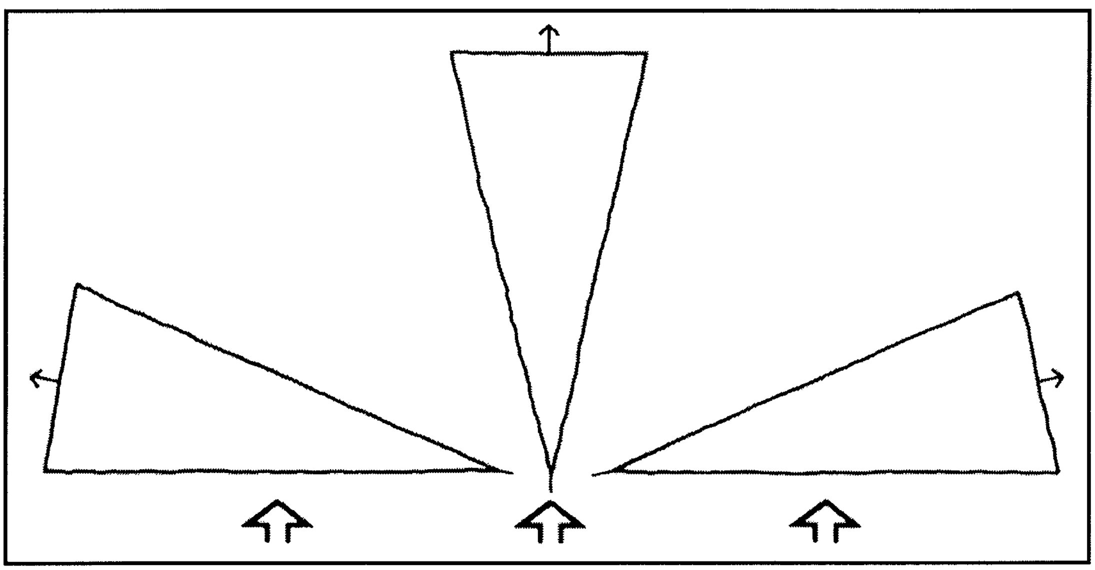
12.1 Introduction

Sedimentological evidence for the depositional hydrodynamic regime is limited within the Chemahawin Member, as mud-sized material typically lacks the strength to support and preserve the characteristic features (Jones and Dennison 1970). Diagenetic alteration to dolomite has also obscured such evidence. Fossils within this unit, however, may provide insight into the conditions of the paleoenvironment. After the death of an organism, the remaining skeleton would act as a sedimentary particle, and would thus be influenced by the prevailing conditions of the paleoenvironment. Therefore, the preserved orientations of fossils may give an indication of the hydrodynamic energy and sedimentologic aspects of the paleoenvironment immediately prior to burial. Disoriented corals and stromatoporoids have been used to determine the water energy of Paleozoic environments, particularly the direction of paleocurrents (e.g. Kobluk et al. 1977; Elias et al. 1987). Unattached corals and stromatoporoids were vulnerable to disorientation and local transportation, either by dislocation from their growth position by hydraulic energy, or by biotic or sedimentary factors (Elias et al. 1987). It is generally accepted that hydraulic energy would have produced directed orientations, whereas other factors would have likely resulted in random orientation (Dodd and Stanton 1990). As well, interpreting the effects of biological or sedimentological disturbances may be limited if there is no evidence of features such as burrow mottling or scour marks in the sediment adjacent to disoriented skeletons. Also, larger organisms are less likely than smaller ones to have been disturbed by the effects of bioturbation (Nagle 1967). Thus, recognition of a common orientation among reoriented skeletons may be evidence to suggest alignment with directed water motion.

Disturbed skeletons were presumably reoriented in the most mechanically stable arrangement. Therefore, elongate objects would be arranged relatively horizontal to the sediment, regardless of the sediment surface conditions (Nagle 1967). Previous workers have presented evidence that currents will rotate elongate fossils with the long axis oriented parallel to the current direction, whereas wave action will roll fossils with the long axis parallel to wave crests (Figure 12.1 A; Nagle 1967; Schneider and Ausich 2002). In contrast, Brenchley and Newall (1970) conducted flume experiments on models of fossil shapes and determined that the preferred orientation for elongate forms was with the long axis rolled perpendicular to current direction, with no models showing a tendency for orientation of the long axis parallel to the current. The models used for the study, however, were developed to imitate disarticulated bivalve shells, which have a concave side that would react differently to currents than a three-dimensional tabular or conical body. A general model for the preferred orientations of elongate, conical objects was presented by Elias et al. (1987). According to their model, the majority of elongate bodies will likely be oriented with the long axis perpendicular to the current direction (Figure 12.1 B). If one end of each body is weighted, an equal number will have the heavy end pointing in either direction, and the resultant bimodal distribution may be slightly skewed if the heavier end is slightly directed upstream. A third peak may also appear if some objects are oriented parallel to the current direction, with the heavier end up-current (Elias et al. 1987). For solitary rugose corals, a unidirectional orientation may be established if the streamlined apex points into the current, resulting in a unimodal distribution (Nagle 1967). As well, the apical ends of most solitary rugosan coralla contains densely spaced and thickened internal skeletal elements, making the apical ends heavy (Elias et al. 1987).



A



B

Figure 12.1: Schematic diagrams of diagnostic orientation patterns for elongate fossils. A) Fossil orientation relative to current direction and wave crests, including idealized rose diagrams (Nagle 1967, Figure 1). Note that elongate fossils will rotate with the long axis parallel to current direction, whereas wave action will roll fossils with the long axis parallel to wave crests. B) Preferred orientations of elongate, conical objects (Elias et al. 1988, Figure 1.2 A). The majority of elongate fossils will be oriented with the long axis perpendicular to the current, with an equal number pointing in either direction. Some fossils may be oriented parallel to the current, with the heavier end pointing up-current.

Thus, currents may have been capable of swinging the calicular end parallel to the current direction, with the apex pointed up-current (Elias et al. 1987). For this study, the model of Elias et al. (1987) will be used to determine the orientations of fossils relative to the paleocurrent direction.

12.2 Paleocurrent Analysis Methods

In order to determine the influence of paleocurrents on the fauna of the Chemahawin Member, the exposed horizontal bedrock surface around the northern edge of the quarry was divided into eight areas and examined (Figure 12.2). Due to the patchiness of exposure, areas varied in size between two and five metres in diameter. Included in this analysis were stromatoporoids, colonial and solitary corals, and articulated echinoderm columnals. Equidimensional skeletons were excluded from analysis. In each area, the orientations of fossils were measured parallel to their long axis. Bidirectional measurements were recorded for all fauna in which the growth direction was not related to the axis of elongation, or if the growth direction could not be determined. Readings for bidirectional objects were recorded (and treated statistically) in the range of 1° to 180°, but were plotted bidirectionally on rose diagrams (Appendix D; Figure 12.3 A-C). Unidirectional readings were measured from the apex towards the calice for solitary rugose corals in which the direction of corallum expansion or the position of the calice could be determined (Figure 12.3 D). It is important to note that the attitude of exposure of colonial corals and stromatoporoids on the horizontal surface may influence form recognition (Kershaw and Brunton 1999). Fossils of various growth forms may appear elongate in horizontal section if the skeleton is differentially exposed

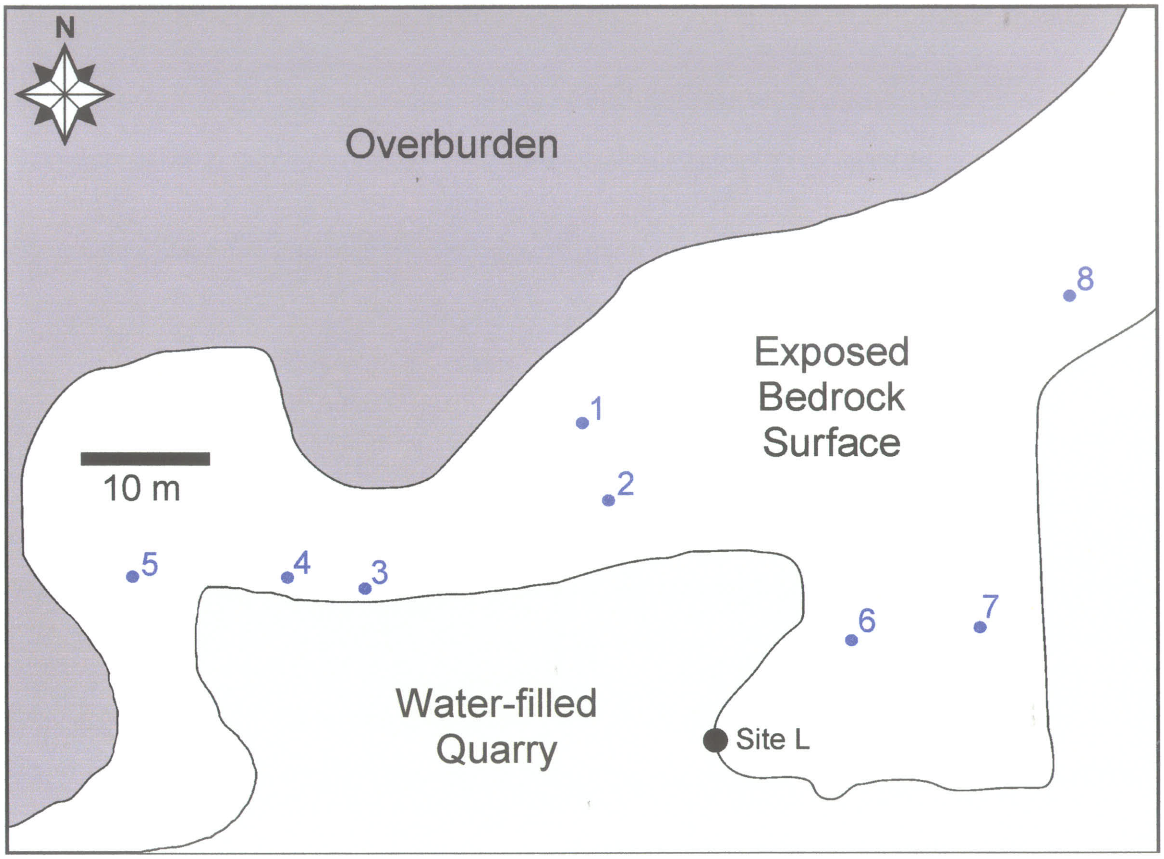


Figure 12.2: Map of the northern edge of the Lundar Quarry, where paleocurrent analysis was conducted on a glacially scoured, exposed bedrock surface. Eight blue points represent GPS coordinates for the approximate centre of each study area (see Figure 5.1 for locations of paleocurrent study areas relative to quarry sites).

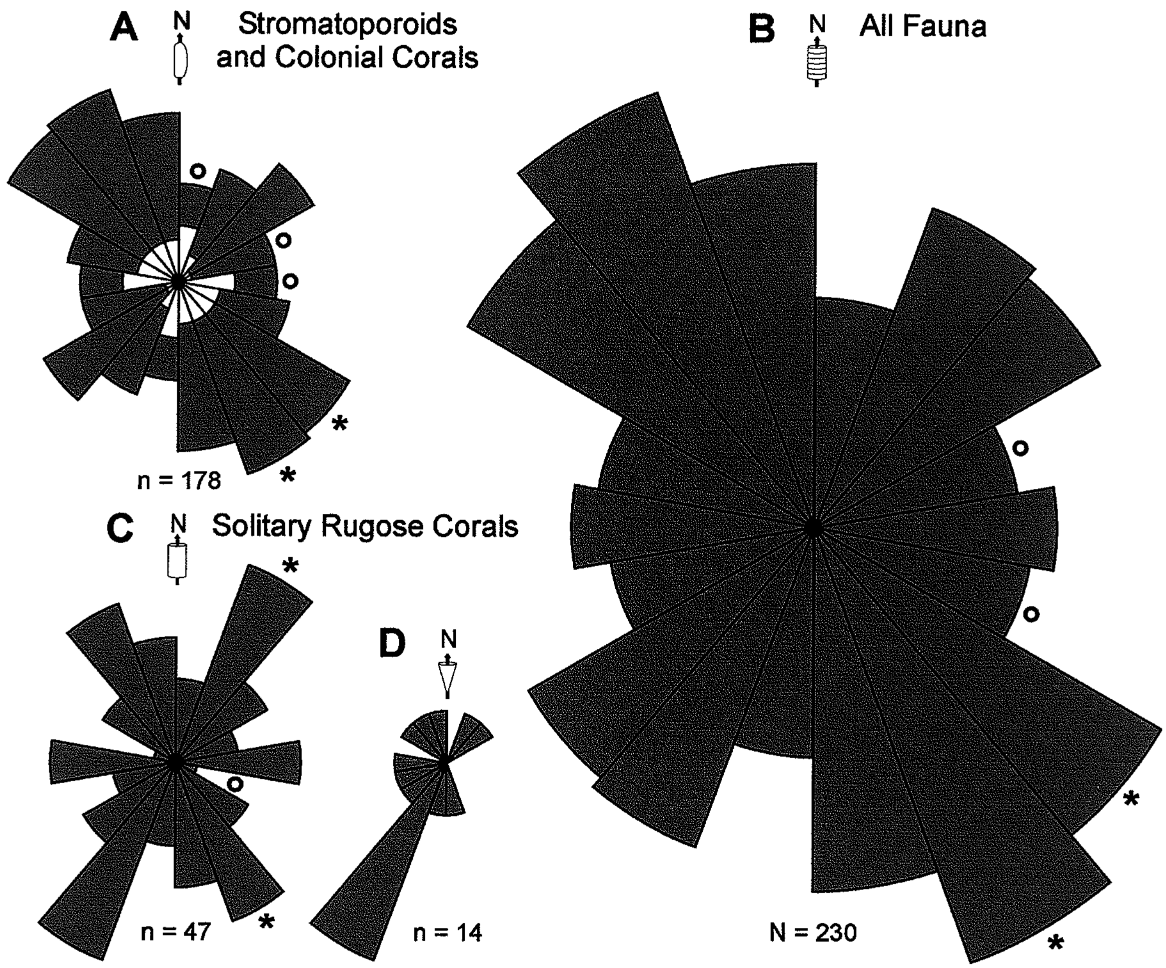


Figure 12.3: Rose diagrams showing the orientation of elongate fossils along the northern edge of the Lundar Quarry. Orientation conventions are depicted for each group of measured fauna, using north arrow as an example. Elongate fossils were measured parallel to the longest axis. A) Stromatoporoids (gray) and colonial corals (white). B) All fauna combined, including articulated echinoderm segments. C) All solitary rugose corals. D) Solitary rugose corals for which unidirectional data could be obtained. Asterisks and open circles indicate classes which have been identified as anomalously high or anomalously low, respectively.

(see Figure 4.1). Although this phenomenon is acknowledged, the effects of such bias are not considered for this study.

As strata within the quarry are essentially horizontal, and all data were obtained from the same glacially scoured horizontal exposure surface, it may be assumed that this surface represents approximately the same interval of time. Based on fossil content, the horizontal bedrock surface represents facies 1. Thus, the data represent the same time interval and the same paleoenvironment. It was therefore considered appropriate to combine data from the eight areas in order to generate one larger data set for statistical analysis.

Chi-square tests were generated to determine if the distribution of data is random or preferred (Appendix D, Part 2). As previously stated, degrees of freedom (d.f.) equals the number of classes minus one (see Chapter 5). Expected values (E) were calculated based on the total number of specimens (n) divided by the number of classes (k), where E must maintain an average class frequency of at least five in order to apply the Chi-square test (Reyment 1971). Expected values were subtracted from the observed values (O) for each class, and the resultant value was then squared. The square root of the sum total of this value for all classes was then calculated, yielding the standard deviation for values (S.D.). Classes were considered to be anomalous if the observed class value differed from the expected values by more than one standard deviation. The value of $(O-E)^2$ for each class was also divided by the expected value, and the sum total of these values represents the value for χ^2. This calculated value for χ^2 was then compared with the tabulated critical value for $\chi^2_{0.05}$ (see Mendenhall 1971, Appendix II, table 5). A preferred orientation was suggested if the calculated value was greater than the critical value.

An additional effect of hydraulic energy considered for this study is the degree of abrasion of fossils within the quarry. Abrasion may suggest higher energy conditions in order to carry sedimentary particles in the water column. Solitary rugose corals are the best specimens for observing the degree of abrasion as a result of hydraulic conditions within the paleoenvironment, as the condition of the outer wall can be easily observed for some specimens. Post-mortem exposure of coralla to the wave or current energy prior to burial would likely result in some degree of abrasion and breakage (Elias 1982). The intensity of the prevailing energy regime prior to burial may be estimated based on the extent of abrasion. Additionally, it may be possible to infer the rate of sedimentation from the degree of abrasion, as longer periods of exposure would likely result in greater removal of skeletal material (Elias 1982). Unequal abrasion of coralla may be the result of partial exposure of coralla resting on the seafloor during periods of reduced sedimentation (Elias 1982). Thus, for all hand samples collected from each site within the quarry, the degree of abrasion was noted for solitary rugose corals, as well as the orientation of unequally abraded sides of coralla relative to the top of the quarry. Since the majority of solitary rugose corals within the Lundar Quarry are fragmented or were cut at an angle in hand samples, not all specimens were appropriate for this analysis.

12.3 Observations

Considering evidence for hydraulic energy conditions in the environment, the abrasion of solitary rugose corals will be addressed first. Of the 39 specimens for which the condition of the outer wall was observable, only 38% show some degree of abrasion (Figure 12.4). Removal of skeletal material appears to be random, as some specimens show almost total removal of the outer wall on all sides, whereas others show minor

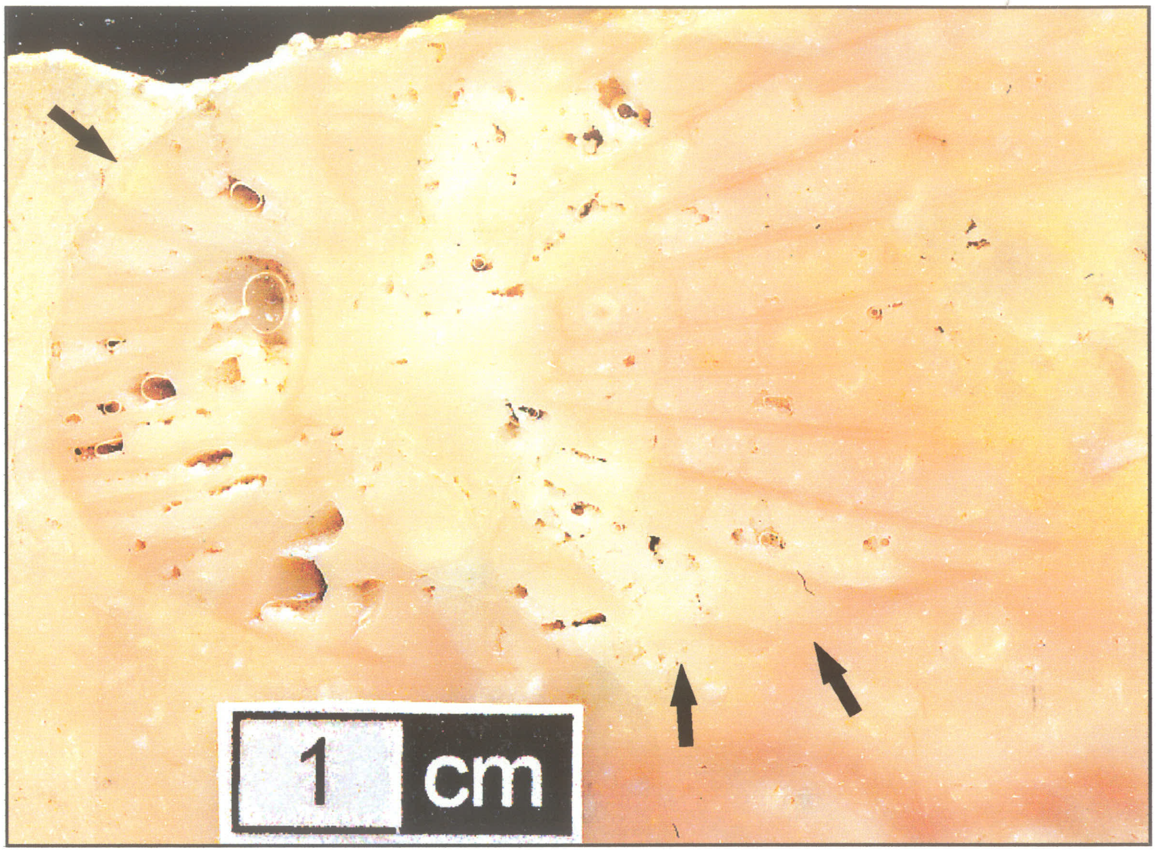


Figure 12.4: Solitary rugose coral showing an example of abrasion of the outer wall (arrows indicate positions where wall is completely removed). The outer wall is relatively intact on the left side of the specimen.

thinning of the outer wall on only one side of the corallum. For the latter specimens, there appears to be little consistency for the orientation of sides of coralla showing unequal abrasion, relative to the top of the quarry. Regardless, the amount of abrasion of these corals suggests some degree of water motion within the paleoenvironment. It is unlikely, however, that energy levels were very high, as such unbound stromatoporoid reefs could likely not tolerate great disturbance (DeFreitas et al. 1993).

The results of paleocurrent analysis can be seen in the rose diagrams of Figure 12.3. Stromatoporoids and colonial corals were grouped together, as the nature of the skeletons of these organisms are assumed to exhibit a homogenous distribution of mass, so they are likely to have behaved in a similar manner when exposed to directional currents (Brenchley and Newall 1970). Solitary corals have been considered as a separate group, since the long axis is the direction of growth, and unidirectional data were obtainable for specimens in which the position of the apex or the direction of growth could be determined. Additionally, due to the densely spaced skeletal elements within the apical end of coralla, it has been determined that the apical end was heavier, and would have thus reacted differently to currents (Elias et al. 1987). Data for each of these faunal groups were grouped into classes for analysis. Nine classes between 1° and 180° were selected in order to satisfy the requirement of an expected number of five for the Chi-square test based on the number of solitary rugosans, as this faunal group has the lowest number of observed values (n = 47).

Figure 12.3 B depicts the results for the orientation of all fauna combined, including stromatoporoids, all corals, and articulated echinoderm columnals. The Chi-square test confirmed a non-random distribution of data ($\chi^2 = 17.3041$; $\chi^2_{0.05} = 15.5073$; 8

d.f.). The frequencies of values between 121° and 160° are considered anomalously high ($O_{121°-140°} = 33$; $O_{141°-160°} = 38$; E + S.D. = 32.5657), and the values between 61° and 80° and 101° and 120° are considered anomalously low ($O_{61°-80°} = 17$; $O_{101°-120°} = 18$; E - S.D. = 18.4563). A second large peak between 21° and 60° occurs approximately perpendicular to the maxima, though the frequencies for these classes are not considered anomalous. The results of this analysis led to the consideration of each faunal group separately, in order to compare the distributions with that for combined fauna.

The combined distribution for stromatoporoids and colonial corals (Figure 12.3 A) is very similar to that for the overall fauna (Figure 12.3 B). The Chi-square test performed for the distribution of stromatoporoids and colonial corals (Figure 12.3 A), however, did not confirm a non-random distribution ($\chi^2 = 15.0448$; $\chi^2_{0.05} = 15.5073$; 8 d.f.), possibly because of the smaller sample size. Nevertheless, the frequencies between 121° and 160° are considered anomalously high ($O_{121°-140°} = 28$; $O_{141°-160°} = 29$; E + S.D. = 25.5279). A second smaller peak occurs between 41° and 60°, perpendicular to the first peak, though the frequency of values for this position is not considered anomalous. In contrast, frequencies that are considered anomalously low occur between 1° and 20°, and 61° and 100° ($O1_{°-20°} = 14$; $O_{61°-80°} = 14$; $O_{81°-100°} = 14$; E - S.D. = 14.0281). It is relevant to note that the trend for colonial corals differs somewhat from the trend for stromatoporoids. The major trend for both stromatoporoids and colonial corals is in a northwest-southeast orientation, though a second peak approximately perpendicular to the main trend is observed for stromatoporoids but not for colonial corals.

Figure 12.3 C is a bidirectional plot of the orientations of all solitary rugose corals measured for this study, including those for which unidirectional readings were obtained

(Figure 12.3 C). Thus, for example, a unidirectional reading in the class 181°-200° was also plotted in the class 1°-20°. For the purpose of conducting the Chi-square test, the resulting frequencies in the classes from 1° to 180° were used. The Chi-square test for this faunal group did not confirm a non-random distribution ($\chi^2 = 11.0218$; $\chi^2_{0.05} = 15.5073$; 8 d.f.), possibly because of the relatively small sample size. Nevertheless, the frequency of values between 21° and 40°, and 141° and 160° are considered anomalously high ($O_{21°\text{-}40°} = 10$; $O_{141°\text{-}160°} = 8$; E + S.D. = 7.7509). The smaller peak corresponds with the maxima observed for stromatoporoids and colonial corals, whereas the larger peak is almost perpendicular. Between 101° and 120° the frequency of values is considered anomalously low ($O_{101°\text{-}120°} = 1$; E - S.D. = 2.6932). Figure 12.3 D depicts the orientation of those solitary rugosans for which unidirectional measurement could be obtained. The majority of these coralla are oriented with the calicular end facing in a southwesterly direction, four times that of any other direction. Though the number of specimens was insufficient for statistical analysis, the resultant trend is nevertheless useful for suggesting the possible direction of paleocurrents.

12.4 Interpretations

From the resultant rose diagrams, several interpretations may be made about the possible direction of the prevailing current within the paleoenvironmental setting of the Chemahawin Member. The rose diagram for all fauna shows a distinct mode oriented northwest-southeast, with a smaller peak perpendicular to the main trend. According to the model of Elias et al. (1987), the majority of elongate objects will be oriented perpendicular to the prevailing current, and a smaller number of objects will be aligned with the current. Thus, the preserved orientation suggests a northeast-southwest paleocurrent direction. It is important, however, to consider the different groups of contributing fauna separately in order to determine which groups are responsible for these general trends.

The rose diagram for stromatoporoids and colonial corals reveals a similar trend to that for the overall fauna, since the majority of measured organisms were stromatoporoids. The dominant orientation for this group of fauna is northwest-southeast, suggesting these elongate fossils were rolled perpendicular to the prevailing current. For stromatoporoids, a smaller peak was observed perpendicular to the main trend. Though Elias et al. (1987) suggested that some forms may become aligned parallel with the paleocurrent, this second mode was not observed for colonial corals. Thus, though elongate colonial corals and stromatoporoids generally respond in a similar manner to prevailing currents, it appears that colonial corals are less likely to be found aligned with the current. Perhaps there exists some inherent feature within the skeleton of colonial corals which imposes a predominantly perpendicular current alignment.

The principal mode for bidirectional solitary rugose corals occurs in a northeast-southwest orientation. Since these fossils may align parallel with the paleocurrent, this provides further evidence to support the dominant paleocurrent direction suggested by the other fauna. A second peak for solitary corals occurs approximately perpendicular to the main trend, which suggests that some fossils must have been rolled by the current. The rose diagram for unidirectional solitary corals shows a dominant mode to the southwest. Since the apical ends would most likely point up-current, this observation suggests that the calicular ends of coralla were swung to face the southwest by a current originating in the northeast. This interpretation, however, must be used with extreme caution, as a sufficient sample size for statistical analysis was not obtained for unidirectional solitary corals.

Chapter 13: Discussion

Information obtained from the carbonate strata exposed within the Lundar Quarry and viewed in drill core allows for a reconstruction of the paleoenvironmental conditions that prevailed prior to burial. As well, the observed lateral and vertical zonation of fauna within the quarry is considered in terms of a paleoecological reconstruction. The presence of a biostrome within the Chemahawin Member also permits consideration of this reef body in the context of local and global sea level for the mid-Early Silurian, and comparison of the Chemahawin biostrome to similar mid-Early Silurian structures worldwide.

13.1 Paleoenvironmental Reconstruction

During the mid-Early Silurian, the paleoenvironmental conditions in the vicinity of the Lundar Quarry were that of a shallow, open marine setting near the northern margin of the Williston Basin. Limited terriginous sediments within this carbonate unit may suggest that the paleo-shoreline was at a greater distance than winds could carry sediments in suspension. Though the actual size and extent of the Chemahawin biostrome cannot be measured due to the limited exposure at Lundar, it is hypothesized that it was not laterally extensive. Examination of the subsurface geology within drill core from the Lundar Quarry revealed facies similar to those as seen in outcrop, including biostromal facies 1 at the top of the cored interval (see Figure 8.1). The drill core obtained from the Mulvihill West Quarry, however, revealed that, though stromatoporoid-dominated facies 2 was present near the top of the core, full-scale development of a biostromal facies was absent (see Figure 8.1). Also, the lack of facies 1 in the south quarry at Lundar confirms the limited extent and patchiness of reef structures in this vicinity during the mid-Early Silurian.

Prior to burial, skeletons of facies 1 fauna were dislocated and oriented relative to the prevailing hydraulic energy regime. Elongate fossils with evenly distributed mass tended to be rolled perpendicular to the current direction, whereas solitary corals tended to be aligned parallel to the current, with their weighted apical ends pointing upstream. The paleocurrent direction prior to burial has been established as originating in the northeast and flowing towards the centre of the Williston Basin to the southwest. The southwest corner of the Lundar Quarry would have been protected from strong currents by the biostrome. Thus, restricted conditions behind the biostrome allowed for the uninterrupted deposition of muds in a quiescent setting.

The arrangement of facies in the southwest corner also suggests that the biostrome formed a minor, wave-resistant ridge, behind which quiet-water, more restricted conditions existed. The presence of finely layered mudstones and unfossiliferous, bioturbated mudstones adjacent to fossiliferous facies near the base of the quarry exposure suggests drastically different conditions in close proximity to one another. In cores of the Cedar Lake Formation from other areas within the Williston Basin, alternating cycles of fossil-rich strata and barren, laminated and massive microdolostone occur, which were suggested to represent oscillating salinity conditions from normal marine to hypersaline (Magathan 1987). Laminated intervals were thought to represent periods of increased salinity, high enough to prevent invertebrate life (Magathan 1987). Within the Lundar Quarry, abundant, normal marine fossils within the biostrome adjacent to the laminated interval, however, do not imply significantly variable salinity conditions within the environment. Although evaporitic molds have been found within facies 1 at sites O and K, it is assumed that they formed as a result of post-depositional diagenetic processes just below the sediment-water interface, and are unlikely to reflect conditions within the paleoenvironment. Thus, the lagoon that formed behind the biostrome was likely a restricted environment with possibly normal to only slightly elevated salinities.

A more likely explanation for limited abundance and diversity of fauna down-current from the biostrome at this interval is related to a high concentration of mud-sized particles held in suspension and being deposited in this setting. The protected conditions provided by the biostrome likely allowed for uninterrupted deposition of carbonate muds. The threat of smothering by sedimentation, and the instability of this newly deposited substrate, were likely unsuitable for the reef fauna of the Chemahawin Member. Rising relative sea level during the transgression that occurred within the Williston Basin during Cedar Lake deposition may have resulted in gradually less-restrictive conditions down-current from the biostrome, thus allowing the normal marine organisms to colonize this environment. In the south quarry, however, a reverse facies pattern was observed, as facies 4 is found near the top of the exposure, with facies 3 and 2 exposed below, respectively. It is possible that the southwestward advancement of the biostrome within the main quarry may have created restricted conditions in this area over time, which caused a gradual transition to lagoonal conditions.

Facies distributions within the southwest corner suggest a westerly advancement of lithologies (see Figure 7.5). It is hypothesized that the biostrome of facies 1 was gradually advancing westward over substrate that had been stabilized by the fauna of facies 2 within a protected back-reef setting. A restricted lagoonal setting was maintained near the vicinity of site Q, and in the south quarry. If the rise in relative sea level during the Cedar Lake transgression had continued, these areas may also have been encroached upon once the laminated muds were worked by burrowers, and stabilized by pioneer stromatoporoids. The regression near the close of Cedar Lake time, however, negatively impacted biostromal development and expansion, resulting in widespread deposition of laminated mudstone at the top of the formation.

13.2 Paleoecological Reconstruction

The distributions of species and growth forms found in the three main zones of the quarry differ from each other among similar time intervals, suggesting that specific microhabitat restrictions controlled faunal distributions. Discrete differences in the depositional paleoenvironment may be evident from the fauna that are not readily apparent from the sedimentary record.

Tabular stromatoporoids, which are poorly suited to avoid smothering by sediment, dominate the faunal assemblage of facies 2. The generally small coenostea suggest early mortality, likely as a result of unstable conditions within the environment. As well, the overall low diversity of suspension feeders in this facies could be the result of higher substrate mobility (see Stel 1978). It is hypothesized that facies 2 represents an environment of relatively low sedimentation rates and energy, which was repeatedly interrupted by higher energy storms that disturbed the muds, and smothered and disoriented the stromatoporoids. The biostromal facies 1 likely offered some protection from currents, allowing stromatoporoids to begin to colonize above the loose muds of facies 3 behind the biostrome. Since these stromatoporoids were subject to repeated disturbance, it must be considered why tabular growth forms persisted in this environment. It is likely that the tabular shape afforded a large surface area to prevent sinking into underlying soupy sediments. As well, tabular growth forms afford rapid lateral expansion over available substrate, so this shape may have been a competitive response. Periodic turbulent conditions and possibly slightly elevated saline conditions in this protected environment likely limited the abundance of corals within this facies.

The biostrome is likely the end result of a period of short-term paleoecological succession, showing transitions from the pioneer community of facies 2, dominated by tabular stromatoporoids and few corals, to the climax community of facies 1, consisting of both stromatoporoids and corals of a variety of growth forms. There is also evidence for both lateral and vertical zonation of taxa within the biostrome. The prevailing environmental conditions, and interspecific competition, likely controlled the distribution and dominance of taxa at any given time.

In the vicinity of locality H in the southern zone, the greater abundances of echinoderm debris, halysitid corals, and domical stromatoporoids were suggested to represent high-energy conditions. Additionally, it is believed that concentrations of echinoderm debris are directly related to the proximity of the living echinoderms on the buildup: the abundance of debris is likely to decrease away from the biostrome core (Meyer and Meyer 1986). Thus, locality H may represent the reef core, where reef development was initiated. This argument is further substantiated by the more advanced community successional stage inferred for the southern zone, as compared to the northern zone and the southwest corner (see Chapter 11). It is possible that the biostrome was slightly taller in the southern zone reef core, placing it within somewhat shallower, more turbulent conditions. In the northern zone, the abundance of larger stromatoporoids and the greater abundance of symbiotic coral-stromatoporoid associations suggest moderately high-energy conditions. In contrast, the distribution of taxa in the southwest corner is dominated by tabular forms, which are poorly suited for areas of high sedimentation rates or sediment disturbance, as they are prone to smothering (Wood 1999), suggesting lower energy conditions and less sedimentation.

The abundance of symbiotic associations within the northern zone may also be related to nutrient supply in this environment. Kershaw (1993) stated that an increase in the number of corals living in symbiotic association with stromatoporoids is possibly a result of nutrient conservation in nutrient-poor settings. This interpretation, however, has been cautioned, as symbiosis may be the result of a lack of suitable substrate for colonization (Kershaw 1993).

Based on temporal data obtained from this study, the distributions of taxa within the quarry are related to the initiation, development, and climax of a biostromal community. This biostrome likely originated in the vicinity of the southern zone, and expanded over available substrate. A back-reef lagoon existed down-current from the biostrome in the southwest corner of the quarry. In this sheltered environment, the gradual transformation of the lagoonal muds by bioturbators, and the subsequent stabilization by a pioneer community of stromatoporoids, allowed for the lateral expansion of the biostrome over previously unsuitable substrate. Biostromal expansion was likely not very extensive, as the fully developed biostromal facies is not present in the south quarry or in the drill core from Mulvihill West Quarry.

Although species zonation, in terms of lateral differences in the abundances of taxa, is evident within the Lundar Quarry, both the northern and southern zones contain the same species; this suggests that the organisms were capable of tolerating a wide range of microenvironments (see Stearn 1982). It is necessary, however, to explain why different growth forms co-occur at most intervals of each zone (See Figure 11.2). It is unlikely that the co-occurrence of growth forms at the same intervals of each zone strictly represents adaptations to the local microenvironmental conditions. Similar levels of genotypic control on the ranges in the potential growth form variation would likely result in similar responses to environmental conditions (Kershaw 1981). Thus, it is possible that each type of stromatoporoid possessed similar levels of genotypic control on potential growth form variation. Additionally, the juxtaposition of varied growth forms may be the result of time-averaging, or post-mortem transport of skeletons.

As bioherms and biostromes within the Chemahawin Member are reportedly patchy in southern Manitoba (e.g. Stearn 1956; Johnson and Lescinsky 1986), and limited elsewhere within the Williston Basin, it is likely that the reef structures must have formed under exceptional local circumstances. Reefs are often found to have initiated on topographic highs perched slightly above the seafloor (Riegl and Piller 1999). It is possible that rare topographic highs located in Manitoba allowed for biostromal and biohermal development. As well, the paleoenvironmental conditions of this setting were sufficiently favourable to support a moderately diverse, biostromal assemblage.

13.3 Benthic Assemblage Zones

In order to recognize relative sea-level changes within the geologic record, the stratigraphic arrangements of fossil communities have been interpreted to represent different depths (Ziegler et al. 1968). Silurian benthic assemblage zones have been defined based on the arrangement of these communities parallel to the shoreline in order of progressively deeper waters during different intervals of time (Ziegler et al. 1968). Estimation of the depths of assemblages is generally based on two factors: the level of hydraulic energy within the environment, including wave and current activity, and the indication of deposition below or above the photic zone (Brett et al. 1993). As it remains unconfirmed whether Silurian corals and stromatoporoids hosted zooxanthellae (symbiotic algae) within their soft tissues, little evidence can be derived from these fossils regarding light requirements. The presence, however, of calcareous algal fragments in facies 3 samples suggests a position above the photic zone. Johnson (1987) proposed the following absolute depths for benthic assemblage zones: Zone 1, 0-10 m; Zone 2, 10-30 m; Zone 3, 30-60 m; Zone 4, 60-90 m; and Zone 5, 90-120 m. These zones were established based on sedimentologic and paleontologic evidence for the position of a unit relative to fair-weather and storm wave bases in shallow-water environments (Johnson 1987; Brett et al. 1993).

In terms of paleontological evidence, benthic assemblage zones were originally defined based on cosmopolitan genera of brachiopods, though corresponding zones have been outlined for faunal assemblages that do not include brachiopods, such as stromatoporoid- and coral-dominated assemblages (Johnson 1980). For the Llandovery, abundant stromatoporoids and corals with flat-lying, tabular growth forms up to 50 cm in diameter have been interpreted to represent a setting above fair-weather wave base in benthic assemblage zone 2 (Johnson et al. 1985). Tabular shapes are interpreted to have been an adaptive outcome for living in agitated waters above wave base, where lateral expansion of the skeleton would be preferred over vertical growth (Johnson 1980). Assemblages in which the majority of specimens are not in life position likely indicate a position above wave base, where high energies disorient skeletons (Stel 1978). Thus, because of the abundant disoriented, tabular growth forms of reef-building fauna found within the Cedar Lake Formation, the reefal interval has been interpreted to represent benthic assemblage zone 2 by Johnson and Lescinsky (1986). Additionally, the large amount of fragmented and disarticulated skeletal material, including abraded fossils, suggests somewhat higher energy conditions typical of shallow waters. Calcareous algal fragments obtained during microfossil analysis also suggest shallower waters within the photic zone. The lack of intertidal or supratidal indicators, such as mud cracks or restricted marine organisms, suggests that the reefal interval of the Cedar Lake Formation likely does not represent conditions shallower than benthic assemblage zone 2. The laminated mudstones of facies 4 have been interpreted by some workers to be stromatolitic (e.g. Stearn 1956; Johnson and Lescinsky 1986), although close examination and analysis of samples in the present study revealed a lack of evidence to suggest the presence of stromatolites. And though very fine-grained muds are typically deposited and best preserved under low-velocity conditions at depth (Ingels 1963), the prevalence of other shallow-water indicators does not support deposition in deep waters.

The information obtained from examining drill core supports the attribution to benthic assemblage zone 2 for the fauna of the Cedar Lake Formation, and the suggestion that the Cedar Lake represents a transgressive episode. Within the Lundar Quarry North core, a gradual deepening upward sequence is evident from the v marker in the East Arm Formation to the biostromal unit at the top of the core. Shallow water indicators, such as oolitic intervals, brecciated intraclasts, and shallow water shelly marine organisms provide evidence that the interspersed thick units of laminated mudstone were deposited in shallow waters rather than in deep settings. These shallow indicators likely indicate a position above fair-weather wave base, between benthic assemblage zones 1 and 2 (see Figure 1.3; Johnson and Lescinsky 1986; Brett et al. 1993). The gradual introduction of reef fauna near the top of the core suggests somewhat deeper conditions, likely within benthic assemblage zone 2, as proposed by Johnson and Lescinsky (1986; see Figure 1.3). A similar progression of facies is evident within the Mulvihill West Quarry core, as shallow water facies near the base of the core grade up into slightly deeper units containing abundant marine organisms equivalent to the biostromal facies of the Lundar Quarry North core. The interval of laminated mudstone just below the Silurian-Devonian contact likely represents a short shallowing upward interval to benthic assemblage zone 1, as proposed by Johnson and Lescinsky (1986; see Figure 1.3).

13.4 Sea-Level Correlation

The observed deepening upwards successions within the Lundar Quarry North drill core and the base of the Mulvihill West Quarry drill core support the transgressive episode for the Cedar Lake Formation proposed by Johnson and Lescinsky (1986; see Figure 1.3). Near the top of the Mulvihill West Quarry core, however, there is a reversion to shallow water, laminated mudstones devoid of fossils, which are also found as intraclasts within the base of the overlying Devonian Ashern Formation. This transition likely represents the subsequent regression for the close of Cedar Lake time suggested by Johnson and Lescinsky (1986; see Figure 1.3). Thus, evidence from core examination supports the interpretation of a transgressive-regressive cycle within the Cedar Lake Formation (Johnson and Lescinsky 1986). As well, the transgressive episode corresponds to the predicted interval of maximum sea-level rise in the late Llandovery on the Laurentian paleocontinent (see Figure 3.2; Johnson et al. 1998). Though the maximum of this sea-level curve extends into benthic assemblage zone 5 in the Iowa type section, a correlative shallower curve has been plotted for the Williston Basin. This transgression can also be correlated with similar sea-level peaks in basins around the world during this time interval (see Johnson 1996). A peak in global reef development corresponds with this major transgression (Johnson et al. 1998). Thus, the Chemahawin biostrome likely developed within the relatively shallow Williston Basin during a major period of worldwide reef development as a result of increased water depth due to a global rise in sea level during the late Llandovery.

The distribution of facies observed by Johnson and Lescinsky (1986) in vertical section is observed laterally within the Lundar Quarry. The lateral and vertical arrangements of facies over a short distance in the southwest corner of the quarry are unlikely to be related to significant differences in water depth. Minor differences in closely spaced microenvironments, such as energy levels, water clarity, or nutrient supply, could account for the similar facies distributions seen in the Lundar Quarry. Thus, the arrangement of facies within the southwest corner of the Lundar Quarry is an example of closely spaced, discrete microenvironments which generated distinct sedimentological and paleontological suites. Furthermore, the distributions of fauna and faunal growth forms, both within and among facies, may be the result of closely spaced microenvironments, unrelated to substantial water depth fluctuations. Reef environments commonly exhibit zonation within and around the structure, both laterally and vertically, often as a result of differential environmental gradients (Riegl and Piller 1999). As the biostrome must have possessed some topographic relief and was therefore capable of influencing the adjacent environments to some degree, it is likely that the structure is responsible for creating different energy conditions in and around the biostrome. Behind the reef structure, protected from intense hydraulic energy conditions, sediments representing quiet-water facies were deposited, and the growth forms that developed were different from those found directly facing the incoming currents and waves. As well, the lower diversity community of facies 2 occupied the back-reef area, likely as a result of restricted conditions which created a less favourable environment.

13.5 Comparison of the Chemahawin Biostrome with Equivalent Buildups

During the Late Ordovician, stromatoporoid-coral assemblages became well established as reef-building communities, which persisted until the Late Devonian (Heckel 1974). Warm, well-oxygenated, shallow-water conditions were favourable for stromatoporoid dominance in many early Paleozoic reefs (Kershaw 1981). On the North American continent, large mid-Silurian reefs are abundant and widespread within the Michigan Basin (Great Lakes Complex), the Hudson Bay Basin, and in eastern Canada (see Figure 3.1). The fauna of the Lundar Quarry includes species that are the same as, or similar to, those in the reef faunas of these basins. Within the Williston Basin, however, reef development is limited and patchy, which suggests that local conditions were not as favourable for large-scale reef growth. It is likely that the overall conditions within this centrally located, shallow basin were relatively restricted in terms of circulation, salinity, and nutrients, which may have limited reef growth. As well, periodic storms likely affected reef development, as the fine muds were disturbed and skeletons were overturned.

The buildup of the Chemahawin Member is likely comparable to the somewhat younger stromatoporoid biostromes within the Hemse Group (Ludlow) of Gotland, Sweden. These mid-Silurian buildups consist of beds of large stromatoporoids within a fine-grained unit that extend for hundreds of metres (Kershaw 1984). Though a few corals and other fossils have been recognized in these beds, stromatoporoids are dominant, and consist of a range of growth forms living in close association (Kershaw 1984). As well, both tabulate and rugose corals are found in symbiotic association with many stromatoporoid specimens (Kershaw 1984). These biostromes even share similar taxa, as species of the stromatoporoid *Clathrodictyon*, and the tabulate coral genus

Plasmopora, are both found within both the Gotland and Chemahawin biostromes. The biostromes of Gotland were presumed to have developed as a response to suppressed deposition of fine-grained sediments, which allowed the biostrome to expand laterally over previously unsuitable substrate (Kershaw 1993). The same is assumed for the Chemahawin biostrome, as evidence suggests that the structure was limited in extent during initiation, and expanded laterally over substrates after stabilization by pioneer fauna. The biostromes of Gotland are also considered to have developed under exceptionally favourable conditions on a shallow, open marine platform, which is likely comparable to the setting in the vicinity of Lundar.

Chapter 14: Conclusions

The Cedar Lake Formation of Manitoba represents a deepening upward succession of facies, from very shallow, possibly intertidal, conditions of benthic assemblage zone 1, to the biostromal-biohermal assemblage of the Chemahawin Member, which has been assigned to benthic assemblage zone 2. This trend can be observed in both the Lundar Quarry North and Mulvihill West Quarry drill cores, and it is followed by a regressive episode just below the Silurian-Devonian contact in the Mulvihill West Quarry core. The sedimentologic and paleontologic evidence within the Chemahawin Member suggests deposition within a shallow, open marine setting, with a strong prevailing current which originated in the northeast.

A lack of evidence for significant topographic relief or a binding agent to suggest a biohermal buildup within the Chemahawin Member at Lundar resulted in the reclassification of this faunal accumulation as a biostrome. The dominant fauna of the Chemahawin Member are stromatoporoids and tabulate and rugose corals. This typical reef assemblage, introduced in the Late Ordovician and further developed in the Silurian, paved the way for the dominance of this fauna in Devonian reefs. Within the Chemahawin biostrome, spatial variation in the distribution of fauna has been attributed to different microenvironments which likely existed at different times and positions within the structure. Additionally, vertical changes in the distributions of fauna are considered to represent ecological succession during the development of the biostrome from a pioneer community up to a climax community.

Spatial facies distributions within the Lundar Quarry allowed for the examination of closely spaced facies associations previously considered to be related strictly to sea level changes. The close proximity of facies in the southwest corner of the quarry, however, could not be related to sea level, and so suggests a restricted environment down-current from the biostrome.

Large mid-Silurian reefs are common structures within other basins on the North American continent, and even include reef-building fauna similar to that found within the Chemahawin Member. Reef development is limited within the Williston Basin, however, suggesting that conditions were not as favourable for large-scale reef growth. Thus, the conditions that existed in the Interlake area of Manitoba must have been exceptional for biostromal development during the transgression, and corresponding global peak in reef development, of the mid-Silurian.

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Appendix A: Map of Lundar Quarry (Part 1), showing orientation of base lines used to coordinate stratigraphic data within the southern and northern zones (Part 2), and the southwest corner (Part 3), and diagrams of the stratigraphic position of each hand sample collected from each site in each zone.

Part 1: Map of the Lundar Quarry (axes equal GPS coordinates in metres). Base lines of stratigraphic cross-section (pink) for the northern and southern zones and the southwest corner, lie between sites within each zone, with the position of each site projected to the base line at right angles (blue). The distance (m) between sites was measured along the base lines.

Part 2: Stratigraphic positions of collected hand samples from each site within the southern (a) and northern zones (b). Hand sample numbers are plotted on stratigraphic columns in order to denote the relative vertical position of each specimen relative to water level 2003. Stratigraphic intervals for which samples could not be obtained are shaded grey. Samples were numbered using the following scheme:

e.g. D 6-9

D = Site D
6 = stratigraphic position as shown on figure
-9 = specimen number (not related to position)
Note: Not all samples have a specimen number

For collected samples crossing two stratigraphic intervals, the stratigraphic position is noted as a multiple position.

e.g. J 18,19-2

J = Site J
18,19 = sample crossing stratigraphic positions 18 and 19
- 2 = specimen number

Horizontal lines (green) represent divisions of samples into intervals for stratigraphic analysis (Temporal Analysis; see Chapter 11).

Part 3: Stratigraphic positions of collected hand samples from the southwest corner. Distances between sites (not to scale) shown on base line.

Only hand samples representing Facies 1 are included in faunal analysis. Hand sample numbers representing other facies, however, and their stratigraphic positions are also provided on the diagram. Stratigraphic intervals for which samples could not be obtained are shaded grey.

Hand sample numbers are plotted on stratigraphic columns for each site in order to denote the relative vertical position of each specimen relative to water level 2003. Samples were numbered using the following scheme:

e.g. Y 1-8

Y = Site Y
1 = stratigraphic position as shown on figure
-8 = specimen number (not related to position)
Note: Not all samples have a specimen number

e.g. T top

T = Site T
top = top of exposure

Hand samples collected between sites were assigned to boxes based on the facies each sample represents. Samples were numbered using the following scheme:

e.g. Y-T +2 m ↑173 cm

Y-T = between Sites Y and T
+2 m = 2 m measured from Site Y towards Site T
↑173 cm = 173 cm measured up from water level 2003

Hand samples collected from between sites Y and T.
Box 1 – includes the following samples:
Y-T +2 m ↑194 cm
Y-T +2 m ↑173 cm

Box 2 – includes the following samples:
Y-T +2 m ↑117 cm

Box 3 – includes the following samples:
Y-T +2 m ↑16 cm
Y-T +2 m ↑82 cm

Hand samples collected from between sites T and S.
Box 4 – includes the following samples:
T-S +1 m ↑201 cm
T-S +2 m ↑208 cm
T-S +5 m ↑210 cm
T-S +7 m ↑233 cm
T-S +1 m top

Box 5 – includes the following samples:
T-S +2 m ↑172 cm
T-S +7 m ↑160 cm
T-S +13 m ↑157 cm

Box 6 – includes the following samples:
T-S +14 m ↑114 cm
T-S +13 m ↑125 cm
T-S +1m ↑30 cm
T-S +11 m ↑32 cm

Box 7 – includes the following samples:

T-S +14 m ↑48 cm	T-S +13 m ↑86 cm
T-S +11 m ↑84 cm	T-S +12 m ↑88 cm

<u>Hand samples collected from between sites S and V.</u>

Box 8 – includes the following samples:

S-V +3 m ↑166 cm

Box 9 – includes the following samples:

S-V +2 m ↑120 cm	S-V +3 m ↑152 cm
S-V +1 m ↑130 cm	S-V +1 m ↑158 cm
S-V +2 m ↑143 cm	

Box 10 – includes the following samples:

S-V +1 m ↑106 cm

<u>Hand samples collected from between sites V and R.</u>

Box 11 – includes the following samples:

V-R +1 m ↑164 cm

Box 12 – includes the following samples:

V-R +6 m ↑95 115 cm

Box 13 – includes the following samples:

V-R +6 m ↑95 cm

<u>Hand samples collected from between sites R and Q.</u>

Box 14 – includes the following samples:

R-Q +3 m ↑178 cm	R-Q +1 m ↑195 cm
R-Q +4 m ↑183 cm	

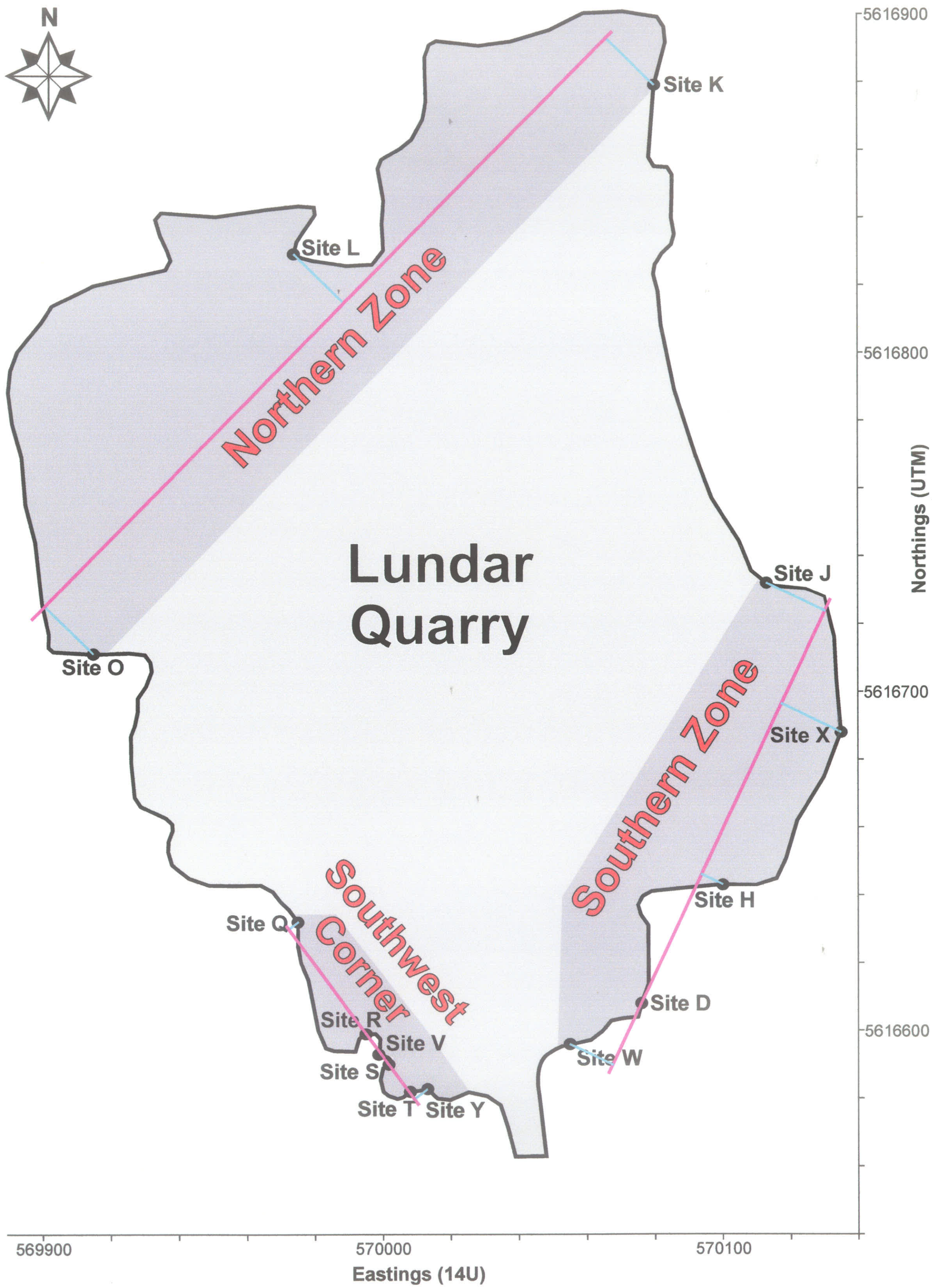
Box 15 – includes the following samples:

R-Q +2 m ↑137 cm	R-Q +4 m ↑157 cm
R-Q +7 m ↑150 cm	

Box 16 – includes the following samples:

R-Q +2 m ↑104 cm	R-Q +4 m ↑117 cm
R-Q +7 m ↑106 cm	

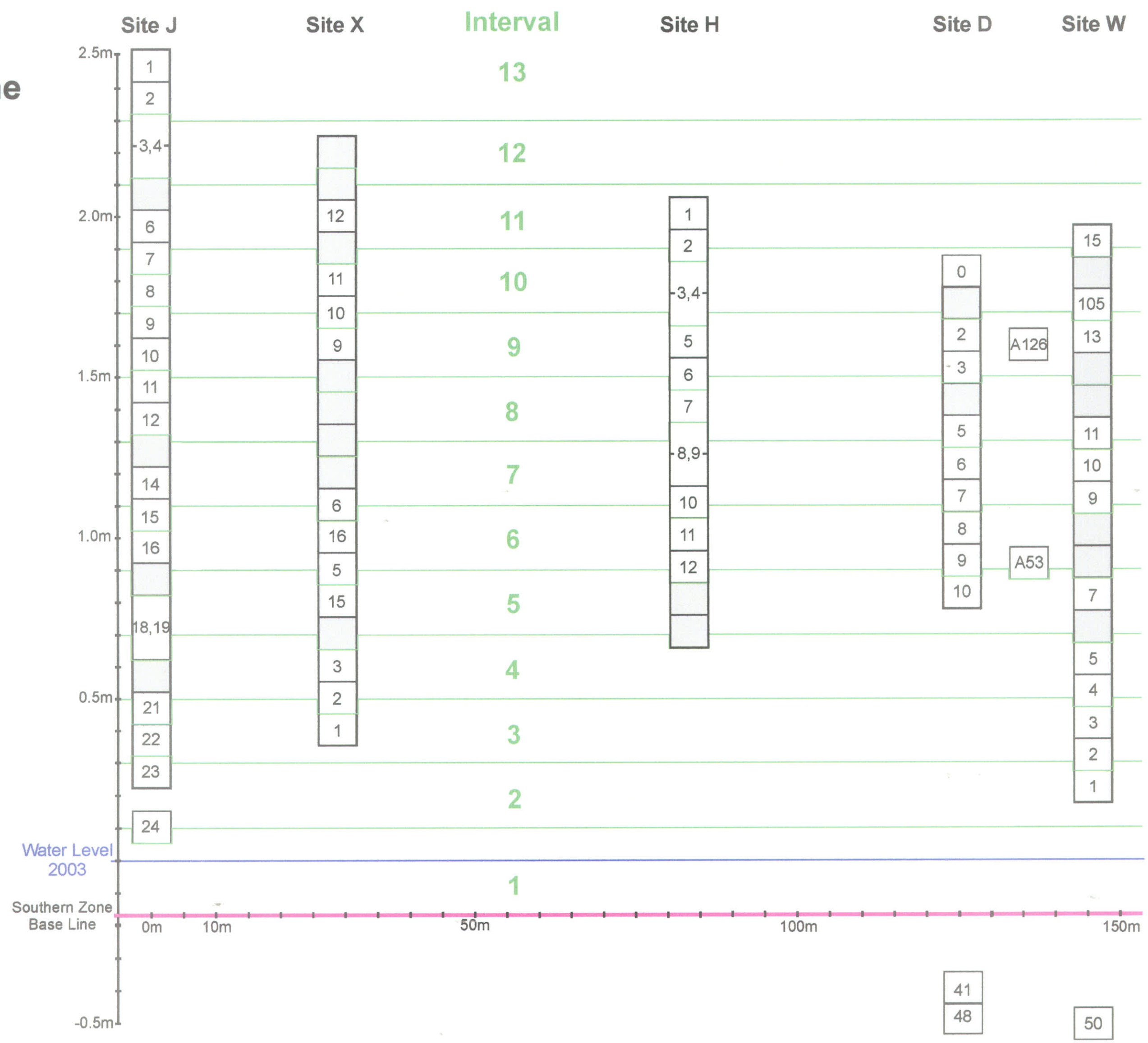
Part 1:



N
Northern Zone
Southern Zone
Southwest Corner
Lundar Quarry
Site K
Site L
Site O
Site J
Site X
Site H
Site D
Site W
Site Q
Site R
Site V
Site S
Site T
Site Y
5616900
5616800
5616700
5616600
Northings (UTM)
569900
570000
570100
Eastings (14U)

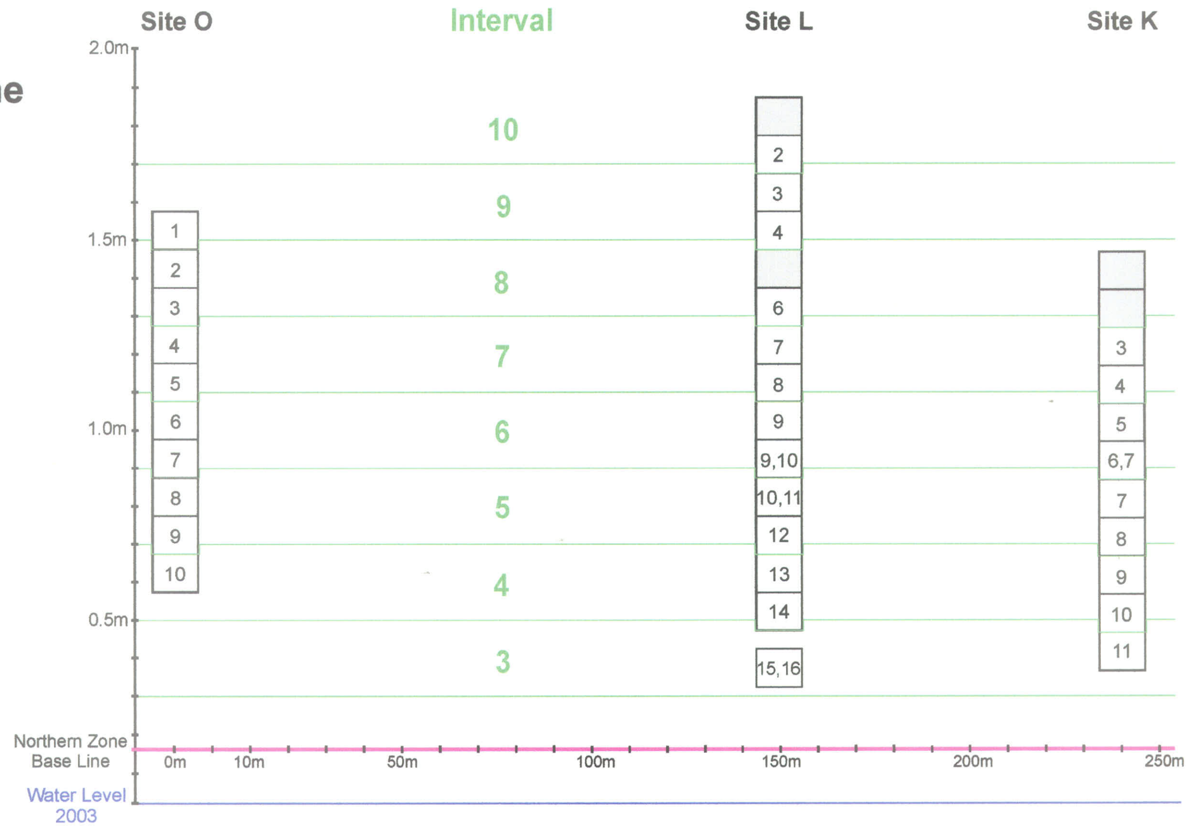
Part 2a:

Southern Zone

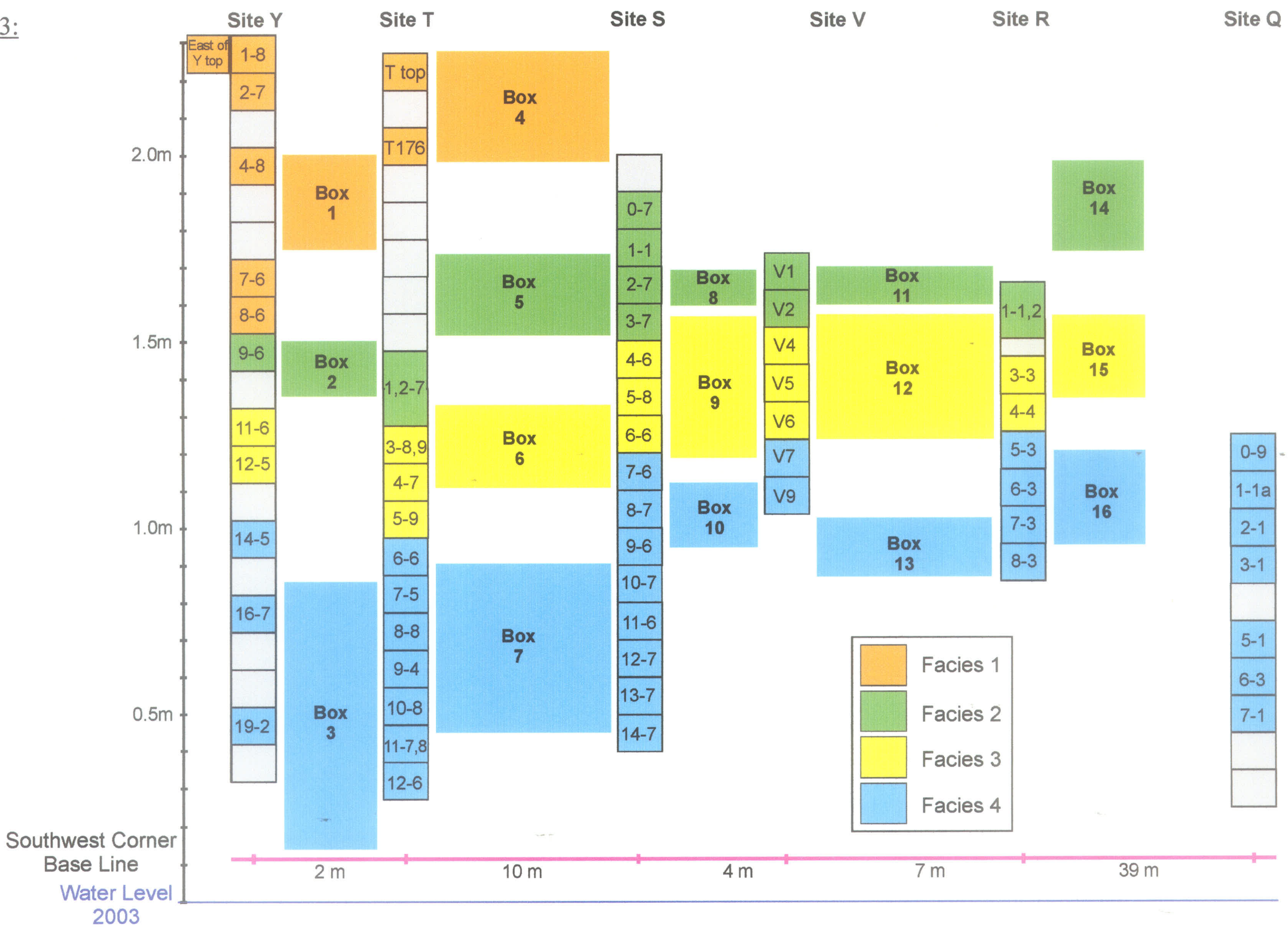


Part 2b:

Northern Zone



Part 3:



Site Y
Site T
Site S
Site V
Site R
Site Q
East of Y top
1-8
2-7
4-8
7-6
8-6
9-6
11-6
12-5
14-5
16-7
19-2
T top
T176
1,2-7
3-8,9
4-7
5-9
6-6
7-5
8-8
9-4
10-8
11-7,8
12-6
0-7
1-1
2-7
3-7
4-6
5-8
6-6
7-6
8-7
9-6
10-7
11-6
12-7
13-7
14-7
V1
V2
V4
V5
V6
V7
V9
1-1,2
3-3
4-4
5-3
6-3
7-3
8-3
0-9
1-1a
2-1
3-1
5-1
6-3
7-1
Box 1
Box 2
Box 3
Box 4
Box 5
Box 6
Box 7
Box 8
Box 9
Box 10
Box 11
Box 12
Box 13
Box 14
Box 15
Box 16
2.0m
1.5m
1.0m
0.5m
Southwest Corner Base Line
Water Level 2003
2 m
10 m
4 m
7 m
39 m
Facies 1
Facies 2
Facies 3
Facies 4

Appendix B: Raw data for 20 cm^2 area on hand samples from facies 1 at each of the seven localities within the Lundar Quarry (see Figure 5.2). Abbreviations within tables are as follows:

Site/strat. pos. = Site name/stratigraphic position from which sample was obtained (see Appendix A, Parts 2 and 3 for stratigraphic positions of samples)

= number of specimens of each major group of fauna at each stratigraphic level

Stromatoporoids
- CY = Stromatoporoid Type CY
- PI = Stromatoporoid Type PI
- CP = Stromatoporoid Type CP
- VC = Stromatoporoid Type VC

Colonial Corals
- Lund = *Favosites niagarensis lundarensis*
- Inaeq = *Favosites niagarensis inaequalis*
- Goth = *Favosites gothlandicus*
- Syn = *Synamplexoides varioseptatus*
- Pycno = *Pycnostylus guelphensis*
- Ch = member of genus *Halysites*
- Prop = member of superfamily Proporicae

Solitary Rugose Corals
- Amp = *Amplexoides* sp. A
- Dino = *Dinophyllum lundarense*
- Cysti = *Cystiphyllum* cf. *niagarensis*

Un = Unidentified specimen belonging to major faunal group

Growth Forms (see Table 5.1 for growth form criteria)
- ▬ Tabular growth form
- ☗ Domical growth form
- ★ Irrregular growth form
- ♈ Domico-columnar growth form (tabulate corals only)

Size Class (see Table 5.2 for categories)

Species Relationships
- inside = symbiotic relationship (1st listed taxon within skeleton of host)
- encr. = encrusting relationship (1st listed taxon encrusting 2nd taxon)

Example:

Locality D-W	Stromatoporoids				Colonial Corals				Solitary Corals			Species Relationships
Site/strat. pos.	#	Type	Shape	Size Class	#	Species	Shape	Size Class	#	Species	Size Class	
W2-6	4	3 CY 1 Pl	◓ ★ ★ ▬	2, 1, 2 2	3	3 Lund	★ ★ ◓	1, 1, 1	1	1 Dino	3	Lund◓1 inside CY◓2 CY★2 encr. CY◓2

Hand sample obtained from Site W, stratigraphic level 2. Four stromatoporoids, 3 colonial corals, and 1 solitary rugose coral were found within 20 cm^2 study area. Three specimens are Stromatoporoid Type CY: the first has a domical growth form, and falls within size class 2, the second has an irregular growth form, and falls within size class 1, etc. Domical specimen of *Favosites niagarensis lundarensis*, size class 1, is found in symbiotic association with domical Stromatoporoid Type CY, size class 2. Stromatoporoid Type CY, irregular growth form, size class 2, is found encrusting Stromatoporoid CY, domical growth form, size class 2.

Locality D-W Site/ strat. pos.	Stromatoporoids				Colonial Corals				Solitary Rugose Corals			Species Relationships
	#	Type	Shape	Size Class	#	Species	Shape	Size Class	#	Species	Size Class	
D 0-9	4	4 Pl	▬▬★★	2, 1, 2, 2	4	2 Lund 1 Pycno 1 Syn	◓ ★	1, 1	0			Lund◓1 encr. Pl★2; both encr. by 2nd Pl★2; Syn, Pycno, & Lund★ in 2nd Pl★2
D 2-9	4	4 CY	▬▬ ★▬	3, 2, 2, 1	3	1 Ch 2 Lund	▬▬	1, 1	1	1 Amp	3	
D 3-10	5	1 CY 4 Pl	▬ ▬▬▬★	2 1, 2, 2, 2	2	2 Lund	★♈	1, 1	0			Lund♈1 inside Pl▬2
D 5-9	3	2 CY 1 Pl	★★ ▬	3, 2 1	2	2 Lund	◓ ◓	1, 1	0			Both Lund inside CY★3
D 6-9	4	3 CY 1 Pl	★▬▬ ▬	2, 2, 1 2	1	1 Lund	◓	1	0			Lund◓1 inside CY★2
D 7-9	4	4 CY	◓ ◓ ▬▬	2, 2, 3, 2	2	1 Lund 1 Un	▬ ▬	3 3	0			
D 8-9	7	3 CY 2 Pl 2 Un.	★ ▬▬ ▬ ★ ★ ▬	2, 2, 2 2, 2 2, 1	0				2	2 Dino	3, 1	
D 9-9	4	1CY 2 Pl 1 CP	▬ ▬▬ ▬	2 2,3 2	1	1 Syn			0			Syn inside CY▬2
D 10-9	3	2 CY 1 Pl	▬▬ ▬	2, 2 1	0				1	1 Amp	1	
D 41	3	2 CY 1 Pl	★▬ ◓	2, 2 2	0				1	1 Amp	1	
D 48	3	2 CY 1 CP	▬★ ▬	3, 1 1	0				0			
A126	10	3 CY 7 Pl	▬★★ ▬▬★★ ▬▬★	2, 1, 1 2, 1, 2, 1 2, 2, 1	4	1 Inaeq 3 Ch	★	1	0			Pl▬2 encr. CY▬2
A53	4	2 CY 2 Pl	◓▬ ▬★	2, 2 3, 1	1	1 Lund	★	1	1	1 Cysti	2	Lund★1 inside CY◓2
W 105	5	5 CY	▬▬▬ ▬▬	2, 2, 2 2, 1	4	1 Syn 1 Goth 1 Inaeq 1 Ch	◓	3	1	1 Amp	2	Syn inside CY▬2 Goth inside 2nd CY▬2 3rd CY▬2 encr. Inaeq◓3

W 15	3	2CY 1 PI	▬◓ ▬	2, 1 2	2	1 Syn 1 Lund	★	1	0			Syn NOT in strome
W 13	4	2 CY 1 PI 1 CP	▬★ ▬ ▬	1, 2 2 3	2	1 Ch 1 Lund	▬	1	0			
W 11	1	1 CP	◓	3	7	1 Pycno 2 Syn 4 Lund	◓★★★	2, 1, 1, 1	0			All Corals inside CP◓3
W 10	8	4 CY 4 CY	◓★▬▬ ▬▬▬▬	2, 1, 1, 1 1, 1, 1, 2	3	1 Syn 1 Lund 1 Pycno	★	1	0			Pycno inside CY◓2 Lund★1 inside CY★1 Syn NOT in strome
W 9	1	1 CP	▬	3	0				0			
W 7	2	2 CY	▬▬	3, 2	0				0			
W 5	7	7 CY	▬▬▬▬ ▬▬▬	2, 2, 2, 1 2, 2, 2	3	1 Inaeq 1 Ch 1 Lund	★ ▬	1 1	0			
W 4	4	2 CY 2 PI	▬▬ ▬▬	2, 2 2, 1	0				2	1 Dino 1 Amp	3 1	
W 3	6	3 CY 3 CP	▬▬▬ ▬◓▬	2, 2, 2 2, 2, 1	1	1 Inaeq	★	1	0			
W 2	4	3 CY 1 PI	◓★★ ▬	2, 1, 2 2	3	3 Lund	★★◓	1, 1, 1	1	1 Un	3	Lund◓1 & Lund★1 inside CY◓2; Lund★1 inside CY★2 CY★2 encr. CY◓2
W 1	1	1 CY	★	3	0				0			
W 50	4	4 CY	◓◓ ▬▬	2, 2 1, 2	1	1 Lund	◓	1	0			
TOTALS	**108**				**46**				**10**			

Locality H	Stromatoporoids				Colonial Corals				Solitary Rugose Corals			Species Relationships
Site/ strat. pos.	**#**	**Type**	**Shape**	**Size Class**	**#**	**Species**	**Shape**	**Size Class**	**#**	**Species**	**Size Class**	
H 1-7	6	2 Pl 4 CY	★ ★ ▬▬★◓	2, 1 2, 1, 3, 2	1	1 Lund	★	1	1	1 Cysti	3	
H 2-9	6	3 CY 3 Pl	◓▬▬ ★▬▬	2, 2, 2 2, 2, 1	3	1 Lund 1 Syn 1 Inaeq	★ ◓	1 2	1	1 Amp	1	Syn inside Pl★2 CY◓2 encr. Lund★1 Pl▬1 encr. In◓2
H 3,4-9	10	3 Pl 3 CY 4 CY	▬▬▬ ▬◓▬ ◓★◓★	1, 2, 1 2, 2, 2 1, 2, 1, 2	1	1 Ch			1	1 Amp	1	Pl▬1 encr. Pl▬1
H 5-9	7	7 CY	★◓◓ ▬▬▬▬	2, 1, 1 2, 1, 2, 2	3	2 Ch 1 Syn			2	2 Un	2, 2,	Syn NOT in strome
H 6-9	4	3 CY 1 Pl	▬★ ★ ▬	3, 2, 2 2	2	1 Ch 1 Lund	▬	2	0			Lund▬2 encr. Pl▬2
H 7-9	3	3 CY	★◓▬	3, 2, 2	5	1 Syn 4 Lund	★★★★	1, 1, 1, 1	0			Syn & 2 Lund★1 inside CY★3 Lund★1 encr. CY★3 Lund★1 encr. CY◓2
H 8,9-9	4	2 CY 2 Pl	◓◓ ◓▬	3, 2 3, 3	3	1 Lund 1 Syn 1 Un	★ ★	1 1	1	1 Un	1	Syn inside CY◓3
H 10-6	7	7 Pl	▬★★★ ◓◓◓	2, 2, 2, 2 2, 2, 1	0				0			Pl◓2 encr. Pl★2 Pl★2 encr. 2nd Pl★2
H 11-9	2	2 CY	◓◓	2, 2	3	2 Syn 1 Pycno			0			1 Syn & Pycno inside CY◓2 1 Syn NOT in strome
H 12-9	6	4 CY 2 Pl	◓◓★★ ◓◓	3, 2, 2, 2 1, 1	2	1 Ch 1 Inaeq	◓	2	0			Inaeq◓2 inside CY★2
TOTALS	**55**				**23**				**6**			

Locality J-X Site/ strat. pos.	Stromatoporoids				Colonial Corals				Solitary Rugose Corals			Species Relationships
	#	Type	Shape	Size Class	#	Species	Shape	Size Class	#	Species	Size Class	
J 1-1	6	3 CY 2 CP 1 Un	★★▬ ▬★ ★	2, 2, 2 3, 2 2	0				0			
J 2-1	1	1 CY	▬	3	1	1 Un	★	1	1	1 Un	2	
J 3,4-0	1	1 CY	▬	1	0				0			
J 6-0	9	3 CY 3 CY 3 PI	★★◓ ◓▬◓ ◓▬▬	2, 1, 2 2, 1, 2 2, 2, 2	0				1	1 Un	1	CY◓2 encr. crinoid stem PI▬2 encr. PI◓2
J 7-3	9	3 CY 4 CY 1 PI 1 CP	◓★▬ ▬▬▬▬ ◓ ◓	2, 1, 2 2, 2, 1, 2 2 2	2	2 Lund	◓◓	2, 1	2	2 Amp	1, 2	Amp 2 inside CY▬2 Lund◓1 inside CY◓2 Lund◓2 encr. CY◓2 2nd CY◓2 encr. 1st CY◓2
J 8-0	2	2 CY	▬▬	2, 1	0				1	1 Dino	3	
J 9-1	5	5 CY	▬▬▬ ★▬	2, 2, 2 3, 1	0				0			
J 10-1	7	3 CY 3 CY 1 CP	▬▬▬ ▬▬★ ▬	2, 1, 2 1, 1, 2 3	0				0			
J 11-1	6	2 CY 4 PI	★▬ ◓▬▬★	2, 2 2, 2, 1, 2	3	1 Lund 2 Syn	♈	2	1	1 Dino	3	One Syn inside CY★2 other Syn encr. same CY PI▬1 encr. Lund♈2 PI▬2 encr. PI▬1
J 12-2	7	3 CY 3 CY 1 CP	▬▬▬ ◓◓★ ▬	2, 1, 2 1, 2, 3 2	3	1 Inaeq 1 Syn 1 Lund	◓ ★	2 2	1	1 Amp	1	Syn NOT in strome Lund inside CY★3
J 14-0	10	2 CP 1 PI 4 CY 3 CY	★◓ ◓ ▬▬▬▬ ◓★▬	2, 2 2 2, 1, 2, 1 1, 2, 1	3	1 Lund 1 Ch 1 Inaeq	★ ◓	1 3	0			Lund★1 encr. CY◓3 CP◓2 encr. CP★2 PI◓2 & CY◓2 encr. Inaeq◓3
J 15-9	7	4 CY 3 PI	▬▬◓◓ ▬▬▬	3, 2, 2, 1 3, 2, 2	1	1 Inaeq	★	1	0			
J 16-0	5	4 CY 1 PI	▬▬★◓ ▬	2, 2, 2, 2 2	1	1 Inaeq	◓	2	1	1 Cysti	3	
J 18,19-2	1	1 CP	◓	3	0				0			
J 21-0	1	1 CP	★	3								

J 22-1	6	4 CY 2 Pl	▬▬▬▬ ▬★	3, 2, 1, 1 2, 2	1	1 Ch			1	1 Amp	2	
J 23-1	7	3 CY 3 Pl 1 VC	▬▬◓ ▬▬▬ ◓	2, 2, 2 2, 2, 2 2	2	1 Lund 1 Un	◓ ★	2 1	2	1 Amp 1 Un	3 2	VC◓2 encr. CY◓2 Lund◓2 encr. VC◓2 CY▬2 encr. Lund◓2 Un★1 inside CY◓2 Pl▬2 encr. 2nd Pl▬2
J 24	1	1 CY	◓	3	1	1 Pycno			0			Pycno inside CY◓2
X 12	3	3 CY	▬▬▬	2, 2, 2	3	2 Lund 1 Inaeq	♈▬ ★	2, 1 1	0			Lund▬1 encr. CY▬2
X 11	3	2 CY 1 Pl	★ ★ ▬	2, 2 2	6	4 Lund 2 Syn	♈♈★★	2, 1, 1, 1	0			Lund★1, Lund★1, Lund♈1 & 1 Syn inside CY★2; Lund♈2 inside 2nd CY★2 Syn encr. 2nd CY★2
X 10	5	2 CY 3 Pl	▬▬ ★★▬	2, 2 1, 1, 2	1	1 Goth		3	0			
X 9	1	1 CP	◓	3	1	1 Inaeq	♈	2				
X 6	1	1 CY	★	2	2	2 Lund	◓★	2, 1	1	1 Dino	2	Lund◓2 inside CY★2
X 16-5	3	3 CY	◓▬▬	2, 2, 2	4	1 Goth 2 Ch 1 Lund	 ▬	3 1	0			Lund▬1 inside CY◓2
X 5	1	1 CP	▬	3	1	1 Syn			0			Syn inside CP▬3
X 15-6	4	3 CY 1 Pl	★▬▬ ▬	2, 3, 2 2	1	1 Ch			1	1 Un	3	Pl▬2 encr. CY▬3
X 3	1	1 CP	◓	3	0				0			
X 2	4	4 CY	▬▬▬◓	3, 1, 1, 1	1	1 Ch			1	1 Amp	2	
X 1	3	3 CY	★▬◓	2, 2, 2	1	1 Pycno			0			Pycno inside CY★2
TOTALS	**120**				**39**				**14**			

Locality K Site/ strat. pos.	Stromatoporoids				Colonial Corals				Solitary Rugose Corals			Species Relationships
	#	Type	Shape	Size Class	#	Species	Shape	Size Class	#	Species	Size Class	
K 3-10	2	2 CP	★ ▬	3, 3	1	1 Lund	★	1	0			
K 4-6	5	1 CY 1 PI 3 CP	▬ ▬ ▬★▬	3 1 1, 1, 2	0				0			
K 5-5	10	3 CY 2 CY 2 PI 3 CP	▬★▬ ▬▬ ▬▬ ⌓▬▬	1, 1, 2 2, 2 2, 1, 1	0				1	1 Cysti	2	
K 6, 7-4	7	4 CY 2 CP 1 PI	▬▬▬★ ⌓▬ ▬	2, 3, 3, 1 2, 1 1	0				0			
K 7-5	7	4 CY 2 PI 1 CP	⌓▬★▬ ▬▬ ▬	2, 1, 1, 1 2, 1 1	0				1	1 Dino	2	
K 8-5	9	2 CY 3 PI 4 PI	▬⌓ ▬▬▬ ★⌓▬▬	1, 1 2, 2, 3 1, 2, 2, 2	1	1 Lund	▬	2	1	1 Dino	2	Lund▬2 inside PI▬2
K 9-3, 4	2	1 CY 1 CP	▬ ⌓	2 2	0				0			
K 10-2	2	2 CY	★ ▬	2, 3	0				0			
K 11-6	7	3 CP 2 CY 2 PI	▬★ ▬▬ ★▬▬	2, 2 2, 2 1, 2, 2	2	1 Lund I Inaeq	★ ⌓	1 1	1	1 Amp	1	Lund★1 inside CP★1
TOTALS	**51**				**4**				**4**			

Locality L Site/ strat. pos.	Stromatoporoids				Colonial Corals				Solitary Rugose Corals			Species Relationships
	#	Species	Shape	Size Class	#	Species	Shape	Size Class	#	Species	Size Class	
L 2-10	1	1 CP	★	3	1	1 Syn			0			Syn inside CP★3
L 3-10	6	4 CY 2 PI	▬▬▬▬ ▬⯊	2, 2, 2, 2 2, 1	0				0			
L 4-10	1	1 PI	⯊	3	2	2 Lund	▬★	3, 2	0			Lund★2 inside PI⯊3
L 6-9	5	1 CY 2 CP 2 PI	▬ ▬▬ ★▬	2 2, 2 1, 2	1	1 Inaeq	▬	2	1	1 Amp	1	
L 7-4	4	2 CY 2 CP	⯊▬ ★★	2, 3 2, 2	2	1 Syn 1 Lund	♈	1	1	1 Amp	1	Lund♈1 inside CY⯊2 Syn inside CP★2
L 8-9	1	1 CP	★	3	1	1 Syn			0			Syn inside CP★3
L 9-11	3	3 PI	★▬▬	3, 2, 3	0				5	3 Cysti 1 Dino 1 Amp	2, 2, 1 2 1	
L 9,10-10	2	2 CP	⯊⯊	3, 2	0				0			
L10,11-11	3	1 CY 2 PI	⯊ ▬▬	1 2, 2	0				5	4 Amp 1 Dino	1, 1, 2, 1 1	
L 12-10	6	1 CY 4 PI 1 CP	★ ▬▬▬★ ▬	2 1, 2, 2, 2 2	2	2 Lund	⯊⯊	1, 1	0			Lund⯊1 inside PI▬2
L 13-10	1	1 CP	⯊	3	1	1 Pycno			0			Pycno inside CP⯊3
L 14-10	3	2 PI 1 CP	▬★ ▬	3, 2 2	0				2	1 Amp 1 Un	1 2	
L 15,16	1	1 CP	▬	3	0				0			
TOTALS	**37**				**10**				**14**			

Locality O Site/ strat. pos.	Stromatoporoids				Colonial Corals				Solitary Rugose Corals			Species Relationships
	#	Type	Shape	Size Class	#	Species	Shape	Size Class	#	Species	Size Class	
O 1-3	3	2 CY 1 PI	▬★ ▬	3, 2 2	2	2 Syn			0			Both Syn inside CY▬3
O 2-8	5	1 CY 2 PI 2 CP	◓ ◓▬ ▬▬	1 2, 2 3, 2	1	1 Lund	◓	2	1	1 Dino	1	Lund◓2 inside PI◓2
O 3-7	4	3 CY 1 PI	▬▬▬ ◓	3, 2, 2 1	1	1 Prop	◓	3	0			
O 4-6	7	3 CY 3 CY 1 PI	◓▬▬ ▬▬▬ ★	2, 2, 1 2, 1, 2 2	1	1 Lund	◓	2	0			Lund◓2 inside CY◓2
O 5-5	5	1 CY 3 PI 1 CP	★ ▬◓▬ ◓	2 2, 1, 2 3	2	1 Lund 1 Pycno	◓	3	0			Pycno inside PI◓1
O 6-6	6	1 CY 1 PI 4 CP	▬ ★ ▬▬▬▬	2 2 2, 2, 2, 2	1	1 Syn			0			Syn inside CY▬2
O 7-0	5	4 CY 1 CP	▬★◓▬ ◓	2, 1, 1, 1 1	0				0			
O 8-9	4	2 CY 2 PI	▬◓ ▬★	2, 1 2, 2	0				0			
O 9-7	5	1 CY 1PI 3 CP	★ ◓ ▬▬▬	2 2 2, 1, 2	2	1 Syn 1 Lund	★	1	1	1 Amp	1	Syn inside CY★2 Lund★1 inside PI◓2 CP▬2 encr. CY★2
O 10,11-5	2	2 CY	★ ★	3, 2	0				0			
TOTALS	**46**				**10**				**2**			

Locality SW corner Site/ strat. pos.	Stromatoporoids				Colonial Corals				Solitary Rugose Corals			Species Relationships
	#	Species	Shape	Size Class	#	Species	Shape	Size Class	#	Species	Size Class	
E. of Y - 1m Top	8	4 CY 3 CY 1 Pl	▬▬▬▬ ▬▬▬ ▬	1, 1, 1, 1 2, 2, 1 2	1	1 Lund	◓	2	0			
Y 1-8	8	3 CY 2 CY 3 Pl	◓◓◓ ◓▬ ◓▬▬	2, 1, 1 2, 1 1, 2, 2	3	2 Lund 1 Un	◓◓ ★	1, 1 1	0			
Y 2-7	9	3 CY 3 CY 3 CY	▬▬▬ ▬▬▬ ▬▬▬	2, 2, 2 2, 2, 1 1, 1, 1	4	1 Inaeq 3 Lund	▬ ◓◓♈	1 3, 2, 1	0			Inaeq. encr. CY▬1 Lund♈1 inside CY▬2 Lund ◓2 inside 2nd CY▬2
Y 5-7	2	2 CY	▬▬	3, 2	0				0			
Y-T +2m ↑194cm	10	4 CY 3 CY 2 CY 1 Pl	▬▬▬▬ ◓◓★ ▬★ ◓	2, 1, 1, 2 2, 2, 2 1, 1 1	3	2 Syn 1 Lund	♈	1	0			Syn inside CY▬1; second Syn NOT in strome
Y-T +2m ↑173cm	8	4 CY 4 CY	▬◓★▬ ▬▬▬▬	2, 2, 2, 1 2, 1, 1, 2	0				1	1 Un	2	
T top	8	4 CY 4 CY	◓◓◓▬ ▬▬▬▬	2, 2, 1, 2 2, 2, 2, 3	3	1 Goth 2 Lund	◓★	1, 1	1	1 Dino	3	Lund★1 inside CY◓2; CY▬2 encr. CY▬3; 2nd CY▬2 encr. 3rd CY▬2
T176	5	5 CY	▬▬▬ ▬★	3, 2, 2 1, 2	1	1 Inaeq	◓	3	1	1 Amp	3	
T-S +1m top	4	3 CY 1 CP	▬▬★ ▬	2, 1, 1 2	2	1 Lund 1 Syn	♈	1	3	3 Amp	1, 1, 1	Syn and Lund♈1 inside CP▬2
T-S +1m ↑201cm	6	3 CY 3 Pl	▬◓▬ ▬▬▬	2, 1, 3 2, 2, 2	3	1 Inaeq 2 Syn	★	2	1	1 Amp	1	Syn inside CY◓1 second Syn encr. CY▬
T-S +2m ↑208cm	5	3 CY 2 CP	▬▬▬ ▬★	1, 1, 1 3, 2	2	1 Lund 1 Inaeq	▬ ♈	2 2	0			Lund▬2 inside CP▬3

T-S +5m ↑210cm	8	3 CY 2 CY 3 PI	▬▬★ ◓◓ ▬▬◓	2, 2, 1 2, 1 3, 2, 1	0				1	1 Dino	3	CY◓2 encr. Dino
T-S +7m ↑233cm	1	1 CY	▬	3	0				0			
T-S +7m ↑196cm	4	2 CY 2 PI	▬▬ ▬▬	2, 2 2, 2	1	1 Goth	◓	3	0			
TOTALS	**86**				**23**				**8**			

Appendix C: Core descriptions for Lundar Quarry North (M-08-69) and Mulvihill West Quarry (M-06-69).

Core analysis for this study was conducted at the Manitoba Industry, Economic Development, and Mines (IEDM) core laboratory. Colour descriptions are derived from the "Geological Society of America Rock-Color Chart."

M-08-69 Lundar Quarry North
3-7-20-4W
5616700N 569950E

Metres	Description
	Cedar Lake Formation
0 – 3.96 m	Very pale orange, sublithographic dolomite; fossiliferous, 30-40% fossils/bioclasts by rock volume; porosity 15-20% of rock volume, predominantly interskeletal and vuggy (small vugs, <5mm); well-established symbiotic associations Fossils: Stromatoporoids – 60% of all fossils; tabular form dominant; 10-40+mm width, average 30mm; Type CY most common, Type CP and Type VP also present Colonial corals – 25-30%; tabular and domical; 7-26mm width; *Favosites niagarensis lundarensis* most common, *F.* sp. 1, *F. gothlandicus*, *Pycnostylus guelphensis* and *Synamplexoides varioseptatus* also present Solitary corals – 5-10%; 9-21mm diameter; *Dinophyllum lundarense, Cystiphyllum* cf. *niagarensis,* and *Amplexoides* sp. A present in equal abundance Echinoderm columnals – 5%; disarticulated
3.96 – 8.08 m	Yellowish gray and moderate orange pink, sublithographic mottled dolomite; 5-7% porosity, vuggy (small vugs, <5mm) and interstitial; 25-35% bioturbation
7.32-8.08m	Contains <10% poorly preserved bioclast fragments
8.08 – 10.13 m	Very pale orange to pale yellowish orange, sublithographic dolomite; fossiliferous, 20-25% fossils/bioclasts by rock volume; 10% porosity, vuggy (small vugs, <5mm); brecciated intraclasts present Fossils: Stromatoporoids – 90%; tabular form dominant; 10-40+mm width, average 20mm; Type CY most common, Type CP and Type PI also present Colonial corals – 10%; dominantly rugosans; fragmented tabulate corals present (5-15mm width)
8.38-8.66 m	Very light gray, sublithgraphic dolomite, 5% vuggy porosity (small vugs, <5mm); devoid of fossils
10.13 – 14.25 m	Very light gray to very pale orange and yellowish gray, sublithographic dolomite; massive; tight; chalky; devoid of fossils; gradual increase in bedding/pseudolamination with depth
14.25 – 15.85 m	Pinkish gray to light brownish gray, sublithographic dolomite with intermittent grayish red to dark reddish brown laminae; tight; massive to bedded to finely laminated

15.85 – 17.81 m	Very pale orange to pale yellowish beige and grayish orange, sublithographic dolomite; 0-5% porosity, vuggy (small vugs, <5mm); massive to pseudolaminated; dendrites and pyrite present as fracture fill
17.81 – 18.42 m	Yellowish gray to light brownish gray and pale olive, sublithographic dolomite; tight; pseudolaminated to laminated; abundant brecciated intraclasts; dendrites as fracture fill
18.42 – 19.07 m	Very light gray, sublithographic dolomite; massive; tight; common dendrites and pyrite as fracture fill, large blebs, and disseminated through rock
19.07 – 21.72 m	Very pale orange to light grayish orange pink, sublithographic dolomite; tight; pseudolaminated to laminated; abundant brecciated intraclasts; minor (<5%) bioturbation
21.72 – 22.20 m	Pale yellowish brown, sublithographic dolomite; 10-15% porosity, vuggy (large vugs, 5-22mm); oolitic
22.20 – 33.02 m	Very light gray to very light brownish gray dolomite; tight; pseudolaminated to laminated; few brecciated intraclasts
	(Presumed) East Arm Formation
33.02 – 35.05 m	White to very light gray and very pale orange, sublithographic to finely crystalline dolomite; 2-5% porosity, vuggy (small vugs, <5mm); bioclastic, with fossil content ranging between 0-10% of rock volume Fossils: echinoderm columnals, shells (brachiopods and ?gastropods), and bioclastic debris; stromatoporoids may be present, but highly dissolved, unidentifiable; few solitary corals present (*Amplexoides* sp. A and ?*Dinophyllum lundarense)*, 10-15mm diameter
35.05 – 36.65 m	Missing core
36.65 – 42.29 m	White to very light gray, sublithographic dolomite; tight; massive to pseudolaminated; devoid of fossils
42.29 – 42.44 m	Moderate to dark reddish brown, argillaceous material – presumed to be v marker of the East Arm Formation

M-06-69 Mulvihill West Quarry
15-31-22-6W
5643875N 550450E

Metres	Description
	Ashern Formation
0 – 1.85 m	Dark reddish brown, sublithographic dolomite; argillaceous; massive; tight; devoid of fossils
1.85 – 2.13 m	Dark reddish brown, sublithographic dolomite, containing suspended rip-up clasts of light yellowish gray, finely laminated, sublithographic dolomite (presumably Cedar Lake Formation); gray clasts 5-40+mm, 25-30% of rock volume
	Cedar Lake Formation
2.13 – 2.74 m	Light yellowish gray, sublithographic dolomite; tight; minor lamination
2.13-2.34 m	Decreasing brecciation with; reddish brown material infilling fractures in gray dolomite
2.74 – 3.61 m	Pale yellowish orange to grayish orange, sublithographic dolomite; tight; periodic intervals of lamination; devoid of fossils
3.61 – 10.06 m	Grayish orange pink sublithographic dolomite, grading down to pale grayish orange with depth; intermittent oolitic intervals between bioclastic intervals; 15-20% porosity, vuggy (small vugs, <5mm), and minor mouldic porosity; bioclastic, with fossil content 5-15% of rock volume; minor bioturbation; minor intraclastic brecciation Fossils: gastropod steinkerns, brachiopods, and other unrecognizable bioclastic fragments
10.06 – 13.84 m	Grayish orange to very pale orange, sublithographic dolomite; 10% porosity, vuggy (small vugs, <5mm); fossiliferous (~30-50% of rock volume) Fossils: Stromatoporoids – 90%; tabular form dominant; 8-40+mm width, average 20mm; Type CY dominant, Type CP and Type VP also present Colonial corals – 5-10%; fragmented; 11-26mm width; *Favosites niagarensis lundarensis, F. gothlandicus,* members of genus *Halysites,* and *Pycnostylus guelphensis* present
12.06-12.75 m	Very pale orange, sublithographic dolomite; 1% porosity, vuggy (small vugs, <3mm); devoid of fossils
13.84 – 18.14 m	Very pale orange to grayish orange pink, sublithographic mottled

	dolomite; 5-15% porosity within very pale orange dolomite, vuggy (large vugs, 5-17mm), increasing porosity with depth; grayish orange pink dolomite; tight; few bioclasts near top of interval; 25-35% bioturbated
18.14 – 18.97 m	Very pale orange to pinkish gray, sublithographic dolomite; tight; chalky; pseudolaminated; devoid of fossils
18.97 – 19.64 m	Yellowish gray to pale yellowish brown, sublithographic, mottled dolomite; 10-15% porosity, vuggy (small vugs, <3mm); 3-50% bioturbated; <10% body fossils <u>Fossils</u>: small, tabular stromatoporoids Type CY (~20mm width); unidentified bioclasts
19.64 – 22.0 m	Pale yellowish gray to light brownish gray, sublithographic dolomite; 10-15% porosity, vuggy (small vugs, <3mm); increasing body fossil content with depth (25-40% of rock volume) <u>Fossils</u>: Stromatoporoids – tabular form dominant; 10-40mm width, average 20mm; Type CY dominant, few Type CP and Type PI present
20.04-20.40 m	Interval of unconsolidated, very pale yellowish orange, dolomitic powder
22.0 – 29.54 m	Very light gray, sublithographic dolomite; tight; pseudolaminated; devoid of fossils; dendrite and pyrite fracture fill and larger blebs
29.08-29.29 m	Pale reddish brown and pale grayish olive laminated argillaceous interval

End of hole

Appendix D: Raw data and statistical analyses for paleocurrent analysis (see Chapter 12).

Part 1 – Raw Data

Compiled tables of paleocurrent measurements parallel to the long axis of elongate fossils on the exposed bedrock surface along the northern edge of the Lundar Quarry (see Figure 12.2). Eight areas were selected for analysis based locations with limited overburden (see Figure 12.2 for locations of study areas). All measurements are bidirectional (1°-180°), unless otherwise indicated. Measurements were corrected for a calculated magnetic declination of 5°43' in 2003.

S = Stromatoporoid
T = Tabulate Coral
R= Solitary Rugose Coral
C = Articulated Echinoderm Columnals (crinoids)

Solitary rugose coral entries in bold indicate unidirectional measurements from the apex toward the calice (recorded as azimuths in range 1°-360°).

Part 2 – Statistical Analysis

Chi-square tests (χ^2) were generated in order to test for randomness of directional data (see Chapter 5, 5.5 Statistical Analysis). Analyses were conducted for all fauna combined, including articulated echinoderm segments, then for stromatoporoids and colonial corals separately, and all solitary rugose corals separately. In order to include all solitary rugose corals for this statistical analysis, specimens for which unidirectional measurements could be obtained were treated as if they were bidirectional. Thus, readings between 181° and 360° were converted to their opposite positions between 1° and 180°.

e.g. **R323**
Solitary rugose coral measured from the apex toward the calice at 323° Azimuth.
323° - 180° = 143° Azimuth
Thus, this specimen would be treated as if it were bidirectional, and considered within the class 121°-140° for statistical analysis.

Part 1 – Raw Data

Area 1	**Area 2**	**Area 3**	**Area 4**	**Area 5**	**Area 6**	**Area 7**	**Area 8**
S000	S032	S003	S012	S032	S009	S004	S004
S012	S041	S013	S021	S037	S014	S042	S013
S022	S044	S028	S082	S044	S021	S057	S021
S031	S061	S026	S084	S051	S021	S078	S062
S041	S096	S036	S096	S058	S024	S098	S064
S081	S123	S049	S108	S064	S032	S103	S067
S097	S134	S053	S164	S129	S038	S113	S068
S103	S144	S067	S171	S129	S041	S113	S081
S118	S146	S071	S172	S131	S042	S114	S116
S124	S154	S074	T083	S133	S043	S124	S124
S143	D156	T109	T093	S137	S044	S133	S129
S147	S166	R006	R026	S138	S052	S144	S131
S148	S173	**R041**	R046	S146	S053	S154	S133
S151	T061	**R162**	**R201**	S153	S056	S159	S139
S152	T122	**R198**	**R212**	S159	S058	S171	S151
S159			C114	S161	S059	S177	T044
S168				S166	S059	T154	T106
S173				T002	S059	T167	R014
S174				T092	S066	R071	R021
S174				T104	S069	R121	R029
S174				T137	S076	R126	R057
S177				T164	S079	R128	R063
S178				R036	S096	R146	R084
T007				R149	S099	R176	R096
T011				**R356**	S103	**R237**	R096
T019				C033	S109	**R271**	R099
T022				C133	S113	**R326**	R102
T028				C147	S113		R143
T091					S118		R146
T136					S121		R154
T143					S121		R169
T158					S123		R176
R051					S127		**R213**
R091					S128		**R214**

R158					S132		**R249**
R034					S134		**R313**
					S139		C019
					S144		
					S146		
					S146		
					S148		
					S151		
					S151		
					S152		
					S154		
					S156		
					S161		
					S164		
					S174		
					S176		
					S176		
					T163		
					R011		
					R023		
					R096		
					R151		
					R162		

Part 2 – Statistical Analysis

O = Number of Observed Values
E = Expected Numbers per Cell
d.f. = Degrees of Freedom (#classes-1)
S.D. = Standard Deviation
$\chi^2_{0.05}$ = Critical value of Chi-square at 0.05 (see Mendenhall 1971, Appendix II, Table 5)
$\chi^2_{(calc.)}$ = Calculated value of Chi-square (sum of $(O-E)^2/E$ for all classes)

Combined Fauna (N = 230)

Classes	O	E	$(O-E)^2/E$	$(O-E)^2$	
1-20°	19	25.556	1.681841	42.98114	
21-40°	28	25.556	0.233727	5.973136	
41-60°	27	25.556	0.081591	2.085136	
61-80°	17	25.556	2.864499	73.20514	
81-100°	20	25.556	1.207902	30.86914	
101-120°	18	25.556	2.23404	57.09314	
121-140°	33	25.556	2.168302	55.41314	
141-160°	38	25.556	6.059365	154.8531	
161-180°	30	25.556	0.772779	19.74914	
d.f. = 8			χ^2 = **17.30405**	49.1358	[sum/#classes]
$\chi^2_{0.05}$ = 15.507				**S.D. = 7.009693**	[$\sqrt{(O/E)^2}$]

$\chi^2_{(calc.)} > \chi^2_{0.05}$ E + S.D. = 32.565693
∴ **Preferred Orientation** E - S. D. = 18.546307

Stromatoporoids and Colonial Corals (N = 178)

Classes	O	E	$(O-E)^2/E$	$(O-E)^2$	
1-20°	14	19.778	1.688001	33.38528	
21-40°	17	19.778	0.390195	7.717284	
41-60°	22	19.778	0.249635	4.937284	
61-80°	14	19.778	1.688001	33.38528	
81-100°	14	19.778	1.688001	33.38528	
101-120°	16	19.778	0.721675	14.27328	
121-140°	28	19.778	3.418004	67.60128	
141-160°	29	19.778	4.299994	85.04528	
161-180°	24	19.778	0.901268	17.82528	
d.f. = 8			χ^2 = **15.04477**	33.06173	[sum/#classes]
$\chi^2_{0.05}$ = 15.507				**S.D. = 5.749933**	[$\sqrt{(O/E)^2}$]

$\chi^2_{(calc.)} < \chi^2_{0.05}$ E + S.D. = 25.527933
∴ **No Preferred Orientation** E - S. D. = 14.028067

All Solitary Rugose Corals (N = 47)

Classes	O	E	$(O-E)^2/E$	$(O-E)^2$	
1-20°	4	5.222	0.28596	1.493284	
21-40°	10	5.222	4.371751	22.82928	
41-60°	5	5.222	0.009438	0.049284	
61-80°	3	5.222	0.945478	4.937284	
81-100°	6	5.222	0.11591	0.605284	
101-120°	1	5.222	3.413498	17.82584	
121-140°	4	5.222	0.28596	1.493284	
141-160°	8	5.222	1.477841	7.717284	
161-180°	6	5.222	0.11591	0.605284	
d.f. = 8			χ^2 = **11.02175**	6.395062	[sum/#classes]
$\chi^2_{0.05}$ = 15.507				**S.D. = 2.528846**	[$\sqrt{(O/E)^2}$]

$\chi^2_{(calc.)} < \chi^2_{0.05}$

∴No Preferred Orientation

E + S.D. = 7.750846

E - S. D. = 2.693154

Appendix E: Statistical analyses of raw data (see Appendix B).

Jandel SigmaStat was used to perform Chi-square Tests (χ^2) in order to recognize statistically significant relationships between variables.

$$\chi^2 = \Sigma \frac{(\text{observed} - \text{expected numbers per cell})^2}{\text{expected numbers per cell}}$$

The program applied Yates Correction for continuity for all comparisons with the χ^2 distribution with one degree of freedom in order to yield a higher, and more accurate, computed P value.

P = Probability of error

Appendix E-1: Chi-Square test (χ^2) comparing stromatoporoid types and growth forms for all specimens included in detailed hand sample analysis (excluding single specimen of stromatoporoid Type VC, and unrecognizable specimens).

Subjects	Growth Form			
Stromatoporoid	Domical	Tabular	Irregular	
Type CY	64.0	195.0	60.0	Counts
	58.5	200.7	59.8	Expected Counts
	20.1	61.1	18.8	Row %
	70.3	62.5	64.5	Column %
	12.9	39.3	12.1	Total %
Type PI	14.00	82.0	23.00	Counts
	21.83	74.9	22.31	Expected Counts
	11.76	68.9	19.33	Row %
	15.38	26.3	24.73	Column %
	2.82	16.5	4.64	Total %
Type CP	13.00	35.00	10.00	Counts
	10.64	36.48	10.88	Expected Counts
	22.41	60.34	17.24	Row %
	14.29	11.22	10.75	Column %
	2.62	7.06	2.02	Total %

Power of performed test with alpha = 0.0500: 0.3735

The power of the performed test (0.3735) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 4.84 with 4 degrees of freedom. (P = 0.3042)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.3042)

Appendix E-2: Chi-Square test (χ^2) comparing stromatoporoid types belonging to each of the three assigned size classes for all specimens included in detailed hand sample analysis (excluding single specimen of stromatoporoid Type VC, and unrecognizable specimens). Subsequent analyses (E-2.1 to E-2.3) compare all pairs of stromatoporoid types to determine if there is a significant relationship to size classes of stromatoporoids.

Subjects Stromatoporoid	Size Class Class 1	Class 2	Class 3	
Type CY	93.0	192.0	34.00	Counts
	86.2	191.0	41.80	Expected Counts
	29.2	60.2	10.66	Row %
	69.4	64.6	52.31	Column %
	18.8	38.7	6.85	Total %
Type PI	30.00	78.0	11.00	Counts
	32.15	71.3	15.59	Expected Counts
	25.21	65.5	9.24	Row %
	22.39	26.3	16.92	Column %
	6.05	15.7	2.22	Total %
Type CP	11.00	27.00	20.00	Counts
	15.67	34.73	7.60	Expected Counts
	18.97	46.55	34.48	Row %
	8.21	9.09	30.77	Column %
	2.22	5.44	4.03	Total %

Power of performed test with alpha = 0.0500: 0.9969

Chi-square= 27.5 with 4 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

E-2.1: Chi-square test (χ^2) comparing the relative abundance of stromatoporoid specimens of each size class between stromatoporoid Types CY and PI.

Subjects	Stromatoporoids Type CY	Type PI	
Size Class 1	93.0	30.00	Counts
	89.6	33.42	Expected Counts
	75.6	24.39	Row %
	29.2	25.21	Column %
	21.2	6.85	Total %
Size Class 2	192.0	78.0	Counts
	196.6	73.4	Expected Counts
	71.1	28.9	Row %
	60.2	65.5	Column %
	43.8	17.8	Total %
Size Class 3	34.00	11.00	Counts
	32.77	12.23	Expected Counts
	75.56	24.44	Row %
	10.66	9.24	Column %
	7.76	2.51	Total %

Power of performed test with alpha = 0.0500: 0.1314

The power of the performed test (0.1314) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 1.05 with 2 degrees of freedom. (P = 0.5908)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.5908)

E-2.2: Chi-square test (χ^2) comparing the relative abundance of stromatoporoid specimens of each size class between stromatoporoid Types CY and CP.

Subjects	Stromatoporoids Type CY	Stromatoporoids Type CP	
Size Class 1	93.0	11.00	Counts
	88.0	16.00	Expected Counts
	89.4	10.58	Row %
	29.2	18.97	Column %
	24.7	2.92	Total %
Size Class 2	192.0	27.00	Counts
	185.3	33.69	Expected Counts
	87.7	12.33	Row %
	60.2	46.55	Column %
	50.9	7.16	Total %
Size Class 3	34.00	20.00	Counts
	45.69	8.31	Expected Counts
	62.96	37.04	Row %
	10.66	34.48	Column %
	9.02	5.31	Total %

Power of performed test with alpha = 0.0500: 0.9970

Chi-square= 22.9 with 2 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

<u>E-2.3:</u> Chi-square test (χ^2) comparing the relative abundance of stromatoporoid specimens of each size class between stromatoporoid Types PI and CP.

Subjects	Stromatoporoids Type PI	Type CP	
Size Class 1	30.0	11.00	Counts
	27.6	13.44	Expected Counts
	73.2	26.83	Row %
	25.2	18.97	Column %
	16.9	6.21	Total %
Size Class 2	78.0	27.0	Counts
	70.6	34.4	Expected Counts
	74.3	25.7	Row %
	65.5	46.6	Column %
	44.1	15.3	Total %
Size Class 3	11.00	20.0	Counts
	20.84	10.2	Expected Counts
	35.48	64.5	Row %
	9.24	34.5	Column %
	6.21	11.3	Total %

Power of performed test with alpha = 0.0500: 0.9781

Chi-square= 17.2 with 2 degrees of freedom. (P = 0.0002)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0002)

<u>Appendix E-3:</u> Chi-Square test (χ^2) comparing stromatoporoid types to the number of each type that host one or more tabulate coral in symbiotic association for all specimens included in detailed hand sample analysis (excluding single specimen of stromatoporoid Type VC, and unrecognizable specimens). Multiple tabulate corals found within the same stromatoporoid skeleton were considered as one symbiotic association for the host stromatoporoid. One unrecognizable tabulate coral found in association with a stromatoporoid was included in this calculation.

Subjects Stromatoporoid	Host to 1+ tabulate coral	Without symbiotic tabulate corals	
Type CY	21.00	288.0	Counts
	19.82	289.2	Expected Counts
	6.80	93.2	Row %
	65.63	61.7	Column %
	4.21	57.7	Total %
Type PI	7.00	122.0	Counts
	8.27	120.7	Expected Counts
	5.43	94.6	Row %
	21.88	26.1	Column %
	1.40	24.4	Total %
Type CP	4.000	57.0	Counts
	3.912	57.1	Expected Counts
	6.557	93.4	Row %
	12.500	12.2	Column %
	0.802	11.4	Total %

Power of performed test with alpha = 0.0500: 0.0700

The power of the performed test (0.0700) is below the desired power of 0.8000.
You should interpret the negative findings cautiously.

Chi-square= 0.287 with 2 degrees of freedom. (P = 0.8664)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.8664)

<u>Appendix E-4:</u> Chi-Square test (χ^2) comparing the occurrence of colonial rugose corals found in symbiotic association with each type of stromatoporoid, for all stromatoporoid specimens included in detailed hand sample analysis (excluding single specimen of stromatoporoid Type VC, and unrecognizable specimens). Multiple colonial rugose corals found within the same stromatoporoid skeleton were considered as one symbiotic association for the host stromatoporoid. Subsequent analyses (E-4.1 to E-4.3) compare all pairs of stromatoporoid types to determine if there is a significant relationship between stromatoporoid host type and the presence of symbiotic colonial rugose corals.

Subjects Stromatoporoid	Host to 1+ colonial Rugose coral	Without symbiotic Colonial Rugose corals	
Type CY	16.00	293.0	Counts
	17.34	291.7	Expected Counts
	5.18	94.8	Row %
	57.14	62.2	Column %
	3.21	58.7	Total %
Type PI	3.000	126.0	Counts
	7.238	121.8	Expected Counts
	2.326	97.7	Row %
	10.714	26.8	Column %
	0.601	25.3	Total %
Type CP	9.00	52.0	Counts
	3.42	57.6	Expected Counts
	14.75	85.2	Row %
	32.14	11.0	Column %
	1.80	10.4	Total %

Power of performed test with alpha = 0.0500: 0.9057

Chi-square= 12.4 with 2 degrees of freedom. (P = 0.0021)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0021)

<u>E-4.1:</u> Chi-square test (χ^2) comparing stromatoporoid Types CY and PI that contain one or more colonial rugose corals in symbiotic association.

Subjects	Stromatoporoid Types Type CY	Type PI	
With 1+ colonial rugose corals in symbiotic association	16.00	3.000	Counts
	13.40	5.596	Expected Counts
	84.21	15.789	Row %
	5.18	2.326	Column %
	3.65	0.685	Total %
Without symbiotic colonial rugose corals	293.0	126.0	Counts
	295.6	123.4	Expected Counts
	69.9	30.1	Row %
	94.8	97.7	Column %
	66.9	28.8	Total %

Power of performed test with alpha = 0.0500: 0.1764

The power of the performed test (0.1764) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Yates correction for continuity was used in calculating this test.

Chi-square= 1.16 with 1 degrees of freedom. (P = 0.2808)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.2808)

E-4.2: Chi-square test (χ^2) comparing stromatoporoid Types CY and CP that contain one or more colonial rugose corals in symbiotic association.

Subjects	Stromatoporoid Types Type CY	Type CP	
With 1+ colonial rugose corals in symbiotic association	16.00	9.00	Counts
	20.88	4.12	Expected Counts
	64.00	36.00	Row %
	5.18	14.75	Column %
	4.32	2.43	Total %
Without symbiotic colonial rugose corals	293.0	52.0	Counts
	288.1	56.9	Expected Counts
	84.9	5.1	Row %
	94.8	85.2	Column %
	79.2	4.1	Total %

Power of performed test with alpha = 0.0500: 0.6897

The power of the performed test (0.6897) is below the desired power of 0.8000.
You should interpret the negative findings cautiously.

Yates correction for continuity was used in calculating this test.

Chi-square= 5.97 with 1 degrees of freedom. (P = 0.0145)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0145)

E-4.3: Chi-square test (χ^2) comparing stromatoporoid Types PI and CP that contain one or more colonial rugose corals in symbiotic association.

Subjects	Stromatoporoid Types Type PI	Type CP	
With 1+ colonial rugose corals in symbiotic association	3.00	9.00	Counts
	8.15	3.85	Expected Counts
	25.00	75.00	Row %
	2.33	14.75	Column %
	1.58	4.74	Total %
Without symbiotic colonial rugose corals	126.0	52.0	Counts
	120.9	57.1	Expected Counts
	70.8	29.2	Row %
	97.7	85.2	Column %
	66.3	27.4	Total %

Power of performed test with alpha = 0.0500: 0.8609

Yates correction for continuity was used in calculating this test.

Chi-square= 8.81 with 1 degrees of freedom. (P = 0.0030)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0030)

Appendix E-5: Chi-square test (χ^2) comparing the relative abundances of each type of stromatoporoid at each locality within the Lundar Quarry (see Figure 5.1). All specimens from all stratigraphic levels at each locality were included in this analysis (excluding single specimen of stromatoporoid Type VC, and unidentifiable specimens). Subsequent analyses (E-5.1 to E-5.21) compare all pairs of localities to determine which localities are significantly related.

Subjects	Stromatoporoid Type			
Locality	Type CY	Type PI	Type CP	
D-W	67.0	30.00	8.00	Counts
	66.0	26.67	12.28	Expected Counts
	63.8	28.57	7.62	Row %
	21.5	23.81	13.79	Column %
	13.5	6.05	1.61	Total %
H	35.00	20.00	0.00	Counts
	34.60	13.97	6.43	Expected Counts
	63.64	36.36	0.00	Row %
	11.22	15.87	0.00	Column %
	7.06	4.03	0.00	Total %
J-X	86.0	21.00	9.00	Counts
	73.0	29.47	13.56	Expected Counts
	74.1	18.10	7.76	Row %
	27.6	16.67	15.52	Column %
	17.3	4.23	1.81	Total %
K	21.00	15.00	15.00	Counts
	32.08	12.96	5.96	Expected Counts
	41.18	29.41	29.41	Row %
	6.73	11.90	25.86	Column %
	4.23	3.02	3.02	Total %
L	9.00	16.00	12.00	Counts
	23.27	9.40	4.33	Expected Counts
	24.32	43.24	32.43	Row %
	2.88	12.70	20.69	Column %
	1.81	3.23	2.42	Total %
O	24.00	11.00	11.00	Counts
	28.94	11.69	5.38	Expected Counts
	52.17	23.91	23.91	Row %
	7.69	8.73	18.97	Column %
	4.84	2.22	2.22	Total %
SW corner	70.0	13.00	3.000	Counts

54.1	21.85	10.056	Expected Counts
81.4	15.12	3.488	Row %
22.4	10.32	5.172	Column %
14.1	2.62	0.605	Total %

Power of performed test with alpha = 0.0500: 1.0000

Chi-square= 82.1 with 12 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

E-5.1: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities D-W and H.

Subjects Stromatoporoid	Localities D-W	H	
Type CY	67.0	35.0	Counts
	66.9	35.1	Expected Counts
	65.7	34.3	Row %
	63.8	63.6	Column %
	41.9	21.9	Total %
Type PI	30.0	20.0	Counts
	32.8	17.2	Expected Counts
	60.0	40.0	Row %
	28.6	36.4	Column %
	18.8	12.5	Total %
Type CP	8.00	0.00	Counts
	5.25	2.75	Expected Counts
	100.00	0.00	Row %
	7.62	0.00	Column %
	5.00	0.00	Total %

Power of performed test with alpha = 0.0500: 0.4826

The power of the performed test (0.4826) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 4.89 with 2 degrees of freedom. (P = 0.0866)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.0866)

E-5.2: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities D-W and J-X.

Subjects Stromatoporoid	Localities D-W	J-X	
Type CY	67.0	86.0	Counts
	72.7	80.3	Expected Counts
	43.8	56.2	Row %
	63.8	74.1	Column %
	30.3	38.9	Total %
Type PI	30.0	21.00	Counts
	24.2	26.77	Expected Counts
	58.8	41.18	Row %
	28.6	18.10	Column %
	13.6	9.50	Total %
Type CP	8.00	9.00	Counts
	8.08	8.92	Expected Counts
	47.06	52.94	Row %
	7.62	7.76	Column %
	3.62	4.07	Total %

Power of performed test with alpha = 0.0500: 0.3519

The power of the performed test (0.3519) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 3.47 with 2 degrees of freedom. (P = 0.1766)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.1766)

E-5.3: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities D-W and K.

Subjects	Localities		
Stromatoporoid	D-W	K	
Type CY	67.0	21.0	Counts
	59.2	28.8	Expected Counts
	76.1	23.9	Row %
	63.8	41.2	Column %
	42.9	13.5	Total %
Type PI	30.0	15.00	Counts
	30.3	14.71	Expected Counts
	66.7	33.33	Row %
	28.6	29.41	Column %
	19.2	9.62	Total %
Type CP	8.00	15.00	Counts
	15.48	7.52	Expected Counts
	34.78	65.22	Row %
	7.62	29.41	Column %
	5.13	9.62	Total %

Power of performed test with alpha = 0.0500: 0.9440

Chi-square= 14.2 with 2 degrees of freedom. (P = 0.0008)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0008)

<u>E-5.4:</u> Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities D-W and L.

Subjects Stromatoporoid	Localities D-W	L	
Type CY	67.0	9.00	Counts
	56.2	19.80	Expected Counts
	88.2	11.84	Row %
	63.8	24.32	Column %
	47.2	6.34	Total %
Type PI	30.0	16.0	Counts
	34.0	12.0	Expected Counts
	65.2	34.8	Row %
	28.6	43.2	Column %
	21.1	11.3	Total %
Type CP	8.00	12.00	Counts
	14.79	5.21	Expected Counts
	40.00	60.00	Row %
	7.62	32.43	Column %
	5.63	8.45	Total %

Power of performed test with alpha = 0.0500: 0.9954

Chi-square= 21.7 with 2 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

E-5.5: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities D-W and O.

Subjects Stromatoporoid	Localities D-W	O	
Type CY	67.0	24.0	Counts
	63.3	27.7	Expected Counts
	73.6	26.4	Row %
	63.8	52.2	Column %
	44.4	15.9	Total %
Type PI	30.0	11.00	Counts
	28.5	12.49	Expected Counts
	73.2	26.83	Row %
	28.6	23.91	Column %
	19.9	7.28	Total %
Type CP	8.00	11.00	Counts
	13.21	5.79	Expected Counts
	42.11	57.89	Row %
	7.62	23.91	Column %
	5.30	7.28	Total %

Power of performed test with alpha = 0.0500: 0.7017

The power of the performed test (0.7017) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 7.72 with 2 degrees of freedom. (P = 0.0210)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0210)

<u>E-5.6:</u> Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities D-W and SW corner.

Subjects Stromatoporoid	Localities D-W	 SW corner	
Type CY	67.0	70.0	Counts
	75.3	61.7	Expected Counts
	48.9	51.1	Row %
	63.8	81.4	Column %
	35.1	36.6	Total %
Type PI	30.0	13.00	Counts
	23.6	19.36	Expected Counts
	69.8	30.23	Row %
	28.6	15.12	Column %
	15.7	6.81	Total %
Type CP	8.00	3.00	Counts
	6.05	4.95	Expected Counts
	72.73	27.27	Row %
	7.62	3.49	Column %
	4.19	1.57	Total %

Power of performed test with alpha = 0.0500: 0.6694

The power of the performed test (0.6694) is below the desired power of 0.8000.
You should interpret the negative findings cautiously.

Chi-square= 7.24 with 2 degrees of freedom. (P = 0.0268)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0268)

E-5.7: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities H and J-X.

Subjects Stromatoporoid	Localities H	J-X	
Type CY	35.0	86.0	Counts
	38.9	82.1	Expected Counts
	28.9	71.1	Row %
	63.6	74.1	Column %
	20.5	50.3	Total %
Type PI	20.0	21.0	Counts
	13.2	27.8	Expected Counts
	48.8	51.2	Row %
	36.4	18.1	Column %
	11.7	12.3	Total %
Type CP	0.00	9.00	Counts
	2.89	6.11	Expected Counts
	0.00	100.00	Row %
	0.00	7.76	Column %
	0.00	5.26	Total %

Power of performed test with alpha = 0.0500: 0.8260

Chi-square= 10.0 with 2 degrees of freedom. (P = 0.0066)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0066)

<u>E-5.8:</u> Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities H and K.

Subjects Stromatoporoid	Localities H	K	
Type CY	35.0	21.0	Counts
	29.1	26.9	Expected Counts
	62.5	37.5	Row %
	63.6	41.2	Column %
	33.0	19.8	Total %
Type PI	20.0	15.0	Counts
	18.2	16.8	Expected Counts
	57.1	42.9	Row %
	36.4	29.4	Column %
	18.9	14.2	Total %
Type CP	0.00	15.00	Counts
	7.78	7.22	Expected Counts
	0.00	100.00	Row %
	0.00	29.41	Column %
	0.00	14.15	Total %

Power of performed test with alpha = 0.0500: 0.9883

Chi-square= 19.1 with 2 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

E-5.9: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities H and L.

Subjects Stromatoporoid	Localities H	L	
Type CY	35.0	9.00	Counts
	26.3	17.70	Expected Counts
	79.5	20.45	Row %
	63.6	24.32	Column %
	38.0	9.78	Total %
Type PI	20.0	16.0	Counts
	21.5	14.5	Expected Counts
	55.6	44.4	Row %
	36.4	43.2	Column %
	21.7	17.4	Total %
Type CP	0.00	12.00	Counts
	7.17	4.83	Expected Counts
	0.00	100.00	Row %
	0.00	32.43	Column %
	0.00	13.04	Total %

Power of performed test with alpha = 0.0500: 0.9988

Chi-square= 25.3 with 2 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

E-5.10: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities H and O.

Subjects Stromatoporoid	Localities H	O	
Type CY	35.0	24.0	Counts
	32.1	26.9	Expected Counts
	59.3	40.7	Row %
	63.6	52.2	Column %
	34.7	23.8	Total %
Type PI	20.0	11.0	Counts
	16.9	14.1	Expected Counts
	64.5	35.5	Row %
	36.4	23.9	Column %
	19.8	10.9	Total %
Type CP	0.00	11.00	Counts
	5.99	5.01	Expected Counts
	0.00	100.00	Row %
	0.00	23.91	Column %
	0.00	10.89	Total %

Power of performed test with alpha = 0.0500: 0.9559

Chi-square= 15.0 with 2 degrees of freedom. (P = 0.0006)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0006)

E-5.11: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities H and SW corner.

Subjects Stromatoporoid	Localities H	SW corner	
Type CY	35.0	70.0	Counts
	41.0	64.0	Expected Counts
	33.3	66.7	Row %
	63.6	81.4	Column %
	24.8	49.6	Total %
Type PI	20.0	13.00	Counts
	12.9	20.13	Expected Counts
	60.6	39.39	Row %
	36.4	15.12	Column %
	14.2	9.22	Total %
Type CP	0.00	3.00	Counts
	1.17	1.83	Expected Counts
	0.00	100.00	Row %
	0.00	3.49	Column %
	0.00	2.13	Total %

Power of performed test with alpha = 0.0500: 0.8159

Chi-square= 9.81 with 2 degrees of freedom. (P = 0.0074)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0074)

E-5.12: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities J-X and K.

Subjects	Localities		
Stromatoporoid	J-X	K	
Type CY	86.0	21.0	Counts
	74.3	32.7	Expected Counts
	80.4	19.6	Row %
	74.1	41.2	Column %
	51.5	12.6	Total %
Type PI	21.0	15.00	Counts
	25.0	10.99	Expected Counts
	58.3	41.67	Row %
	18.1	29.41	Column %
	12.6	8.98	Total %
Type CP	9.00	15.00	Counts
	16.67	7.33	Expected Counts
	37.50	62.50	Row %
	7.76	29.41	Column %
	5.39	8.98	Total %

Power of performed test with alpha = 0.0500: 0.9904

Chi-square= 19.7 with 2 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

E-5.13: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities J-X and L.

Subjects Stromatoporoid	Localities J-X	L	
Type CY	86.0	9.00	Counts
	72.0	22.97	Expected Counts
	90.5	9.47	Row %
	74.1	24.32	Column %
	56.2	5.88	Total %
Type PI	21.0	16.00	Counts
	28.1	8.95	Expected Counts
	56.8	43.24	Row %
	18.1	43.24	Column %
	13.7	10.46	Total %
Type CP	9.00	12.00	Counts
	15.92	5.08	Expected Counts
	42.86	57.14	Row %
	7.76	32.43	Column %
	5.88	7.84	Total %

Power of performed test with alpha = 0.0500: 0.9999

Chi-square= 31.0 with 2 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

<u>E-5.14:</u> Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities J-X and O.

Subjects Stromatoporoid	Localities J-X	O	
Type CY	86.0	24.0	Counts
	78.8	31.2	Expected Counts
	78.2	21.8	Row %
	74.1	52.2	Column %
	53.1	14.8	Total %
Type PI	21.0	11.00	Counts
	22.9	9.09	Expected Counts
	65.6	34.38	Row %
	18.1	23.91	Column %
	13.0	6.79	Total %
Type CP	9.00	11.00	Counts
	14.32	5.68	Expected Counts
	45.00	55.00	Row %
	7.76	23.91	Column %
	5.56	6.79	Total %

Power of performed test with alpha = 0.0500: 0.8184

Chi-square= 9.87 with 2 degrees of freedom. (P = 0.0072)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0072)

E-5.15: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities J-X and SW corner.

Subjects Stromatoporoid	Localities J-X	SW corner	
Type CY	86.0	70.0	Counts
	89.6	66.4	Expected Counts
	55.1	44.9	Row %
	74.1	81.4	Column %
	42.6	34.7	Total %
Type PI	21.0	13.00	Counts
	19.5	14.48	Expected Counts
	61.8	38.24	Row %
	18.1	15.12	Column %
	10.4	6.44	Total %
Type CP	9.00	3.00	Counts
	6.89	5.11	Expected Counts
	75.00	25.00	Row %
	7.76	3.49	Column %
	4.46	1.49	Total %

Power of performed test with alpha = 0.0500: 0.2253

The power of the performed test (0.2253) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 2.11 with 2 degrees of freedom. (P = 0.3474)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.3474)

<u>E-5.16:</u> Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities K and L.

Subjects Stromatoporoid	Localities K	L	
Type CY	21.0	9.00	Counts
	17.4	12.61	Expected Counts
	70.0	30.00	Row %
	41.2	24.32	Column %
	23.9	10.23	Total %
Type PI	15.0	16.0	Counts
	18.0	13.0	Expected Counts
	48.4	51.6	Row %
	29.4	43.2	Column %
	17.0	18.2	Total %
Type CP	15.0	12.0	Counts
	15.6	11.4	Expected Counts
	55.6	44.4	Row %
	29.4	32.4	Column %
	17.0	13.6	Total %

Power of performed test with alpha = 0.0500: 0.3092

The power of the performed test (0.3092) is below the desired power of 0.8000.
You should interpret the negative findings cautiously.

Chi-square= 3.01 with 2 degrees of freedom. (P = 0.2215)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.2215)

E-5.17: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities K and O.

Subjects Stromatoporoid	Localities K	O	
Type CY	21.0	24.0	Counts
	23.7	21.3	Expected Counts
	46.7	53.3	Row %
	41.2	52.2	Column %
	21.6	24.7	Total %
Type PI	15.0	11.0	Counts
	13.7	12.3	Expected Counts
	57.7	42.3	Row %
	29.4	23.9	Column %
	15.5	11.3	Total %
Type CP	15.0	11.0	Counts
	13.7	12.3	Expected Counts
	57.7	42.3	Row %
	29.4	23.9	Column %
	15.5	11.3	Total %

Power of performed test with alpha = 0.0500: 0.1419

The power of the performed test (0.1419) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 1.18 with 2 degrees of freedom. (P = 0.5554)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.5554)

E-5.18: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities K and SW corner.

Subjects Stromatoporoid	Localities K	SW corner	
Type CY	21.0	70.0	Counts
	33.9	57.1	Expected Counts
	23.1	76.9	Row %
	41.2	81.4	Column %
	15.3	51.1	Total %
Type PI	15.0	13.00	Counts
	10.4	17.58	Expected Counts
	53.6	46.43	Row %
	29.4	15.12	Column %
	10.9	9.49	Total %
Type CP	15.00	3.00	Counts
	6.70	11.30	Expected Counts
	83.33	16.67	Row %
	29.41	3.49	Column %
	10.95	2.19	Total %

Power of performed test with alpha = 0.0500: 0.9995

Chi-square= 27.4 with 2 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

E-5.19: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities L and O.

Subjects Stromatoporoid	Localities L	O	
Type CY	9.00	24.0	Counts
	14.71	18.3	Expected Counts
	27.27	72.7	Row %
	24.32	52.2	Column %
	10.84	28.9	Total %
Type PI	16.0	11.0	Counts
	12.0	15.0	Expected Counts
	59.3	40.7	Row %
	43.2	23.9	Column %
	19.3	13.3	Total %
Type CP	12.0	11.0	Counts
	10.3	12.7	Expected Counts
	52.2	47.8	Row %
	32.4	23.9	Column %
	14.5	13.3	Total %

Power of performed test with alpha = 0.0500: 0.6447

The power of the performed test (0.6447) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 6.89 with 2 degrees of freedom. (P = 0.0319)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0319)

E-5.20: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities L and SW corner.

Subjects Stromatoporoid	Localities L	 SW corner	
Type CY	9.00	70.0	Counts
	23.76	55.2	Expected Counts
	11.39	88.6	Row %
	24.32	81.4	Column %
	7.32	56.9	Total %
Type PI	16.00	13.0	Counts
	8.72	20.3	Expected Counts
	55.17	44.8	Row %
	43.24	15.1	Column %
	13.01	10.6	Total %
Type CP	12.00	3.00	Counts
	4.51	10.49	Expected Counts
	80.00	20.00	Row %
	32.43	3.49	Column %
	9.76	2.44	Total %

Power of performed test with alpha = 0.0500: 1.0000

Chi-square= 39.6 with 2 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

E-5.21: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between localities O and SW corner.

Subjects Stromatoporoid	Localities O	SW corner	
Type CY	24.0	70.0	Counts
	32.8	61.2	Expected Counts
	25.5	74.5	Row %
	52.2	81.4	Column %
	18.2	53.0	Total %
Type PI	11.00	13.00	Counts
	8.36	15.64	Expected Counts
	45.83	54.17	Row %
	23.91	15.12	Column %
	8.33	9.85	Total %
Type CP	11.00	3.00	Counts
	4.88	9.12	Expected Counts
	78.57	21.43	Row %
	23.91	3.49	Column %
	8.33	2.27	Total %

Power of performed test with alpha = 0.0500: 0.9739

Chi-square= 16.7 with 2 degrees of freedom. (P = 0.0002)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0002)

Appendix E-6: Chi-square test (χ^2) comparing the size of solitary rugose corals between the southern and northern zones (see Figure 5.1).

Subjects	Size Class 1	Size Class 2	Size Class 3	
Southern Zone	10.00	10.00	10.00	Counts
	13.20	10.80	6.00	Expected Counts
	33.33	33.33	33.33	Row %
	45.45	55.56	100.00	Column %
	20.00	20.00	20.00	Total %
Northern Zone	12.00	8.00	0.00	Counts
	8.80	7.20	4.00	Expected Counts
	60.00	40.00	0.00	Row %
	54.55	44.44	0.00	Column %
	24.00	16.00	0.00	Total %

Power of performed test with alpha = 0.0500: 0.7632

The power of the performed test (0.7632) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 8.75 with 2 degrees of freedom. (P = 0.0126)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0126)

Appendix E-7: Chi-Square test (χ^2) comparing the relative abundances of growth forms of stromatoporoids at each locality within the Lundar Quarry (see Figure 5.1). All specimens from all stratigraphic levels at each locality were included in this analysis (excluding single specimen of stromatoporoid Type VC, and unidentifiable specimens). Subsequent analyses (E-7.1 to E-7.21) compare all pairs of localities to determine which localities are significantly related.

Subjects	Growth Forms			
Locality	Tabular	Domical	Irregular	
D-W	74.0	10.00	23.00	Counts
	66.8	19.90	20.33	Expected Counts
	69.2	9.35	21.50	Row %
	23.7	10.75	24.21	Column %
	14.8	2.00	4.60	Total %
H	20.00	20.00	15.00	Counts
	34.32	10.23	10.45	Expected Counts
	36.36	36.36	27.27	Row %
	6.41	21.51	15.79	Column %
	4.00	4.00	3.00	Total %
J-X	71.0	24.00	23.00	Counts
	73.6	21.95	22.42	Expected Counts
	60.2	20.34	19.49	Row %
	22.8	25.81	24.21	Column %
	14.2	4.80	4.60	Total %
K	36.00	6.00	9.00	Counts
	31.82	9.49	9.69	Expected Counts
	70.59	11.76	17.65	Row %
	11.54	6.45	9.47	Column %
	7.20	1.20	1.80	Total %
L	22.00	6.00	9.00	Counts
	23.09	6.88	7.03	Expected Counts
	59.46	16.22	24.32	Row %
	7.05	6.45	9.47	Column %
	4.40	1.20	1.80	Total %
O	26.00	11.00	9.00	Counts
	28.70	8.56	8.74	Expected Counts
	56.52	23.91	19.57	Row %
	8.33	11.83	9.47	Column %
	5.20	2.20	1.80	Total %
SW corner	63.0	16.00	7.00	Counts

53.7	16.00	16.34	Expected Counts
73.3	18.60	8.14	Row %
20.2	17.20	7.37	Column %
12.6	3.20	1.40	Total %

Power of performed test with alpha = 0.0500: 0.9917

Chi-square= 34.2 with 12 degrees of freedom. (P = 0.0006)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0006)

E-7.1: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities D-W and H.

Subjects Growth Form	Localities D-W	H	
Tabular	74.0	20.0	Counts
	62.1	31.9	Expected Counts
	78.7	21.3	Row %
	69.2	36.4	Column %
	45.7	12.3	Total %
Domical	10.00	20.0	Counts
	19.81	10.2	Expected Counts
	33.33	66.7	Row %
	9.35	36.4	Column %
	6.17	12.3	Total %
Irregular	23.0	15.00	Counts
	25.1	12.90	Expected Counts
	60.5	39.47	Row %
	21.5	27.27	Column %
	14.2	9.26	Total %

Power of performed test with alpha = 0.0500: 0.9951

Chi-square= 21.6 with 2 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

E-7.2: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities D-W and J-X.

Subjects Growth Form	Localities D-W	J-X	
Tabular	74.0	71.0	Counts
	69.0	76.0	Expected Counts
	51.0	49.0	Row %
	69.2	60.2	Column %
	32.9	31.6	Total %
Domical	10.00	24.0	Counts
	16.17	17.8	Expected Counts
	29.41	70.6	Row %
	9.35	20.3	Column %
	4.44	10.7	Total %
Irregular	23.0	23.0	Counts
	21.9	24.1	Expected Counts
	50.0	50.0	Row %
	21.5	19.5	Column %
	10.2	10.2	Total %

Power of performed test with alpha = 0.0500: 0.5183

The power of the performed test (0.5183) is below the desired power of 0.8000.
You should interpret the negative findings cautiously.

Chi-square= 5.30 with 2 degrees of freedom. (P = 0.0706)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.0706)

E-7.3: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities D-W and K.

Subjects Growth Form	Localities D-W	K	
Tabular	74.0	36.0	Counts
	74.5	35.5	Expected Counts
	67.3	32.7	Row %
	69.2	70.6	Column %
	46.8	22.8	Total %
Domical	10.00	6.00	Counts
	10.84	5.16	Expected Counts
	62.50	37.50	Row %
	9.35	11.76	Column %
	6.33	3.80	Total %
Irregular	23.0	9.00	Counts
	21.7	10.33	Expected Counts
	71.9	28.13	Row %
	21.5	17.65	Column %
	14.6	5.70	Total %

Power of performed test with alpha = 0.0500: 0.0835

The power of the performed test (0.0835) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 0.462 with 2 degrees of freedom. (P = 0.7936)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.7936)

E-7.4: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities D-W and L.

Subjects	Localities		
Growth Form	D-W	L	
Tabular	74.0	22.0	Counts
	71.3	24.7	Expected Counts
	77.1	22.9	Row %
	69.2	59.5	Column %
	51.4	15.3	Total %
Domical	10.00	6.00	Counts
	11.89	4.11	Expected Counts
	62.50	37.50	Row %
	9.35	16.22	Column %
	6.94	4.17	Total %
Irregular	23.0	9.00	Counts
	23.8	8.22	Expected Counts
	71.9	28.13	Row %
	21.5	24.32	Column %
	16.0	6.25	Total %

Power of performed test with alpha = 0.0500: 0.1837

The power of the performed test (0.1837) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 1.65 with 2 degrees of freedom. (P = 0.4371)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.4371)

E-7.5: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities D-W and O.

Subjects Growth Form	Localities D-W	O	
Tabular	74.0	26.0	Counts
	69.9	30.1	Expected Counts
	74.0	26.0	Row %
	69.2	56.5	Column %
	48.4	17.0	Total %
Domical	10.00	11.00	Counts
	14.69	6.31	Expected Counts
	47.62	52.38	Row %
	9.35	23.91	Column %
	6.54	7.19	Total %
Irregular	23.0	9.00	Counts
	22.4	9.62	Expected Counts
	71.9	28.13	Row %
	21.5	19.57	Column %
	15.0	5.88	Total %

Power of performed test with alpha = 0.0500: 0.5615

The power of the performed test (0.5615) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 5.82 with 2 degrees of freedom. (P = 0.0546)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.0546)

E-7.6: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities D-W and SW corner.

Subjects	Localities		
Growth Form	D-W	SW corner	
Tabular	74.0	63.0	Counts
	76.0	61.0	Expected Counts
	54.0	46.0	Row %
	69.2	73.3	Column %
	38.3	32.6	Total %
Domical	10.00	16.00	Counts
	14.41	11.59	Expected Counts
	38.46	61.54	Row %
	9.35	18.60	Column %
	5.18	8.29	Total %
Irregular	23.0	7.00	Counts
	16.6	13.37	Expected Counts
	76.7	23.33	Row %
	21.5	8.14	Column %
	11.9	3.63	Total %

Power of performed test with alpha = 0.0500: 0.7557

The power of the performed test (0.7557) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 8.62 with 2 degrees of freedom. (P = 0.0134)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0134)

E-7.7: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities H and J-X.

Subjects	Localities		
Growth Form	H	J-X	
Tabular	20.0	71.0	Counts
	28.9	62.1	Expected Counts
	22.0	78.0	Row %
	36.4	60.2	Column %
	11.6	41.0	Total %
Domical	20.0	24.0	Counts
	14.0	30.0	Expected Counts
	45.5	54.5	Row %
	36.4	20.3	Column %
	11.6	13.9	Total %
Irregular	15.00	23.0	Counts
	12.08	25.9	Expected Counts
	39.47	60.5	Row %
	27.27	19.5	Column %
	8.67	13.3	Total %

Power of performed test with alpha = 0.0500: 0.7691

The power of the performed test (0.7691) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 8.86 with 2 degrees of freedom. (P = 0.0119)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0119)

E-7.8: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities H and K.

Subjects Growth Form	Localities H	K	
Tabular	20.0	36.0	Counts
	29.1	26.9	Expected Counts
	35.7	64.3	Row %
	36.4	70.6	Column %
	18.9	34.0	Total %
Domical	20.0	6.00	Counts
	13.5	12.51	Expected Counts
	76.9	23.08	Row %
	36.4	11.76	Column %
	18.9	5.66	Total %
Irregular	15.0	9.00	Counts
	12.5	11.55	Expected Counts
	62.5	37.50	Row %
	27.3	17.65	Column %
	14.2	8.49	Total %

Power of performed test with alpha = 0.0500: 0.9311

Chi-square= 13.5 with 2 degrees of freedom. (P = 0.0012)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0012)

<u>E-7.9:</u> Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities H and L.

Subjects Growth Form	Localities H	L	
Tabular	20.0	22.0	Counts
	25.1	16.9	Expected Counts
	47.6	52.4	Row %
	36.4	59.5	Column %
	21.7	23.9	Total %
Domical	20.0	6.00	Counts
	15.5	10.46	Expected Counts
	76.9	23.08	Row %
	36.4	16.22	Column %
	21.7	6.52	Total %
Irregular	15.0	9.00	Counts
	14.3	9.65	Expected Counts
	62.5	37.50	Row %
	27.3	24.32	Column %
	16.3	9.78	Total %

Power of performed test with alpha = 0.0500: 0.5630

The power of the performed test (0.5630) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 5.84 with 2 degrees of freedom. (P = 0.0541)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.0541)

E-7.10: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities H and O.

Subjects Growth Form	Localities H	O	
Tabular	20.0	26.0	Counts
	25.0	21.0	Expected Counts
	43.5	56.5	Row %
	36.4	56.5	Column %
	19.8	25.7	Total %
Domical	20.0	11.0	Counts
	16.9	14.1	Expected Counts
	64.5	35.5	Row %
	36.4	23.9	Column %
	19.8	10.9	Total %
Irregular	15.0	9.00	Counts
	13.1	10.93	Expected Counts
	62.5	37.50	Row %
	27.3	19.57	Column %
	14.9	8.91	Total %

Power of performed test with alpha = 0.0500: 0.4133

The power of the performed test (0.4133) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 4.13 with 2 degrees of freedom. (P = 0.1271)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.1271)

E-7.11: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities H and SW corner.

Subjects Growth Form	Localities H	SW corner	
Tabular	20.0	63.0	Counts
	32.4	50.6	Expected Counts
	24.1	75.9	Row %
	36.4	73.3	Column %
	14.2	44.7	Total %
Domical	20.0	16.0	Counts
	14.0	22.0	Expected Counts
	55.6	44.4	Row %
	36.4	18.6	Column %
	14.2	11.3	Total %
Irregular	15.00	7.00	Counts
	8.58	13.42	Expected Counts
	68.18	31.82	Row %
	27.27	8.14	Column %
	10.64	4.96	Total %

Power of performed test with alpha = 0.0500: 0.9908

Chi-square= 19.8 with 2 degrees of freedom. (P = <0.0001)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = <0.0001)

E-7.12: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities J-X and K.

Subjects Growth Form	Localities J-X	K	
Tabular	71.0	36.0	Counts
	74.7	32.3	Expected Counts
	66.4	33.6	Row %
	60.2	70.6	Column %
	42.0	21.3	Total %
Domical	24.0	6.00	Counts
	20.9	9.05	Expected Counts
	80.0	20.00	Row %
	20.3	11.76	Column %
	14.2	3.55	Total %
Irregular	23.0	9.00	Counts
	22.3	9.66	Expected Counts
	71.9	28.13	Row %
	19.5	17.65	Column %
	13.6	5.33	Total %

Power of performed test with alpha = 0.0500: 0.2285

The power of the performed test (0.2285) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 2.15 with 2 degrees of freedom. (P = 0.3414)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.3414)

E-7.13: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities J-X and L.

Subjects Growth Form	Localities J-X	L	
Tabular	71.0	22.0	Counts
	70.8	22.2	Expected Counts
	76.3	23.7	Row %
	60.2	59.5	Column %
	45.8	14.2	Total %
Domical	24.0	6.00	Counts
	22.8	7.16	Expected Counts
	80.0	20.00	Row %
	20.3	16.22	Column %
	15.5	3.87	Total %
Irregular	23.0	9.00	Counts
	24.4	7.64	Expected Counts
	71.9	28.13	Row %
	19.5	24.32	Column %
	14.8	5.81	Total %

Power of performed test with alpha = 0.0500: 0.0919

The power of the performed test (0.0919) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 0.568 with 2 degrees of freedom. (P = 0.7526)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.7526)

E-7.14: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities J-X and O.

Subjects Growth Form	Localities J-X	O	
Tabular	71.0	26.0	Counts
	69.8	27.2	Expected Counts
	73.2	26.8	Row %
	60.2	56.5	Column %
	43.3	15.9	Total %
Domical	24.0	11.00	Counts
	25.2	9.82	Expected Counts
	68.6	31.43	Row %
	20.3	23.91	Column %
	14.6	6.71	Total %
Irregular	23.0	9.00	Counts
	23.0	8.98	Expected Counts
	71.9	28.13	Row %
	19.5	19.57	Column %
	14.0	5.49	Total %

Power of performed test with alpha = 0.0500: 0.0689

The power of the performed test (0.0689) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 0.273 with 2 degrees of freedom. (P = 0.8726)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.8726)

E-7.15: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities J-X and SW corner.

Subjects	Localities		
Growth Form	J-X	SW corner	
Tabular	71.0	63.0	Counts
	77.5	56.5	Expected Counts
	53.0	47.0	Row %
	60.2	73.3	Column %
	34.8	30.9	Total %
Domical	24.0	16.00	Counts
	23.1	16.86	Expected Counts
	60.0	40.00	Row %
	20.3	18.60	Column %
	11.8	7.84	Total %
Irregular	23.0	7.00	Counts
	17.4	12.65	Expected Counts
	76.7	23.33	Row %
	19.5	8.14	Column %
	11.3	3.43	Total %

Power of performed test with alpha = 0.0500: 0.5546

The power of the performed test (0.5546) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 5.73 with 2 degrees of freedom. (P = 0.0569)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.0569)

E-7.16: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities K and L.

Subjects Growth Form	Localities K	L	
Tabular	36.0	22.0	Counts
	33.6	24.4	Expected Counts
	62.1	37.9	Row %
	70.6	59.5	Column %
	40.9	25.0	Total %
Domical	6.00	6.00	Counts
	6.95	5.05	Expected Counts
	50.00	50.00	Row %
	11.76	16.22	Column %
	6.82	6.82	Total %
Irregular	9.00	9.00	Counts
	10.43	7.57	Expected Counts
	50.00	50.00	Row %
	17.65	24.32	Column %
	10.23	10.23	Total %

Power of performed test with alpha = 0.0500: 0.1424

The power of the performed test (0.1424) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 1.18 with 2 degrees of freedom. (P = 0.5538)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.5538)

E-7.17: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities K and O.

Subjects Growth Form	Localities K	O	
Tabular	36.0	26.0	Counts
	32.6	29.4	Expected Counts
	58.1	41.9	Row %
	70.6	56.5	Column %
	37.1	26.8	Total %
Domical	6.00	11.00	Counts
	8.94	8.06	Expected Counts
	35.29	64.71	Row %
	11.76	23.91	Column %
	6.19	11.34	Total %
Irregular	9.00	9.00	Counts
	9.46	8.54	Expected Counts
	50.00	50.00	Row %
	17.65	19.57	Column %
	9.28	9.28	Total %

Power of performed test with alpha = 0.0500: 0.2922

The power of the performed test (0.2922) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 2.83 with 2 degrees of freedom. (P = 0.2425)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.2425)

E-7.18: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities K and SW corner.

Subjects Growth Form	Localities K	SW corner	
Tabular	36.0	63.0	Counts
	36.9	62.1	Expected Counts
	36.4	63.6	Row %
	70.6	73.3	Column %
	26.3	46.0	Total %
Domical	6.00	16.0	Counts
	8.19	13.8	Expected Counts
	27.27	72.7	Row %
	11.76	18.6	Column %
	4.38	11.7	Total %
Irregular	9.00	7.00	Counts
	5.96	10.04	Expected Counts
	56.25	43.75	Row %
	17.65	8.14	Column %
	6.57	5.11	Total %

Power of performed test with alpha = 0.0500: 0.3495

The power of the performed test (0.3495) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 3.44 with 2 degrees of freedom. (P = 0.1789)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.1789)

E-7.19: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities L and O.

Subjects Growth Form	Localities L	O	
Tabular	22.0	26.0	Counts
	21.4	26.6	Expected Counts
	45.8	54.2	Row %
	59.5	56.5	Column %
	26.5	31.3	Total %
Domical	6.00	11.00	Counts
	7.58	9.42	Expected Counts
	35.29	64.71	Row %
	16.22	23.91	Column %
	7.23	13.25	Total %
Irregular	9.00	9.00	Counts
	8.02	9.98	Expected Counts
	50.00	50.00	Row %
	24.32	19.57	Column %
	10.84	10.84	Total %

Power of performed test with alpha = 0.0500: 0.1136

The power of the performed test (0.1136) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 0.838 with 2 degrees of freedom. (P = 0.6577)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.6577)

E-7.20: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities L and SW corner.

Subjects / Growth Form	Localities: L	SW corner	
Tabular	22.0	63.0	Counts
	25.6	59.4	Expected Counts
	25.9	74.1	Row %
	59.5	73.3	Column %
	17.9	51.2	Total %
Domical	6.00	16.0	Counts
	6.62	15.4	Expected Counts
	27.27	72.7	Row %
	16.22	18.6	Column %
	4.88	13.0	Total %
Irregular	9.00	7.00	Counts
	4.81	11.19	Expected Counts
	56.25	43.75	Row %
	24.32	8.14	Column %
	7.32	5.69	Total %

Power of performed test with alpha = 0.0500: 0.5767

The power of the performed test (0.5767) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 6.00 with 2 degrees of freedom. (P = 0.0497)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0497)

E-7.21: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between localities O and SW corner.

Subjects	Localities		
Growth Form	O	SW corner	
Tabular	26.0	63.0	Counts
	31.0	58.0	Expected Counts
	29.2	70.8	Row %
	56.5	73.3	Column %
	19.7	47.7	Total %
Domical	11.00	16.0	Counts
	9.41	17.6	Expected Counts
	40.74	59.3	Row %
	23.91	18.6	Column %
	8.33	12.1	Total %
Irregular	9.00	7.00	Counts
	5.58	10.42	Expected Counts
	56.25	43.75	Row %
	19.57	8.14	Column %
	6.82	5.30	Total %

Power of performed test with alpha = 0.0500: 0.4820

The power of the performed test (0.4820) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 4.89 with 2 degrees of freedom. (P = 0.0869)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.0869)

Appendix E-8: Examples of Chi-square tests (χ^2) comparing the relative abundances of each type of stromatoporoid between stratigraphic levels within the southern zone, northern zone, and comparison between zones (see Figure 11.1).

Part 1 – Southern Zone

All specimens at equivalent stratigraphic levels from sites within the southern zone were included in this analysis (excluding single specimen of stromatoporoid Type VC, and unidentifiable specimens). The results of tests which demonstrated a statistically significant relationship between a level and at least one other level within the same zone are included.

Part 2 – Northern Zone

All specimens at equivalent stratigraphic levels from sites within the northern zone were included in this analysis (excluding unidentifiable specimens). The results of tests which demonstrated a statistically significant relationship between a level and at least one other level within the same zone are included.

Part 3 - Comparison Between Zones

Comparisons of equivalent stratigraphic levels between the southern and northern zones. The results of tests which demonstrated a statistically significant relationship between levels in the two zones.

Part 1 – Southern Zone

E-8.1: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between level 11 (1.9 m-2.1 m) and level 3 (0.3 m-0.5 m) within the southern zone.

Subjects Stratigraphic Level	Type CY	Stromatoporoids Type PI	Type CP	
Level 11	18.0	9.00	0.00	Counts
(1.9 m-2.1 m)	18.5	6.35	2.12	Expected Counts
	66.7	33.33	0.00	Row %
	51.4	75.00	0.00	Column %
	35.3	17.65	0.00	Total %
Level 3	17.0	3.00	4.00	Counts
(0.3 m-0.5 m)	16.5	5.65	1.88	Expected Counts
	70.8	12.50	16.67	Row %
	48.6	25.00	100.00	Column %
	33.3	5.88	7.84	Total %

Power of performed test with alpha = 0.0500: 0.6435

The power of the performed test (0.6435) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 6.88 with 2 degrees of freedom. (P = 0.0321)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0321)

Part 2 – Northern Zone

E-8.2: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between level 7 (1.1 m-1.3 m) and level 5 (0.7 m-0.9 m) within the northern zone.

Subjects Stratigraphic Level	Type CY	Stromatoporoids Type PI	Type CP	
Level 7 (1.1 m-1.3 m)	10.00	5.00	9.00	Counts
	8.69	9.52	5.79	Expected Counts
	41.67	20.83	37.50	Row %
	47.62	21.74	64.29	Column %
	17.24	8.62	15.52	Total %
Level 5 (0.7 m-0.9 m)	11.0	18.0	5.00	Counts
	12.3	13.5	8.21	Expected Counts
	32.4	52.9	14.71	Row %
	52.4	78.3	35.71	Column %
	19.0	31.0	8.62	Total %

Power of performed test with alpha = 0.0500: 0.6541

The power of the performed test (0.6541) is below the desired power of 0.8000.
You should interpret the negative findings cautiously.

Chi-square= 7.02 with 2 degrees of freedom. (P = 0.0299)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0299)

E-8.3: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types between level 9 (1.5 m-1.7 m) and level 3 (0.3 m-0.5 m) within the northern zone.

Subjects		Stromatoporoids		
Stratigraphic Level	Type CY	Type PI	Type CP	
Level 9	6.00	4.00	0.00	Counts
(1.5 m-1.7 m)	4.44	3.33	2.22	Expected Counts
	60.00	40.00	0.00	Row %
	75.00	66.67	0.00	Column %
	33.33	22.22	0.00	Total %
Level 3	2.00	2.00	4.00	Counts
(0.3 m-0.5 m)	3.56	2.67	1.78	Expected Counts
	25.00	25.00	50.00	Row %
	25.00	33.33	100.00	Column %
	11.11	11.11	22.22	Total %

Power of performed test with alpha = 0.0500: 0.6174

The power of the performed test (0.6174) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 6.52 with 2 degrees of freedom. (P = 0.0383)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0383)

Part 3 – Comparison Between Zones

E-8.4: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types at stratigraphic level 6 (0.9 m-1.1 m) between the southern and northern zones.

Subjects Stratigraphic Level	Type CY	Stromatoporoids Type PI	Type CP	
Southern Zone	23.0	11.00	3.00	Counts
Level 6	19.6	9.51	7.93	Expected Counts
	62.2	29.73	8.11	Row %
	62.2	61.11	20.00	Column %
	32.9	15.71	4.29	Total %
Northern Zone	14.0	7.00	12.00	Counts
Level 6	17.4	8.49	7.07	Expected Counts
	42.4	21.21	36.36	Row %
	37.8	38.89	80.00	Column %
	20.0	10.00	17.14	Total %

Power of performed test with alpha = 0.0500: 0.7360

The power of the performed test (0.7360) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 8.28 with 2 degrees of freedom. (P = 0.0160)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0160)

<u>E-8.5:</u> Chi-square test (χ^2) comparing the relative abundances of stromatoporoid types at stratigraphic level 7 (1.1 m-1.3 m) between the southern and northern zones.

Subjects		Stromatoporoids		
Stratigraphic Level	Type CY	Type PI	Type CP	
Southern Zone	25.0	11.00	3.00	Counts
Level 7	21.7	9.90	7.43	Expected Counts
	64.1	28.21	7.69	Row %
	71.4	68.75	25.00	Column %
	39.7	17.46	4.76	Total %
Northern Zone	10.00	5.00	9.00	Counts
Level 7	13.33	6.10	4.57	Expected Counts
	41.67	20.83	37.50	Row %
	28.57	31.25	75.00	Column %
	15.87	7.94	14.29	Total %

Power of performed test with alpha = 0.0500: 0.7543

The power of the performed test (0.7543) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 8.59 with 2 degrees of freedom. (P = 0.0136)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0136)

Appendix E-9: Examples of Chi-square tests (χ^2) comparing the relative abundances of stromatoporoid growth forms between stratigraphic levels within the southern zone, northern zone, and comparison between zones (see Figure 11.2).

Part 1 – Southern Zone

All specimens at equivalent stratigraphic levels from sites within the southern zone were included in this analysis (excluding single specimen of stromatoporoid Type VC, and unidentifiable specimens). The results of tests which demonstrated a statistically significant relationship between a level and at least one other level within the same zone are included.

Part 2 – Northern Zone

All specimens at equivalent stratigraphic levels from sites within the northern zone were included in this analysis (excluding unidentifiable specimens). As the results of tests did not demonstrate a statistically significant relationship between any level and at least one other level in this zone, a single analysis producing negative results is included as an example.

Part 3 - Comparison Between Zones

Comparisons of equivalent stratigraphic levels between the southern and northern zones. The results of tests which demonstrated a statistically significant relationship between levels in the two zones are included.

Part 1 – Southern Zone

E-9.1: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between level 9 (1.5 m-1.7 m) and level 7 (1.1 m-1.3 m) within the southern zone.

Subjects Stratigraphic Level	Tabular	Growth Form Domical	Irregular	
Level 9 (1.5 m-1.7 m)	31.0	3.00	13.0	Counts
	27.3	8.20	11.5	Expected Counts
	66.0	6.38	27.7	Row %
	62.0	20.00	61.9	Column %
	36.0	3.49	15.1	Total %
Level 7 (1.1 m-1.3 m)	19.0	12.00	8.00	Counts
	22.7	6.80	9.52	Expected Counts
	48.7	30.77	20.51	Row %
	38.0	80.00	38.10	Column %
	22.1	13.95	9.30	Total %

Power of performed test with alpha = 0.0500: 0.7658

The power of the performed test (0.7658) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 8.80 with 2 degrees of freedom. (P = 0.0123)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0123)

E-9.2: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between level 9 (1.5 m-1.7 m) and level 6 (0.9 m-1.1 m) within the southern zone.

Subjects Stratigraphic Level	Growth Form Tabular	 Domical	 Irregular	
Level 9	31.0	3.00	13.0	Counts
(1.5 m-1.7 m)	28.4	7.65	10.9	Expected Counts
	66.0	6.38	27.7	Row %
	59.6	21.43	65.0	Column %
	36.0	3.49	15.1	Total %
Level 6	21.0	11.00	7.00	Counts
(0.9 m-1.1 m)	23.6	6.35	9.07	Expected Counts
	53.8	28.21	17.95	Row %
	40.4	78.57	35.00	Column %
	24.4	12.79	8.14	Total %

Power of performed test with alpha = 0.0500: 0.6947

The power of the performed test (0.6947) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 7.62 with 2 degrees of freedom. (P = 0.0222)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0222)

<u>E-9.3:</u> Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between level 9 (1.5 m-1.7 m) and level 2 (0.1 m-0.3 m) within the southern zone.

Subjects		Growth Form		
Stratigraphic Level	Tabular	Domical	Irregular	
Level 9	31.0	3.00	13.0	Counts
(1.5 m-1.7 m)	30.2	5.04	11.8	Expected Counts
	66.0	6.38	27.7	Row %
	86.1	50.00	92.9	Column %
	55.4	5.36	23.2	Total %
Level 2	5.00	3.00	1.00	Counts
(0.1 m-0.2 m)	5.79	0.964	2.250	Expected Counts
	55.56	33.333	11.111	Row %
	13.89	50.000	7.143	Column %
	8.93	5.357	1.786	Total %

Power of performed test with alpha = 0.0500: 0.5824

The power of the performed test (0.5824) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 6.08 with 2 degrees of freedom. (P = 0.0480)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0480)

E-9.4: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between level 8 (1.3 m-1.5 m) and level 4 (0.5 m-0.7 m) within the southern zone.

Subjects Stratigraphic Level	Growth Form Tabular	Domical	Irregular	
Level 8	9.00	5.00	6.00	Counts
(1.3 m-1.5 m)	12.50	3.75	3.75	Expected Counts
	45.00	25.00	30.00	Row %
	45.00	83.33	100.00	Column %
	28.13	15.63	18.75	Total %
Level 4	11.00	1.00	0.00	Counts
(0.5 m-0.7 m)	7.50	2.25	2.25	Expected Counts
	91.67	8.333	0.00	Row %
	55.00	16.667	0.00	Column %
	34.38	3.125	0.00	Total %

Power of performed test with alpha = 0.0500: 0.6751

The power of the performed test (0.6751) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 7.32 with 2 degrees of freedom. (P = 0.0257)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0257)

<u>E-9.5:</u> Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between level 7 (1.1 m-1.3 m) and level 4 (0.5 m-0.7 m) within the southern zone.

Subjects		Growth Form		
Stratigraphic Level	Tabular	Domical	Irregular	
Level 7	19.0	12.00	8.00	Counts
(1.1 m-1.3 m)	22.9	9.94	6.12	Expected Counts
	48.7	30.77	20.51	Row %
	63.3	92.31	100.00	Column %
	37.3	23.53	15.69	Total %
Level 4	11.00	1.00	0.00	Counts
(0.5 m-0.7 m)	7.06	3.059	1.88	Expected Counts
	91.67	8.333	0.00	Row %
	36.67	7.692	0.00	Column %
	21.57	1.961	0.00	Total %

Power of performed test with alpha = 0.0500: 0.6631

The power of the performed test (0.6631) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 7.15 with 2 degrees of freedom. (P = 0.0280)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0280)

Part 2 – Northern Zone

E-9.6: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms between level 7 (1.1 m-1.3 m) and level 5 (0.7 m-0.9 m) within the northern zone.

Subjects Stratigraphic Level	Growth Form Tabular	Domical	Irregular	
Level 7 (1.1 m-1.3 m)	13.0	4.00	7.00	Counts
	14.5	4.14	5.38	Expected Counts
	54.2	16.67	29.17	Row %
	37.1	40.00	53.85	Column %
	22.4	6.90	12.07	Total %
Level 5 (0.7 m-0.9 m)	22.0	6.00	6.00	Counts
	20.5	5.86	7.62	Expected Counts
	64.7	17.65	17.65	Row %
	62.9	60.00	46.15	Column %
	37.9	10.34	10.34	Total %

Power of performed test with alpha = 0.0500: 0.1354

The power of the performed test (0.1354) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 1.10 with 2 degrees of freedom. (P = 0.5770)

The proportions of observations in different columns of the contingency table do not vary from row to row. The two characteristics that define the contingency table are not significantly related. (P = 0.5770)

Part 3 – Comparison Between Zones

E-9.7: Chi-square test (χ^2) comparing the relative abundances of stromatoporoid growth forms at stratigraphic level 4 (0.5 m-0.7 m) between the southern and northern zones.

Subjects Stratigraphic Level	Tabular	Growth Form Domical	Irregular	
Southern Zone Level 4	11.00	1.000	0.00	Counts
	8.18	1.636	2.18	Expected Counts
	91.67	8.333	0.00	Row %
	73.33	33.333	0.00	Column %
	50.00	4.545	0.00	Total %
Northern Zone Level 4	4.00	2.00	4.00	Counts
	6.82	1.36	1.82	Expected Counts
	40.00	20.00	40.00	Row %
	26.67	66.67	100.00	Column %
	18.18	9.09	18.18	Total %

Power of performed test with alpha = 0.0500: 0.6857

The power of the performed test (0.6857) is below the desired power of 0.8000. You should interpret the negative findings cautiously.

Chi-square= 7.48 with 2 degrees of freedom. (P = 0.0238)

The proportions of observations in different columns of the contingency table vary from row to row. The two characteristics that define the contingency table are significantly related. (P = 0.0238)

<u>Appendix F:</u> Cluster analysis raw data. The abundances of individual specimens of each taxon at each locality within the Lundar Quarry were tabulated and computed using PAST software (Hammer et al. 2001).

Locality	Stromatoporoids				Tabulate Corals					Rugose Corals				
	CY	PI	CP	VC	Lund	Inaeq	Goth	Haly	Prop	Syn	Pycno	Amp	Dino	Cysti
D-W	68	30	8	0	23	4	1	7	0	7	3	5	3	1
H	35	20	0	0	8	2	0	5	0	6	1	2	0	1
J-X	83	23	12	1	15	6	2	6	0	6	2	6	3	1
K	21	15	15	0	3	1	0	0	0	0	0	1	2	1
L	9	16	12	0	5	1	0	0	0	3	1	8	2	3
O	24	12	11	0	4	0	0	0	1	4	1	1	1	0
SW cor.	70	13	3	0	11	4	2	0	0	5	0	5	2	0

SW cor. = southwest corner

Stromatoporoids

- CY = Stromatoporoid Type CY
- PI = Stromatoporoid Type PI
- CP = Stromatoporoid Type CP
- VC = Stromatoporoid Type VC

Tabulate Corals

- Lund = *Favosites niagarensis lundarensis*
- Inaeq = *Favosites niagarensis inaequalis*
- Goth = *Favosites gothlandicus*
- Haly = both species of genus *Halysites*
- Prop = both members of superfamily Proporicae

Rugose Corals

- Colonial
  - Syn = *Synamplexoides varioseptatus*
  - Pycno = *Pycnostylus guelphensis*
- Solitary
  - Amp = *Amplexoides* sp. A
  - Dino = *Dinophyllum lundarense*
  - Cysti = *Cystiphyllum* cf. *niagarensis*