The Upper Cretaceous Cardium Formation at Seebe Alberta:

Shallow Marine Storm Deposits

The Upper Cretaceous Cardium Formation at Seebe, Alberta: Shallow Marine Storm Deposits

By

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ABSTRACT

The Cardium Formation in the study area can be defined by twelve different facies. Ordering of facies forms five coarsening upward cycles. Three different cycle types are present. The two thicker ones are characterized by 1) basal Bioturbated Siltstone Facies, grading up into 2) various interbedded siltstones and hummocky cross-stratified (H.C.S.) sandstone facies; followed by 3) more massive Bioturbated Sandstone Facies in one cycle type, and H.C.S. Sandstone Facies in the other. These two cycle types terminate sharply with or without a conglomerate veneer. The third cycle type consists of 1) Less Bioturbated Shale Facies which coarsens upward into 2) Bioturbated Siltstone Facies and the cycle is terminated by 3) Concretionary Conglomerate Facies.

H.C.S. is a newly-defined sedimentary structure formed by long period storm waves, and commonly preserved below fairweather wave base. In the Cardium, the abundance of H.C.S. accompanied by small wave ripples, graded bedding, and a deeper water fauna (together with the absence of medium scale cross bedding) suggests deposition below fairweather wave base. Near-shore sediment is entrained by powerful storm-surge bottom currents. Storm waves feeling the bottom imprint H.C.S. on these density current deposits. Fairweather conditions cannot rework the H.C.S. and produce only bioturbated siltstones and shales.

The main ichnofauna is a Rhizocorallium-Zoophycos assemblage with abundant Chondrites and some Ophiomorpha. This suggests a depositional environment well off-shore in deeper water, which agrees with the interpretation derived from the H.C.S. The foraminiferal assemblage also suggests an open marine rather than nearshore environment.

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CHAPTER 1

INTRODUCTION AND SETTING

Introduction

The Upper Cretaceous Cardium Formation is well exposed in outcrop below the Kananaskis Dam, at Seebe, Alberta (Figures 1 and 2). Due to its proximity to Calgary, this locality is often visited on field trips as a good example of the Cardium Formation. One of the most recent has been the Exploration Update '79 Bow Valley Field Trip (de Wit, 1979).

Prior to this study, no comprehensive detailed mapping of the local structural geology had been attempted. The structural complications of this outcrop were not understood and hence no stratigraphic sections corrected for structure have been available. Most importantly, no recent detailed sedimentological study of this exposure has been done, incorporating advances in shallow marine sedimentation made in the last five to ten years. In 1978, during reconnaissance work by Walker and Hamblin (pers. comm.), it was noted that the Cardium below the Kananaskis Dam at Seebe exhibited abundant well developed hummocky cross stratification. This is a newly defined sedimentary structure (Harms et al., 1975) commonly interpreted as being formed below fairweather wave base by storm waves (Harms et al., 1975, p. 88). Its abundance here is believed to be important in the interpretation of Cardium depositional environments and processes. In the past, there was

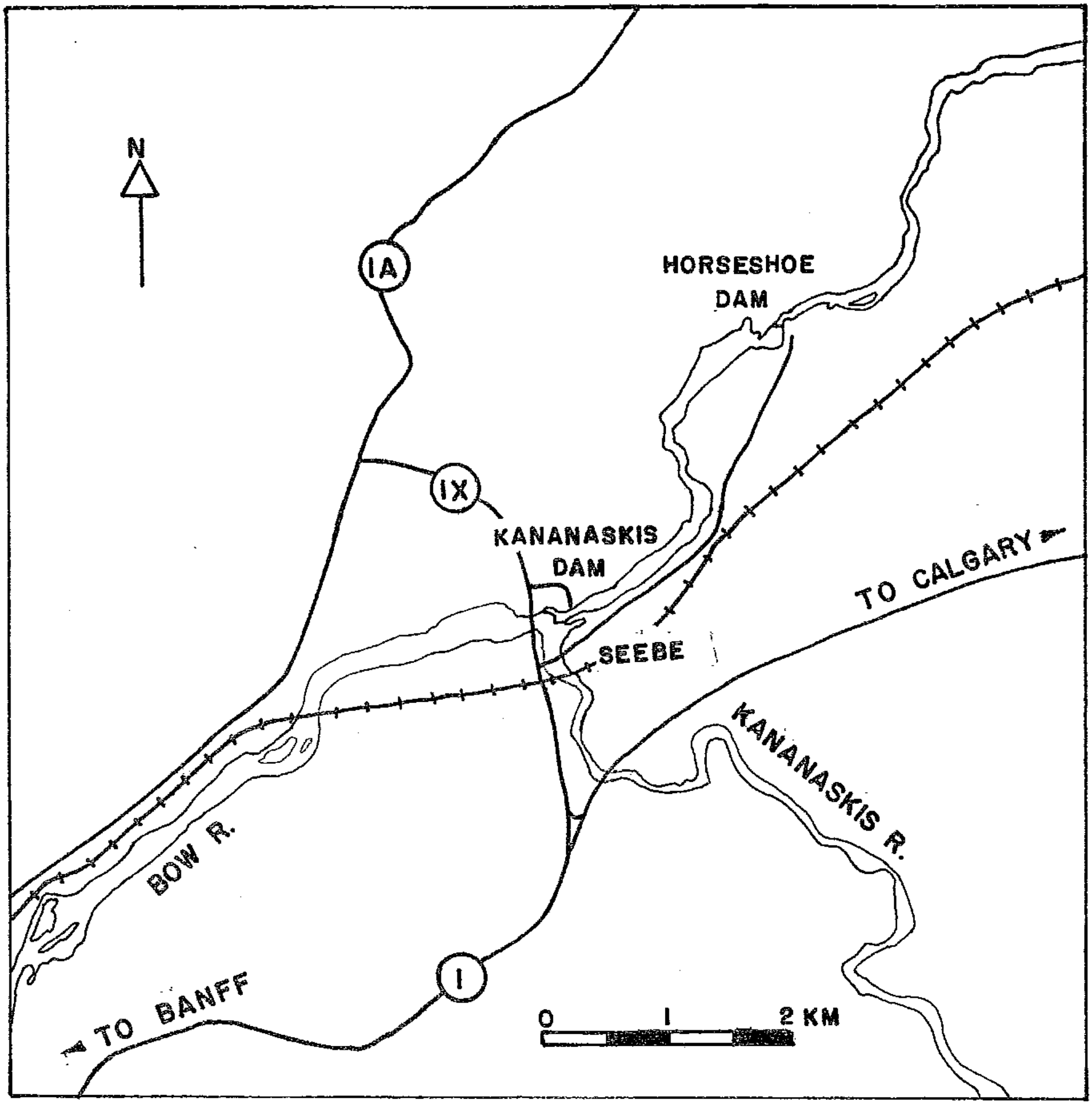

Figure 1. Outcrop location map.
The circled characters indicate highway numbers.

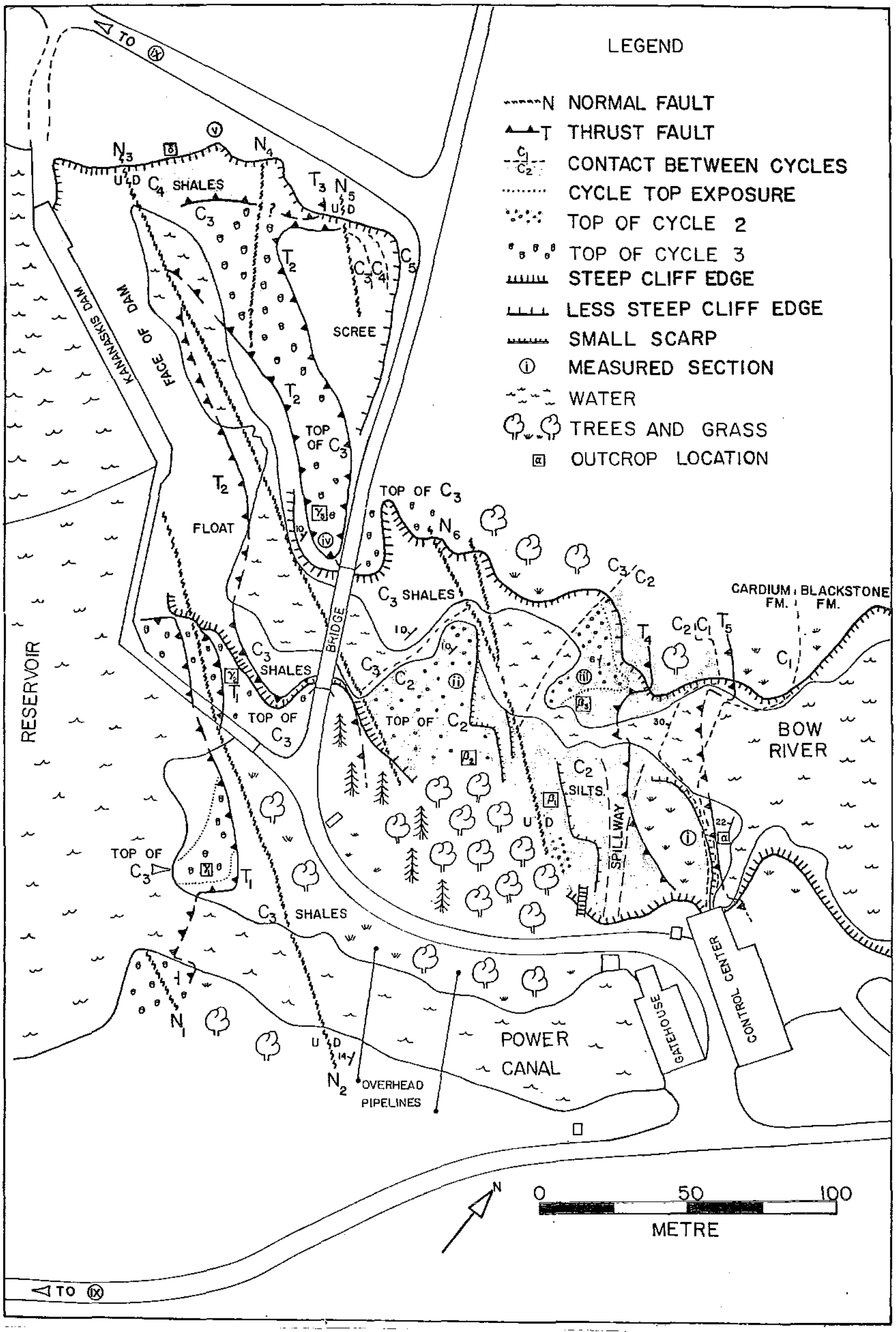

Figure 2. Detailed Geologic Map of the Seebe Outcrop, below the Kananaskis Dam.

a controversy active in the literature about whether the Cardium was formed as a near shore to beach deposit, or as a deeper shelf, or even turbidity current deposit. At present the near shore to beach interpretation is widely accepted.

The purpose of this study was to examine in detail the stratigraphy, sedimentology and structural geology of the Cardium Formation exposed in outcrop at this locality. Mapping was completed during the summer of 1979, and that winter work was done in the lab using both samples and collected data.

Another continuous and less faulted outcrop, exposed a few kilometres downstream (northeast) at the Horseshoe Dam (Figure 3), was also studied with the intention of comparing stratigraphy and sedimentology with that at Seebe.

Detailed study of the stratigraphy determined that the stratigraphic section could be broken down into a number of distinctive and often repeated facies. These facies were defined by grain size, sedimentary structures, fauna and ichnofauna (Walker, 1979a, p. 1). Additional information was gained from petrology and grain orientation done in the lab. Facies relationships determined that the Cardium, at this location, could be divided into five coarsening upward sequences (Figure 4). These results, combined with the abundance of hummocky cross stratification, have led to the formation of a depositional model involving storm-dominated shallow marine conditions.

At the present there is no tectonically equivalent continental epeiric sea, bounded on one shoreline by active uplift. Because of this,

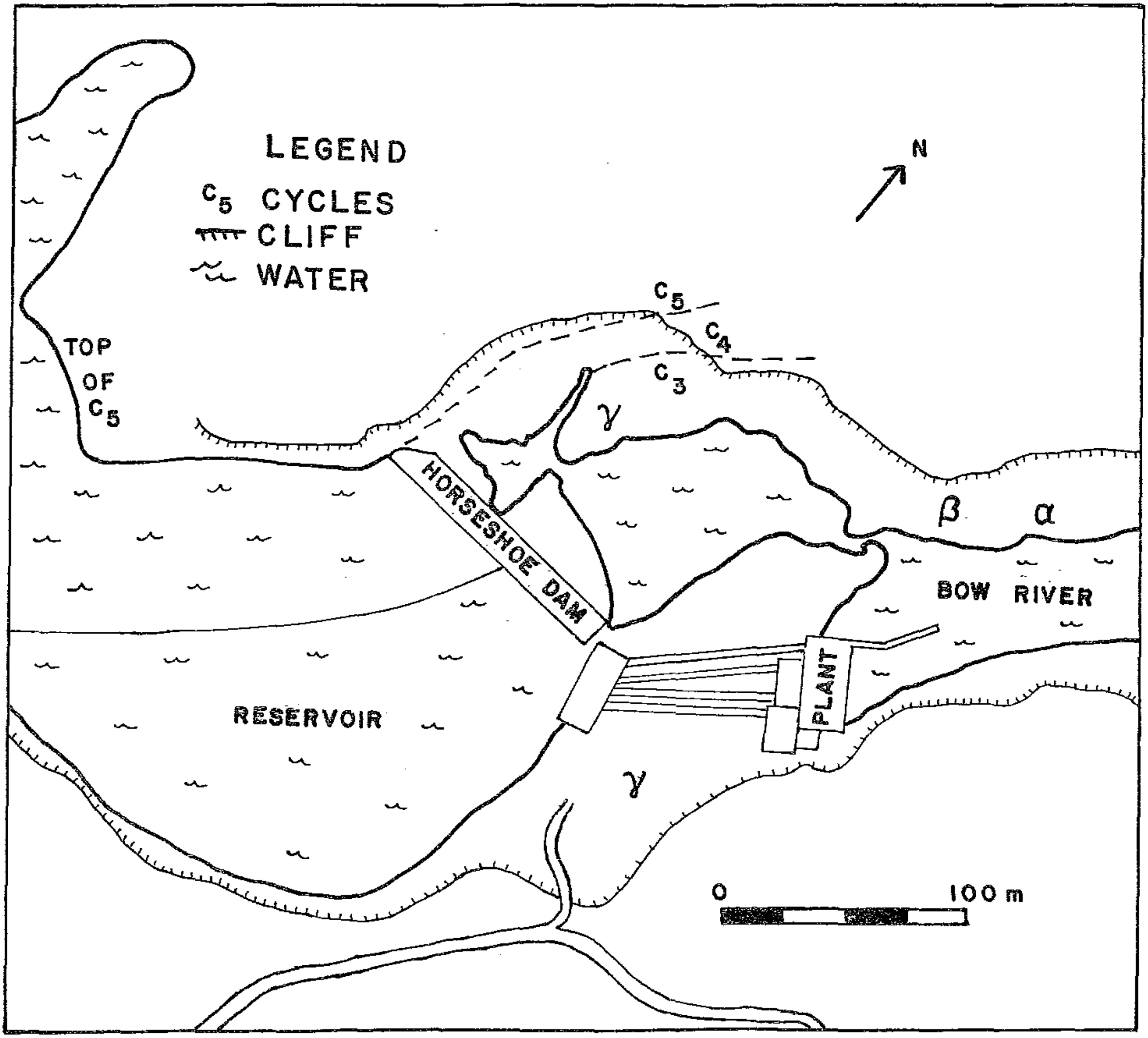

Figure 3. Detail Map of the Horseshoe Dam area, with approximate locations of some cycles. The Greek symbols correspond with the equivalent stratigraphic levels of Figure 2.

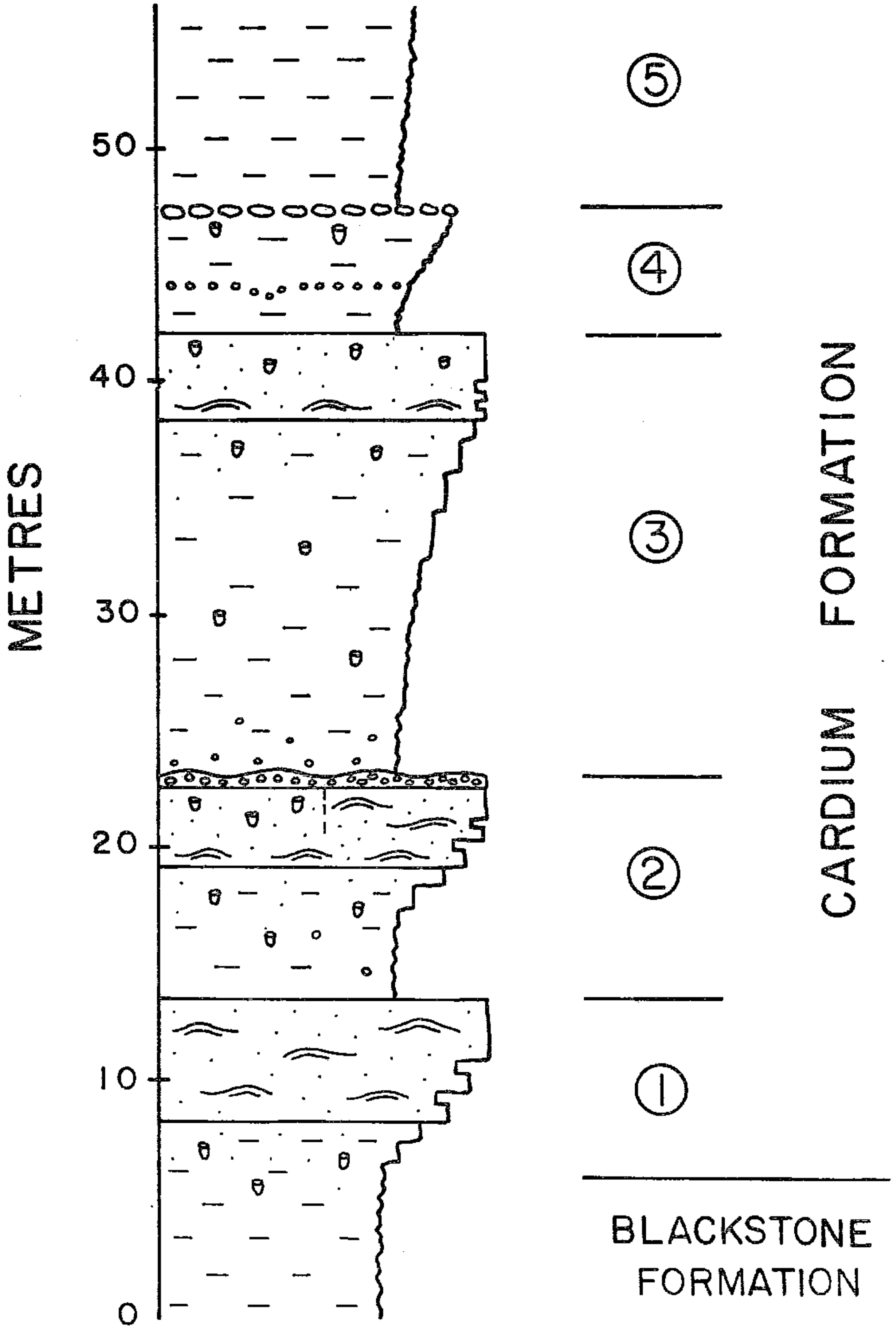

Figure 4. Undetailed Measured Section of the Cardium Formation at Seebe.
Circled numbers indicate Cycles.

there is not yet a well developed facies model for the Cretaceous shallow marine which has been tied to the recent. However, a great deal of work is being done on modern continental shelves and many of the results have brought important insights to the understanding of shallow marine environments.

Location

The two outcrops of this study are exposed in river gorges below Calgary Power dams located on the Bow River. Both are near the town of Seebe in southern Alberta (latitude 51°6' N, longitude 115°3.6' W, near 15-33-24-8W5), which lies just north of the Trans Canada Highway between Calgary and Banff (Figure 1).

The "Seebe" (or Kananaskis Dam) outcrop lies closest to Seebe, situated below the Kananaskis Dam at the confluence of the Kananaskis and Bow Rivers. Easy access is obtained from the Trans Canada Highway at the Seebe-Exshaw turnoff, about twenty five kilometres east of Canmore. North along Highway 1X about one kilometre is a bridge crossing the Kananaskis Dam Reservoir. Access to the dam is gained by turning right just past this bridge (across from the Brewster Ranch).

The Horseshoe Dam site is reached by turning right from Highway 1X before the bridge. This road leads through the town of Seebe and along the Bow River. Three kilometres downstream from the Kananaskis Dam Control Centre is a steep road on the left leading down to the dam. The outcrop lies on the north side of the river and is accessible only by crossing the dam. Permission and assistance, in the form of unlocking doors and setting up ladders is required from Calgary Power. There are some outcrops on the south side of the river but the section is incomplete due to poor exposure and accessibility.

Geologic Setting

The Cardium Formation is a major sand development within the Upper Cretaceous Alberta Group. It is bounded below and above by the thick marine shales of the Blackstone and Wapiabi Formations, respectively (Figure 5). The age of the Cardium, in the area studied, is considered to be Turonian (Wall, 1967).

The study area lies near the eastern limits of the Rocky Mountain Belt of Monger and Price (1979). Late Cretaceous to Paleogene time marked a period of northeastward thrust faulting and folding (Monger and Price, 1979). The result, in this area, was multiple thrust sheet imbricates of Mesozoic clastics which overlie Paleozoic carbonates (Bruce, 1978). To the west are the major thrust sheets of the Front Ranges which stack mostly sequences of upper and middle Paleozoic carbonates and Precambrian sediments (Bruce, 1978). To the east the degree of deformation fades into the undisturbed region of the Plains.

The basic configuration of the Rocky Mountain Belt was established during the span of time from the Middle Jurassic to the Mid-Cretaceous. This occurred in response to compression in the area resulting from subduction and related magmatism in the Western Cordillera. In late Portlandian time the eastward shedding of clastic

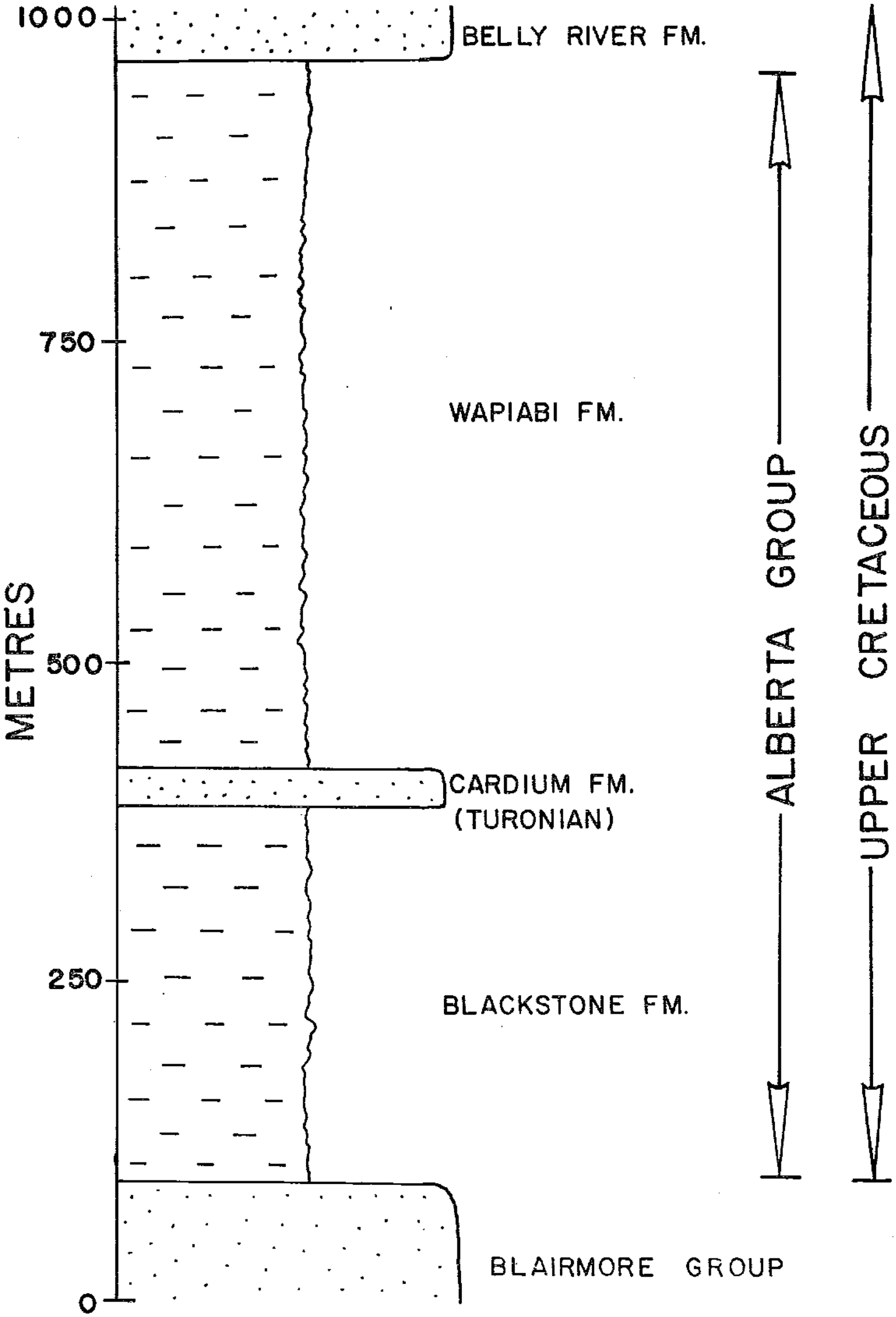

Figure 5. Incomplete stratigraphic column illustrating the relative position of the Cardium Formation.

sediment was initiated (Monger and Price, 1979). It was during the deposition of this clastic wedge into a shallow continental basin that Wheeler et al. (1972) believe the Alberta Group was formed.

The Cardium Formation extends from the International Boundary north at least as far as the Pine and Peace River country (Stott, 1963). Its east-west extent is from the Front Ranges east, across the Rocky Mountain Belt and into the Plains (Stott, 1963).

The outcrop at Seebe forms part of the westward dipping limb of an anticline. The dominant structural elements of the area are low angle thrust faults which have been subsequently cut by small normal faults with throws up to a few metres. Local deformation is not extensive and detailed mapping shows that stratigraphic units can be easily matched across faults.

To the east of the anticline at Seebe is a linking syncline-anticline pair. On the westward dipping limb of this anticline is the Horseshoe Dam outcrop. It is a complete, continuous section with no structural complications.

CHAPTER 2

HISTORICAL BACKGROUND

An Historical Review

Most of the work published on the Cardium Formation before 1955 pertained to field mapping and stratigraphic correlation. Little in the way of interpretation of depositional environment was considered at that time. This historical work has been well summarized by Stott (1963).

With the discovery of the Pembina Oil Field in 1953 it became economically important to understand the Cardium in terms of depositional environment rather than just its mappable extent. The high density of drilling provided petroleum geologists with a profusion of data. General opinion at that time was that much of this sediment was deposited in shallow water and was distributed by longshore currents in a sea subject to a "shifting strandline" (de Wiel, 1956).

A controversy concerning the mode of deposition of the Cardium Formation was sparked by F.K. Beach in 1955. He published a brief paper in which he described Viking conglomerates as being distributed by turbidity currents. He then noted the similarity of the Viking conglomerates to the Cardium conglomerates and extended his turbidity current model to the Cardium as well. For support of these ideas he cited the extensive, uniform lateral continuity of the pebble layers which were too coarse to be explained by pelagic sedimentation and the fact that they were often found within shale beds. These are criteria that Passega (1954) had set for turbidity current deposits.

One year later a reply to this paper was published by de Wiel (1956). He wholeheartedly refuted Beach's suggestions on the grounds of an unfair comparison. The Grand Banks turbidity current described by Passega (1954) was on a much steeper slope, involved greater depths than would exist in an epeiric sea, and the turbidity current was initiated by earthquake induced slumping. Also turbidites should have shown individual interbedded graded beds rather than the existing overall sequence of coarsening upward grain size, and they should create channels leading down dip from the source. Instead he noted the existence of sand lentils which he described as striking "parallel to the ancient sea floor". De Wiel (1956) preferred to interpret the Cardium by what he termed "more conventional principles of sedimentation". By this he envisaged a flat bottomed sea which would require very little sea level change to displace the shoreline laterally. A sediment source was formed by tectonic rise and these sediments were then distributed laterally by longshore currents.

Beach (1956) replied to this criticism in the same publication. He agreed with de Wiel's point that the sea was not abyssal. It was pointed out that transgressive beach conglomerates should be overlain by a fining upward sequence, but this was not the case. The idea that the Cardium and Viking sediments were not indicative of pelagic conditions was restated and he questioned how it was that a transgressive beach conglomerate could overlie marine beds, as Stott (1956) had suggested they did. Beach felt that conglomerates having a clay matrix and sands having erratic lateral thicknesses, as was the case for the Cardium, were indicative of turbidity current deposits much more so than normal pelagic sedimentation. For a means of initiating these turbidity flows he noted the tectonic activity of the area during Cardium time. A tsunami model was invoked where by he postulated that earthquakes generated turbidity currents which in turn created a tsunami. He felt that this tsunami would have the ability to transport coarse clastics a great distance. In this way descent over a large vertical height and steep slopes was not necessary. Formations in Wyoming of equivalent age were noted as having similarities to the Cardium, and their distribution had been interpreted previously as the result of turbidity current activity.

In April 1957 the Alberta Society of Petroleum Geologists held a Cardium Symposium. This was a result of the high level of interest in the Pembina oil field and the papers presented were mostly from subsurface studies using electric logs and core.

In his paper, Nielsen (1957) discussed the lack of evidence for a deltaic model for the Cardium at Pembina. His reasons were that the type of cross lamination within the sandstones was not of deltaic magnitude and the sets were much too well sorted to be deltaic. The concept of deposition by turbidity currents was also rejected on the basis that the nature of the basin would not support this mechanism and also, criteria set by Kuenen (1957) for turbidity deposits did not fit the Cardium. These criteria included: graded bedding, regular interbedding of sandstone and shale, poor sorting of dirty sands and the absence of scour. The model put forward by Nielsen for the formation of the lower, middle and upper sands was that of a continually shallowing sea, with the sands always below wave base. The conglomerates were accounted for by raising of the sea floor above wave base, accompanied by western uplift and an influx of second or third generation conglomerate material.

The next paper, by Michaelis (1957), was a study in outcrop of the Pembina River area. His model for the Cardium was based upon regressive sequences for each of five cycles, each one being separated by a transgression. He believed that sedimentation was active near a distributary channel and this sediment was then distributed by storms and slumping. Reasons for this model were based upon a resemblance of the size distribution of the poorly sorted siltstones to deltaic deposits, as well as comparison of the interbedded sands and shales to recent delta front sands found in association with inflow channels. He interpreted the lower fine siltstones having ripple cross lamination and burrow casts as tidal flat sediments. The overlying sands were considered to be upper foreshore beach deposits, due to their very low angle foresets and beach-like sorting. The conglomerates formed the cap of a coarsening upward beach bar. Where they were found to overlie shale, it was postulated that the gravels had been driven over top of shoreward tidal flat sediment by wave action which accompanied a transgression.

The third paper of the symposium was a very short presentation by Roessigh (1957). He noted that the "Cardium sand" at Pigeon Lake and Leduc appeared to have some similarities to turbidity current deposits as described by Schneeberger (1955). These characteristics included: well sorted sands, sharp based sands overlaying shales, a lenticular form, and well defined lateral limits. He also noted that some aspects of the Viking sand may also have been indicative of turbidite deposits.

The final presentation of this series was by MacDonald (1957) who discussed the development of a Cardium delta system in the Peace River area. His conclusions were based upon isopach and structure contour maps.

The next major work pertaining to the Cardium was an extensive outcrop study by Stott (1963) of the Alberta Group throughout much of Alberta. Previous to this, Stott (1961) had subdivided the Cardium into members. These were, in ascending stratigraphic order: Ram, Moosehound, Kiska, Cardinal, Leyland and Sturrock members. The Ram, Cardinal and Sturrock Members were sandstone units while the other three were siltstones and shales. The Cardium was thought to have formed during the end of a major regressive phase. Within this were minor cycles having shale representing transgressions and sand representing regressions. Conglomerates were formed by very rapid transgressions. Environmental interpretation involved a beach, off-beach, barrier bar complex. Stott believed that this was indicated by: the sand thickness, lateral continuity, well sorted beach type grain sizes and uniform lamination. The conglomerates were also believed to be a beach type deposit. However, it was noted that many sands had grain size ranges distinctive of sand much farther offshore, to as deep as 100 feet (30 m). Many features such as ripple cross lamination, oscillation ripples and burrows were considered to be indicative of shallow water, but it was pointed out that they were also known to exist in deep water. An important observation made was the decided absence of distributary channels within the Cardium in the study area.

In 1969, Michaelis and Dixon noted the absence of dune cross beds and dominance of plane beds within the Cardium sandstones. They suggested that the low angle intersections in these sands were caused by periodic planation of beds by the activity of abnormally high currents, possibly storm derived. Subsequent sedimentation then followed the orientation of this planed surface. Trace fauna was interpreted as being indicative of shallow water. From this evidence, a complex of beach, offshore and river environments was suggested for the Cardium. In this system sandstones represented shoaling-upwards, and deepening was represented by siltstones. It was observed that scoured surfaces were much like those formed by turbidity currents.

In an unpublished M.Sc. thesis, McCormack (1972) studied both outcrop and subsurface data. His interpretations, with respect to environment, were based primarily upon those of Stott (1963). A very detailed environment of deposition was worked out with a subdivision of environments into lagoon, off beach, backshore, upper and lower foreshore and outer neritic. A lagoonal environment was determined by the presence of organic matter and a landward sandstone pinchout. The offbeach was considered to be represented by the interbedding of sandstones and shales, wavy bedding, grain size and sorting, ripple surfaces, burrow parallelling bedding and a "strong burrowing effect".

Landward dipping cross laminations were thought to be indicative of small "backshore deltas" or upper foreshore ridges. Conglomerates were believed to have been deposited in the surf zone of the foreshore with the shale matrix being deposited after the pebbles. Following this the entire deposit was mixed, without the clays being winnowed out. Conglomerate distribution was thought to be the result of a rapid transgression. McCormack (1972) proposed that the bioturbated sandstones were biogenically reworked foreshore sediment with a possibility that the bioturbation post-dated rather than accompanied deposition of the sand. Some "plano-convex" crossbeds having "bimodal dips" were observed by McCormack (1972) and he proposed that these were submerged bars or sand waves of the lower foreshore. "Clay chips" were thought to have been washed on shore by storms. A feature having a "shallow 'V' cross section" with scattered pebbles on its surface was interpreted as being a tidal channel with the pebbles indicative of high flow velocities. Siltstones were considered to have been deposited in the outer neritic environment below wave base. Grain size was used to determine this interpretation. These interpretations were based upon many features previously noted by Stott (1963), as well as comparisons to alternative environments. However, the alternatives seldom include the many possibilities cited in the literature.

A subsurface study for the Carrot Creek Field was done by Swagor in 1975 for his M.Sc. thesis. In this he stressed the significant role that storms played in the deposition of the Cardium. The turbidity current model was discounted on the basis of requiring steeper slopes than would have existed and reverse grading which was seen in the Carrot Creek Field was not thought to be present in turbidity current deposits. It was noted, however, that Davies and Walker (1974) had reported some occurrences of reverse graded turbidity current deposits. The beach model was also rejected because there was no westward land deposits or evidence of river activity. Other features not suitable to a beach model included: the unsorted nature of the conglomerates, reverse graded bedding, inclined pebble discs and a coarsening upward sequence. Swagor preferred to postulate an atypical offshore bar in a sea which was too shallow for significant tidal influence. Fluctuating current energy was to be responsible for forming the different facies. He felt that a significant amount of sand and gravel was deposited by the action of either wind generated storm waves or storm surge. The coarsening upward sequence was indicative of gaining storm strength and the overlying shales represented waning flow.

The Cardium Controversy

From this historical review it can be seen that there are two extreme end member interpretations for the Cardium, with degrees of variation between. Most adhere to the nearshore and even river influenced depositional environment end member first proposed in detail by Stott (1956, 1961, 1963). The odd-man out is Beach (1955, 1956) with his elaborate earthquake generated tsunami-turbidity current model forming the extreme opposite end member.

Stott (1956, 1961, 1963) and Nielson (1957) proposed a fluctuating relative sea level to explain the distribution of sandstone and siltstone units. Michaelis (1957) and Michaelis and Dixon (1969) incorporated this model with river influence along the coastline. McCormack (1972) elaborated upon the ideas of Stott (1956, 1961, 1963), adding detail but leaving the basic premise unchanged. The most recent work was by Swagor (1975) who took many features which had been interpreted as nearshore indicators and reinterpreted them, along with other supporting evidence, as distinctive of a shoreline-detached offshore bar. By proposing shoreline-detached, deeper water sedimentation Swagor (1975) has made an environmental interpretation of the Cardium which is closer to the end member model of Beach (1955, 1956). However, the process by which sediment is deposited is quite different.

It is my intent to develop and extend some of the basic concepts of Swagor (1975) in proposing a shoreline-detached, storm dominated model of deposition for the Cardium Formation in the study area. Deposition, rather than being related to an offshore bar, will be propsed to have been the result of storm-surge-generated density currents. This model is one step closer to the Beach (1955, 1956) end member, as indicated both by an absence of shoreline facies and by turbidity current transport of sediment into an offshore, deeper water environment. Sediment transport by turbulent sediment-laden density flow is by definition a turbidity current. However, because in this situation the sediment is reworked by storm waves, the resultant deposit does not resemble a "classical" turbidite and care must be taken not to confuse Cardium storm deposits with classical turbidites and related facies (Mutti and Ricci Lucchi, 1972; Walker, 1978). It must also be noted that the mode of generation of these turbidity currents varies quite appreciably from the model proposed by Beach (1956).

CHAPTER 3

LOCAL STRUCTURAL GEOLOGY

The structural geology of the Seebe area is illustrated on the map of Figure 2. In this area low angle thrust faults trending northwest-southeast are intersected by subparallel normal faults, having dips between 55° and 90° (Plate 1). Both fault types show very small displacements.

The major thrust sheets of the Front Ranges lie to the west and are not involved in the thrusting of this area. Both outcrops studied lie on the same folded thrust sheet which is one of the Foothills multiple thrust sheet imbricates. The thrusts of Figure 2 are smaller imbricate thrusts within this same thrust sheet, having displacements in the order of metres to a few tens of metres. Displacement along these thrusts is small enough that the pattern of folding is not greatly disturbed.

Some estimates of vertical displacement along the normal faults were made in the field. Displacement along N_1 is 1 to 2 m, N_2 is about 2.5 m, N_3 is about 2 m, N_5 is almost 3 m, and N_6 is 4 m (Plate 2). Fault N_4 poses a problem because there are no markers available to estimate displacement. There is a block of siltstone which lies in the plane of this fault and appears to be either a stratification or cleavage which parallels the fault plane. Because

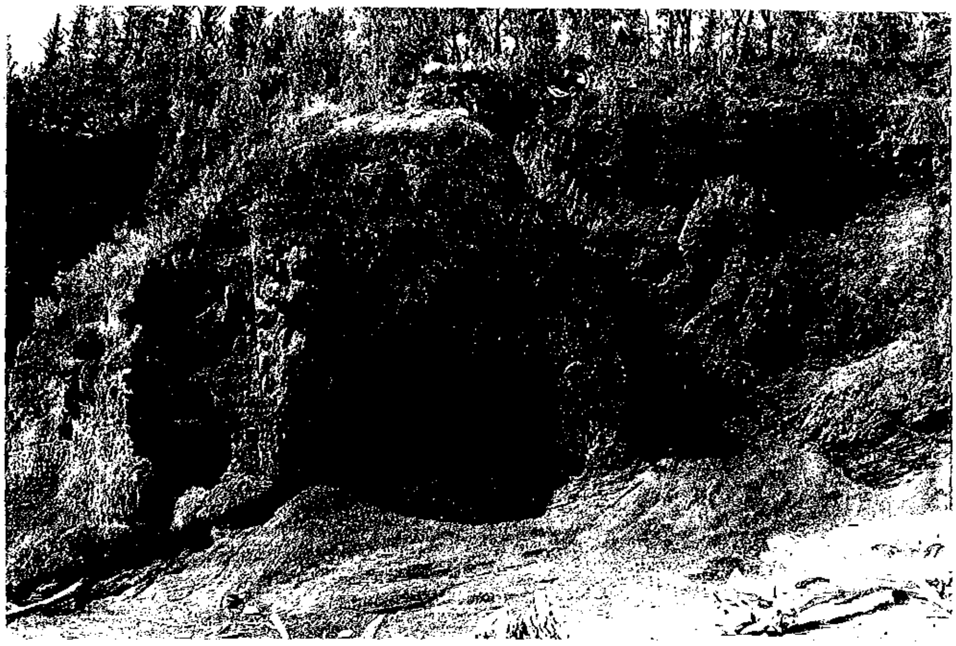

Plate 1: Fault N_s intersecting T_2 at Seebe.

Plate 2: Displacement along N_6 of the β surface at Seebe. The arrows indicate equivalent top surfaces.

of its inaccessible position in the cliff it could not be determined if this block had been rotated, indicating perhaps more than a few metres movement, or if a cleavage developed due to small motions along the fault. N_4 seemed to crosscut T_3 with no apparent displacement of the thrust. The relationship between these two faults is uncertain. It is not known if N_4 intersected T_2 or not, because the normal fault was lost in float blocks near the river.

During the Paleogene and Late Cretaceous, uplift and thrusting due to compression in the west was active in the eastern Cordillera (Monger and Price, 1979). This compressional system would be the cause of the thrust faults which cut the Seebe outcrop. Muecke and Charlesworth (1966) believe that after orogenesis the stress system acting on the Cardium in this area became modified to one of lateral tension. This new stress system is considered by Muecke and Charlesworth (1966) to be the cause of the jointing pattern which developed within the Cardium. It appears likely that this was also the cause of the normal faults seen to intersect the thrust faults in the area.

CHAPTER 4

FACIES AND CYCLE DESCRIPTIONS

Twelve facies have been defined within the Cardium Formation of the study area as a result of work done in the field. Facies definition was based upon grain size, siltstone:sandstone ratios, bed thickness, sedimentary structures and extent of bioturbation.

Positions of facies occurrences in the measured sections are shown in Figures 6, 7 and 8. Faulting of the Seebe outcrop made it necessary to piece together a measured section. Figure 6 illustrates how this was done as well as keying each piece of measured section to its location on the map of Figure 2. Figure 7 is a compilation section for Figure 6. The measured section of Horseshoe Dam is shown in Figure 8. A summary of the petrology is given in Appendix I.

Facies Descriptions

A. Less Bioturbated Shale

The black to dark grey shales of this facies appear well stratified and quite fissile. Bioturbation is low to absent and sideritic concretions are scattered throughout. Up section from the base in each occurrence the colour gradually becomes lighter and the shales appear less fissile and more massive. This corresponds with a coarsening upwards of grain size. Interbeds or lenses of sandstone or

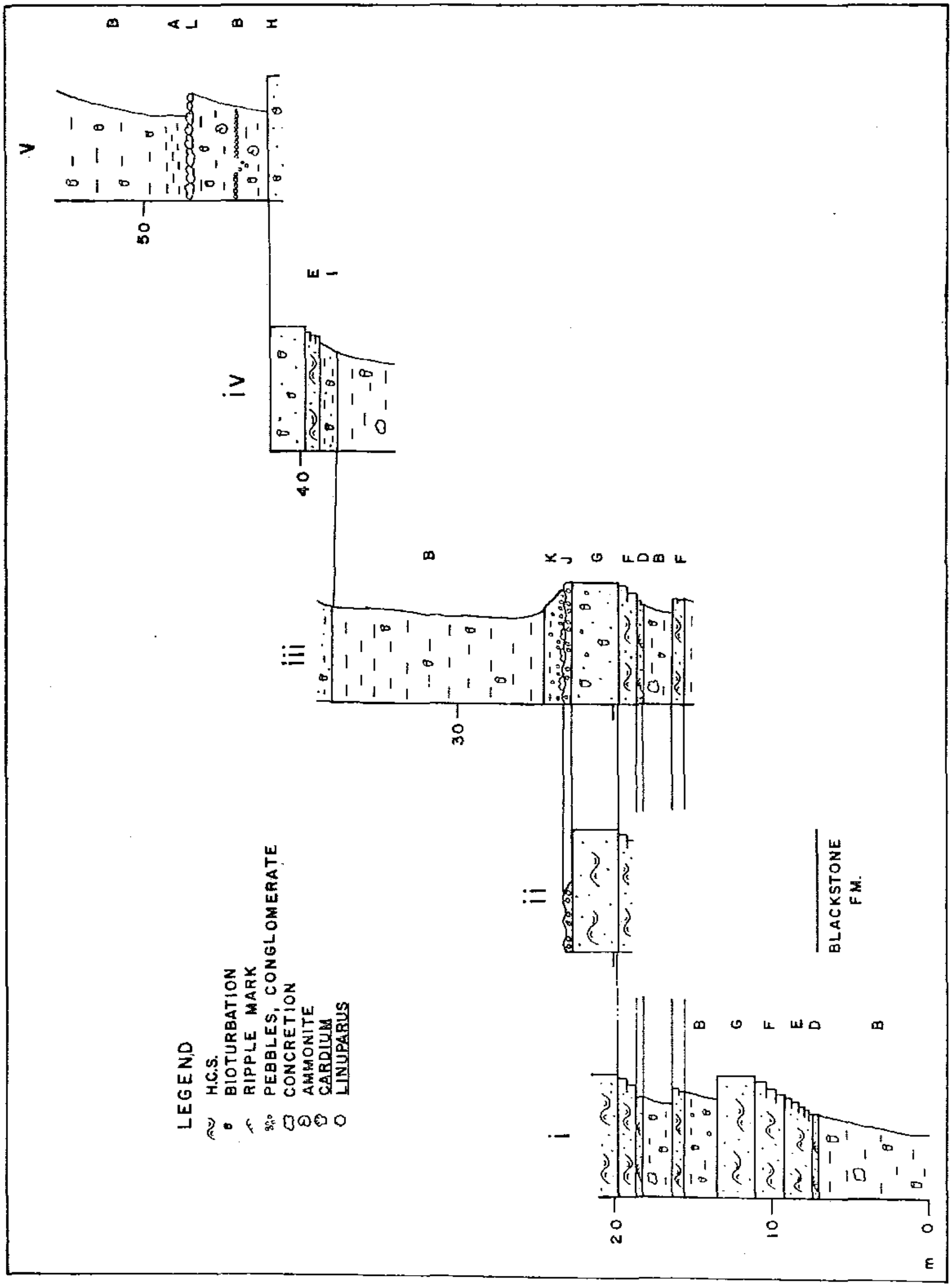

Figure 6. Measured section intervals of the Seebe outcrop. The Roman numerals key the measured interval to its location on the map of Figure 2. The capital letters are facies.

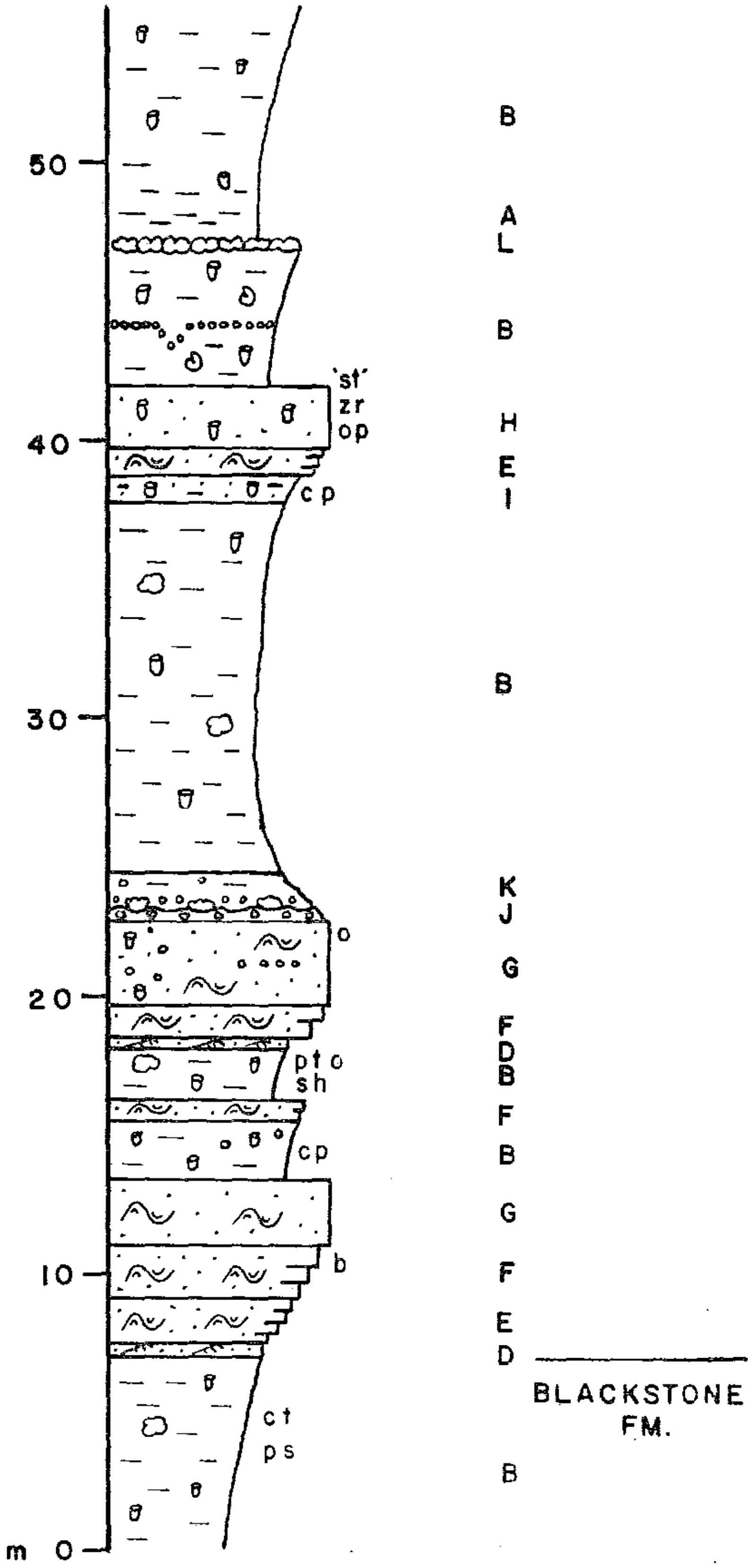

Figure 7. Compiled measured section of the Seebe outcrop.

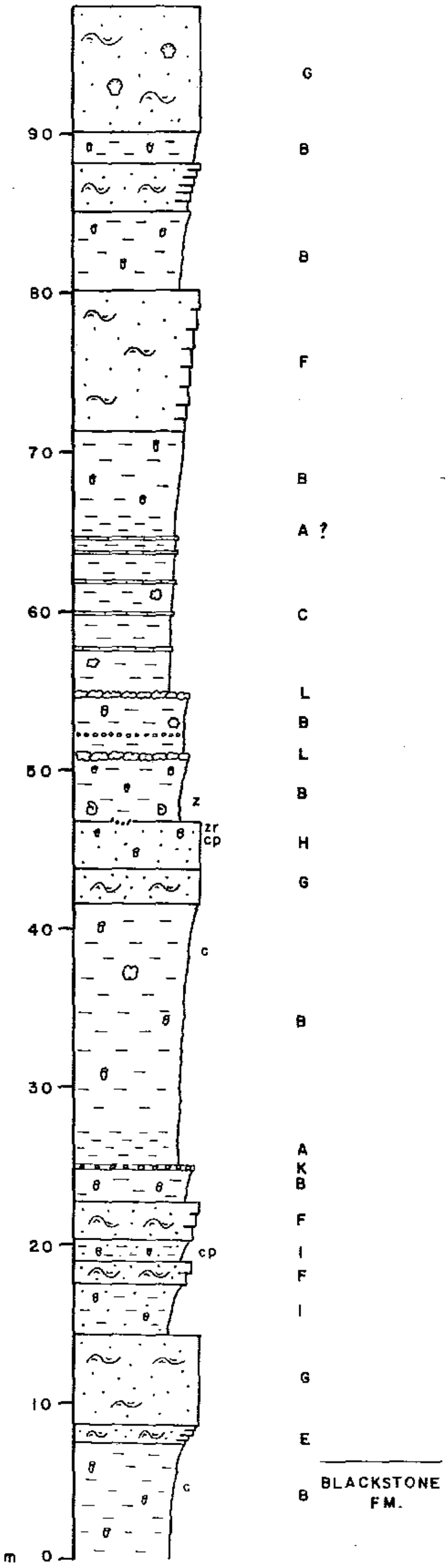

Figure 8. Measured section of the Horseshoe Dam outcrop.

siltstone are absent. This facies is not common, appearing only once at Seebe (45.7 m - 55.5 m) and twice at Horseshoe Dam (25.1 m - 34.1 m and 64.7 m - 66.0 m).

B. Bioturbated Siltstone

Bioturbation dominates the dark grey siltstones of this facies. This is a very common facies, occurring four times at Seebe and eight times at Horseshoe Dam (see Figures 7 and 8 for positions within the section). These siltstones weather to a rubbly or massive appearance, becoming more massive and coarser grained upward (Plate 3). Scattered sideritic concretions and iron staining are common throughout the facies. Sandstone ribs and lenses are common but not always present. When they occur, the sandstone ribs usually increase in thickness and frequency upward, having an average thickness ranging from 1.0 up to 8.0 cm. The alternating siltstone thickness usually varies within a range from 20.0 cm to 5.0 cm, with a silt:sand ratio of 5.7 decreasing upward to 4. The sandstone ribs are sharp based and often seem to undulate or may have symmetrical ripples on their top surfaces. Usually there is little preservation of sedimentary structures but a few ribs have low angle intersections of laminae preserved within them. Some of the sandstone lenses may have either good graded bedding or parallel laminations but usually they are featureless. Occurrences of this facies often grade upward into interbedded sandstone facies.

Scattered chert pebbles or continuous pebble horizons occur within the Bioturbated Siltstone Facies at 45.0 m at Seebe and 50.4 m at Horseshoe Dam (Plate 4). Pebble diameters average between 2 and

Plate 3: Bioturbated Siltstone Facies (lower arrow) overlain by Concretionary Conglomerate Facies (upper arrow) (Seebe, 40.9 - 45.7 m). Lower arrow indicates position of pebble layer of Plate 4. (Photo courtesy of Dr. R.G. Walker.)

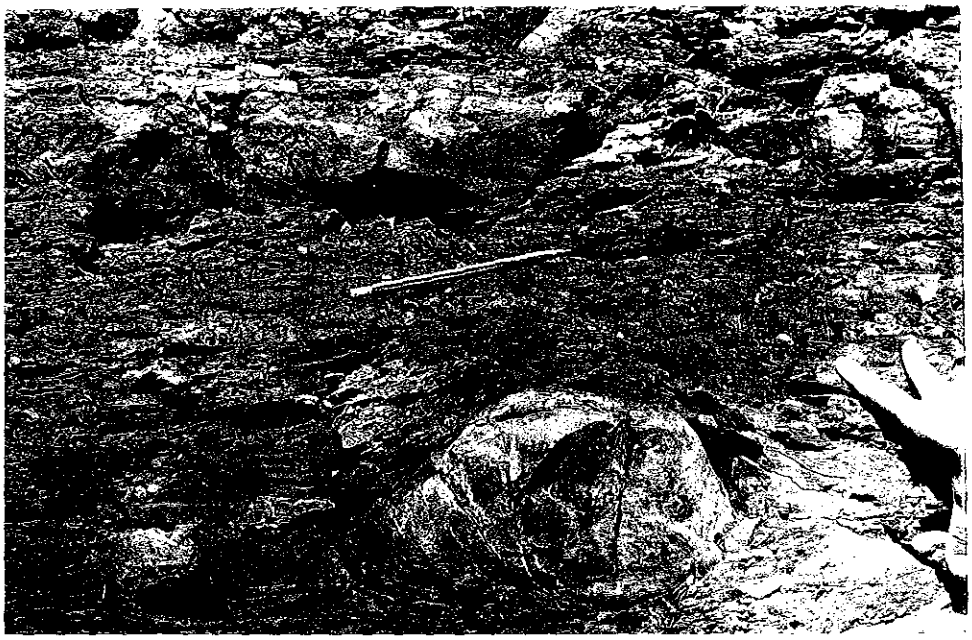

Plate 4: The pebble layer within the Bioturbated Siltstone Facies (Seebe, within 40.9 - 45.7 m) is parallel to the pen. The fingers indicate pebbles which have been dispersed downward by bioturbators.

10 mm, with the horizons being one to two pebbles total thickness. Localized downwards dispersal of these pebbles appears to have resulted from the activities of bioturbators.

Fauna includes ammonites (Scaphites sp., Acanthoceras sp.?) within the interval 40.9 m to 45.7 m at Seebe and two lobster-like decapods, identified as Linuparus canadensis by Feldmann (pers. comm., 1979), at 53.2 m at Horseshoe Dam. A detailed description follows in the paleontology discussion in Chapter 5. Ichnofauna includes Scolithos, having diameters less than 1.0 cm; Planolites, with diameters usually between 1.0 and 1.5 cm; Teichicnus; Ophiomorpha; Gyrochorte; and some examples in which distinction between Scolithos and Arenicolites was not possible.

C. Ribby Shale

This is a shale facies having very thin, sharp based sandstone ribs within it (Plate 5). The shales are black, well stratified, little bioturbated and have lumpy concretions scattered throughout them. Within an occurrence of this facies these shales coarsen upward, becoming less well stratified and more bioturbated. The sandstone ribs average 1 cm thick and show ripple cross lamination and very little bioturbation. The sharp based sandstone ribs are persistent throughout an occurrence of this facies but tend to decrease in frequency upward. Usually this can be seen by a gradual transition into an overlying occurrence of a Bioturbated Siltstone Facies. Occurrences of this facies are limited to one location at Horseshoe Dam (54.9 m - 64.7 m).

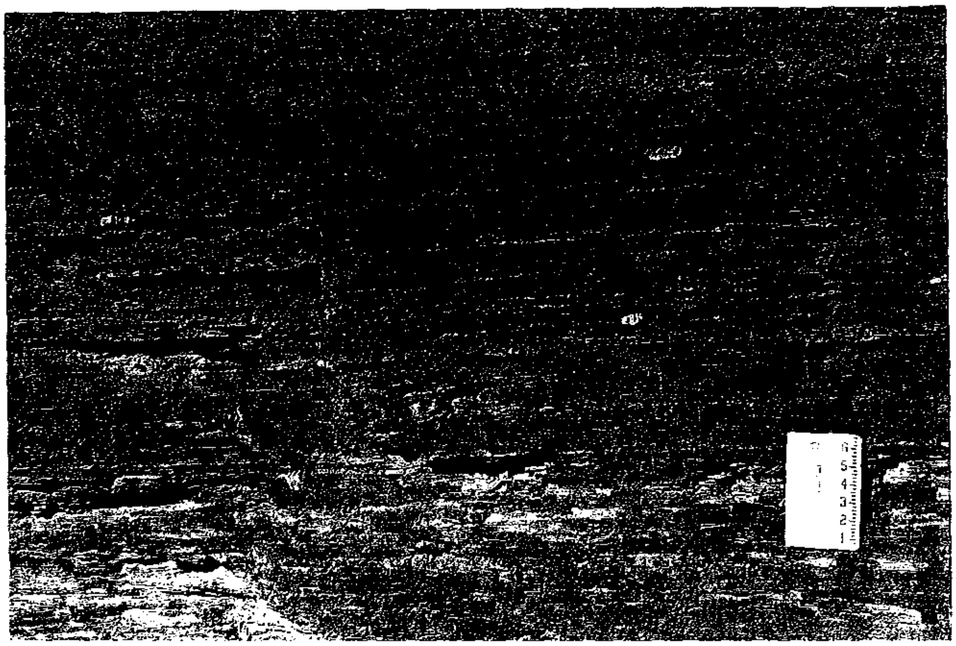

Plate 5: Ribby Shale Facies (Horseshoe Dam, 54.9 m).

Plate 6: Thin Bedded H.C.S. Sandstone Facies (Horseshoe Dam, 8.0 m) with H.C.S. visible in the sandstone beds.

D. Rippled Interbedded Sandstone

Thin sandstones alternate with dark grey, bioturbated siltstones in this facies. The only sedimentary structure recognizable in the sandstones is the common occurrence of symmetrical ripples on their top surfaces. The presence of these ripples and absence of all other structures within the sandstones is distinctive of this facies. Only two occurrences at Seebe (6 m - 7 m and 16.8 m - 18.1 m) make this a relatively uncommon facies. The siltstones normally dominate, having thicknesses between 5 and 20 cm, giving an average siltstone:sandstone ratio of about 2.5. However this ratio can vary anywhere between 20 and 0.5. Both upper and lower contacts are quite gradational. Sideritic concretions and iron staining often occur throughout the siltstones. Ichnofauna recognized within these siltstones includes very high density Chondrites with Planolites, Teichichnus, Cyindrichnus, and Gyrochorte.

E. Thin Bedded H.C.S. Sandstone

Both outcrops have occurrences of thin hummocky cross stratified sandstones interbedded with thicker siltstones (Plate 6). The sandstone beds are light grey, weathering almost white with some iron staining. These beds have average thicknesses between 5 and 20 cm and increase in thickness upward through any one occurrence of the facies. The sandstone beds are sharp based and some have graded tops. Usually, H.C.S. is well to poorly developed throughout, with no parallel lamination at the base; the H.C.S. is manifest in some beds by low angle curved intersections of laminae. H.C.S. wavelengths are normally a little under 2 m, with amplitudes averaging about 0.1 m. At times these sandstones may be undulating, have localized bioturbation and top surfaces may display symmetrical ripples. Grain size averages 0.06 to 0.1 mm with an overall coarsening upward within any one occurrence of the facies. Tool marks were observed by Walker (pers. comm., 1979) on some pieces of float at Horseshoe Dam but none was observed in place. A trace fossil appearing like a beaded trail was found on the top surface of one sandstone bed but the trace has not been identified (see Plate 28 in Chapter 5).

Dark grey siltstones are interbedded with the sandstones giving a siltstone:sandstone ratio averaging about 2 at the basal contact of any one occurrence of the facies and decreasing to 1 near the upper contact. The siltstones are normally thoroughly bioturbated but occasionally some may show good planar lamination. Sand lenses a few centimetres long occur in these siltstones but are much less common than the continuous sandstone beds.

F. Thick Bedded H.C.S. Sandstone

The Thick Bedded H.C.S. Sandstone Facies is similar to the thin bedded version and is often found overlying the thin bedded facies. When this occurs there is a very gradual transition between them. The Thick Bedded Facies may, in turn, grade upwards into an Amalgamated H.C.S. Sandstone Facies. The Thick Bedded H.C.S. Sandstone Facies may also occur between shale or siltstone facies and have no relationship to any other sandstone facies.

Sharp based sandstones dominate the alternating bioturbated siltstones, having a siltstone:sandstone ratio of 0.5 or less. The siltstones may have good planar stratification but generally are well bioturbated. Sand lenses are not uncommon within these siltstones. Each sandstone bed is usually in the order of 20 to 60 cm thick. When an occurrence of this facies is transitional to other sandstone facies the siltstone:sandstone ratio decreases and the sandstone thickness increases upward within the occurrence. H.C.S. is usually well developed within the sandstone beds but local bioturbation may leave only remnants of the structure in isolated locations. However, overall, bioturbation of the sandstones is not particularly common. When bioturbation is present the top surfaces of the sandstones are irregular and pitted. When bioturbation is absent there are often symmetrical ripples on these top surfaces. In one location, at 19.5 m at Seebe, there are current ripples preserved. In a few other instances these top surfaces are graded (Plate 7). The average grain size is usually between 0.1 and 0.15 mm, with an overall upward coarsening when this facies occurs gradationally below and Amalgamated H.C.S. Sandstone Facies.

G. Amalgamated H.C.S. Sandstone

Amalgamated H.C.S. Sandstone Facies are considered to be those occurrences of hummocky cross stratified sandstones which have no siltstone interbeds (Plate 8). This facies is quite massive, appearing as one of the most resistant within the Cardium Formation of the sections studied. Occurrences of this facies usually have a thickness between 2 and 8 m, with individual sets averaging between 5 and 20 cm thick. H.C.S. is usually well developed, and low angle intersections are fairly

Plate 7: Thick Bedded H.C.S. Sandstone Facies with graded top (Horseshoe Dam, within 71.3 - 80.3 m).

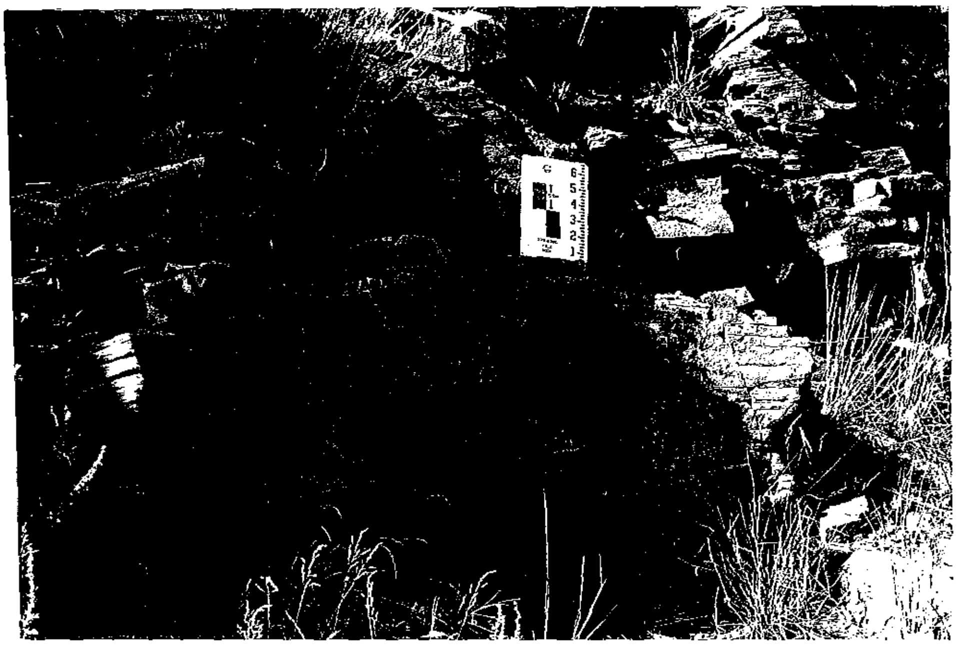

Plate 8: Amalgamated H.C.S. Sandstone Facies (Horseshoe Dam, within 90.3 - 98.1 m).

common (Plate 9, 10). In some instances, sets of H.C.S. sandstone may alternate with bioturbated sandstone intervals, averaging between 5 and 10 cm thick. The upper surfaces of the bioturbated intervals are typically pitted and irregular. The top surfaces of the H.C.S. sets are either well laminated and smooth, undulating, symmetrically rippled (Plate 11) or have Ophiomorpha traces along the bedding plane. Sideritic concretion layers a few centimetres thick may occur on any of these upper surfaces. Rippled surfaces may also occur within H.C.S. sets. Cross beds near angle of repose are very rare, but occur once at 12 m at the Seebe location. Upper contact surfaces sometimes have pebble veneers (Plate 12). Grain size averages 0.1 mm. There are two occurrences at Seebe (11 m - 13 m, 18.1 m - 21.8 m) and two occurrences at Horseshoe Dam (8.4 m - 14.3 m and 90.2 m - 98.1 m).

At Seebe, on the southeast side of the river (section ii, β_2 in Figure 2) within the interval 20.0 m and 21.8 m, there are thin veneers of chert pebbles extending over the top of hummocks and into the swales. These pebbles average 0.5 cm in diameter and the veneers can be traced laterally along the same bedding surface for several metres. Most of these veneers are found in the upper 20 to 30 cm of this interval. At the same stratigraphic level on the northeast side of the river (section iii, β_3 in Figure 2) the sandstone is thoroughly bioturbated with high density Ophiomorpha traces. This structureless sandstone is broken only by pitted parting surfaces. Chert pebbles are found dispersed throughout this sandstone. Because of the common stratigraphic level with the Amalgamated H.C.S. Sandstone across the river and the presence of chert pebbles in both, it is concluded that the bioturbated

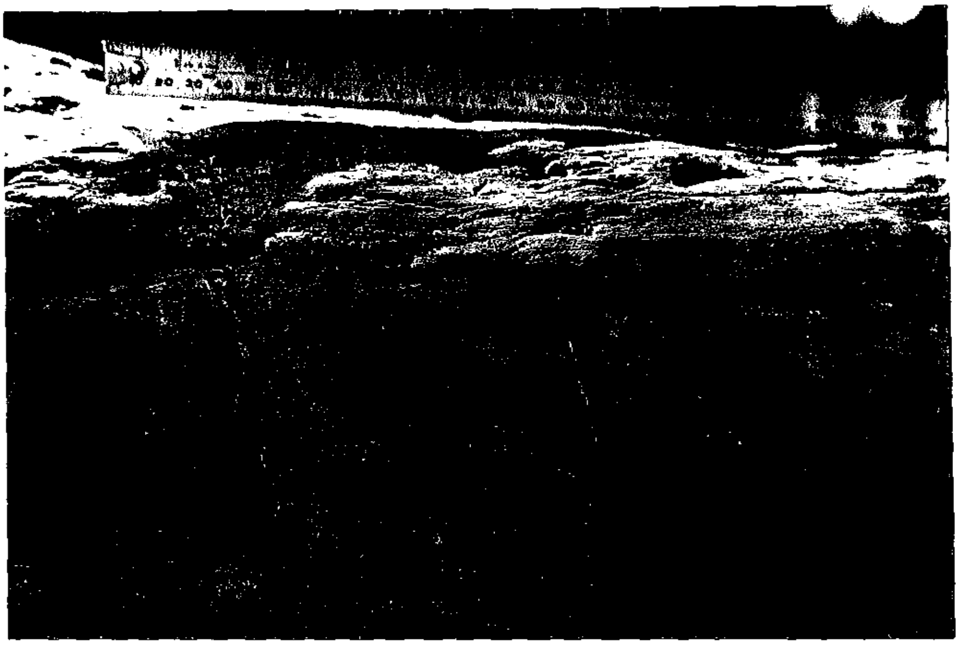

Plate 9: Low angle curved intersections of H.C.S. (Seebe, β_2, 19.6 m).

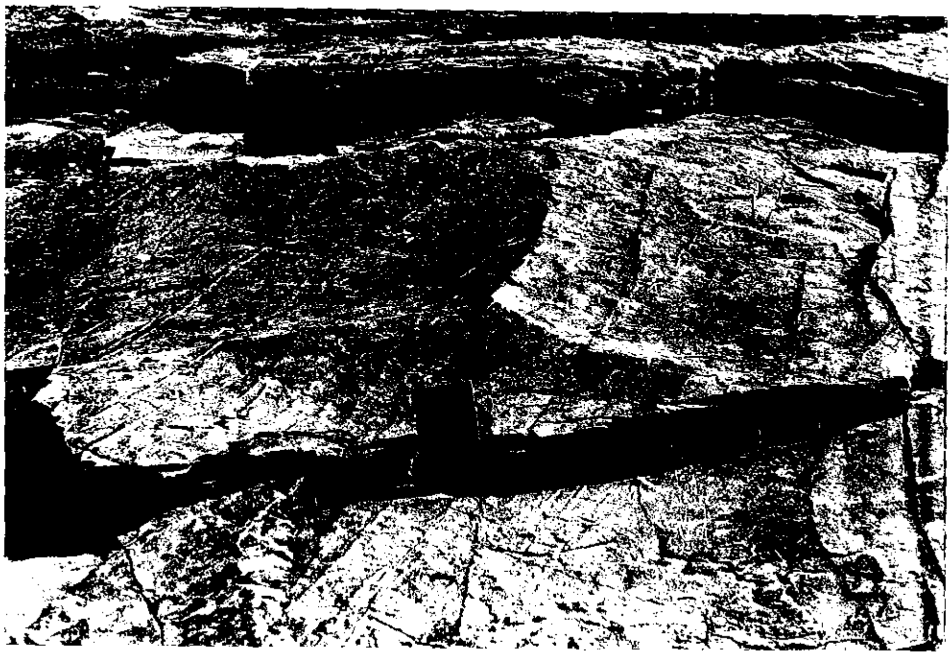

Plate 10: Plan view of the intersection of three shales illustrating how the low angle intersections of Plate 9 are formed (Seebe, β_1, 19.0 m).

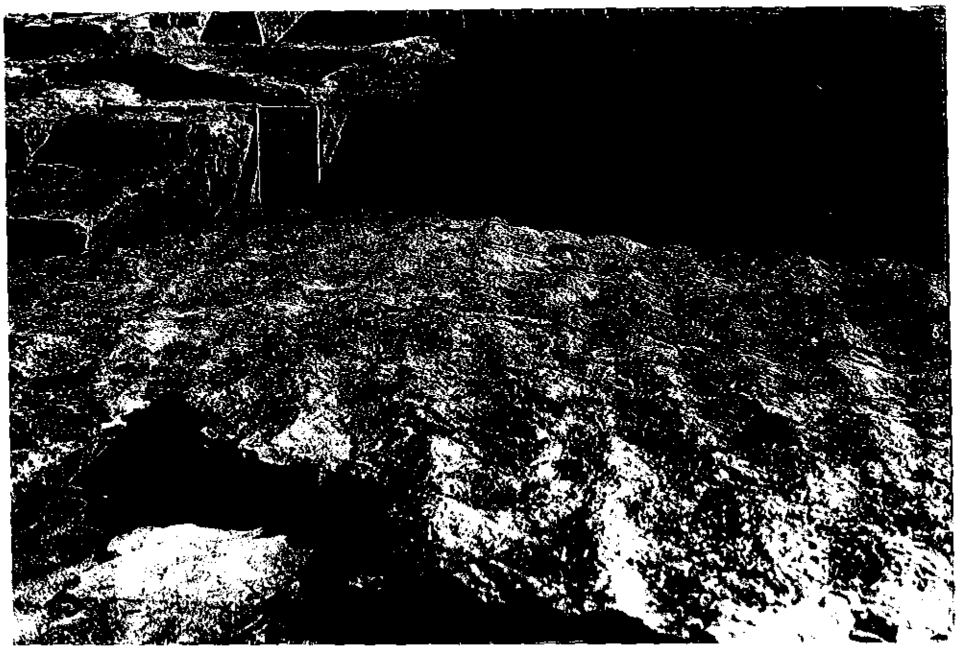

Plate 11: Symmetrical ripples within Amalgamated H.C.S. Sandstone Facies, on the top surface of a set of H.C.S. (Seebe, 22 m).

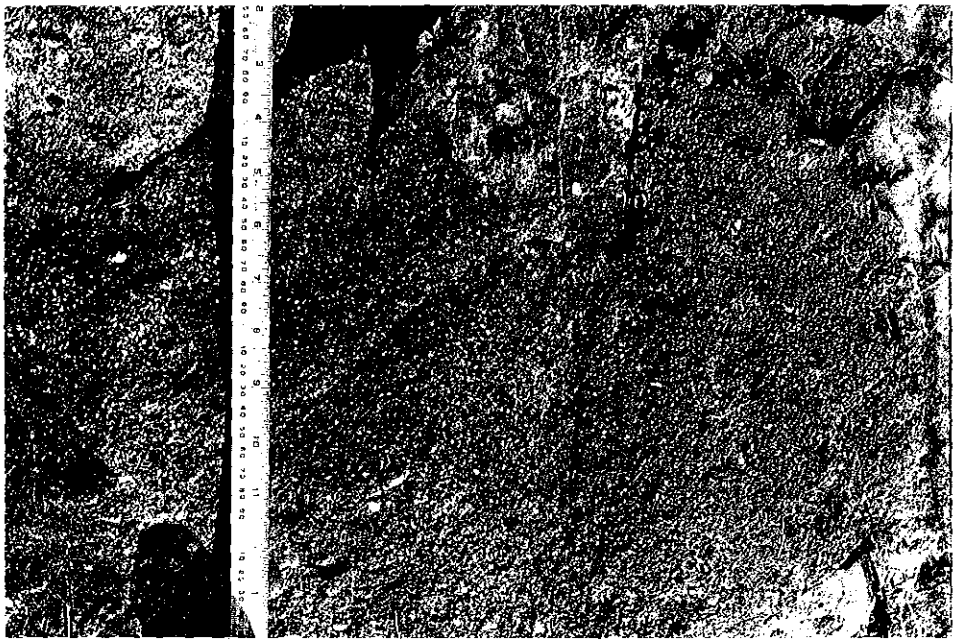

Plate 12: Pebble veneer on the upper surface of a sandstone (Horseshoe Dam, 98.1 m).

sandstone was once hummocky cross stratified and subsequent localized bioturbation destroyed all sedimentary structures and displaced the chert pebbles.

Very small (5 mm) Cardium sp. casts and molds are present within this facies only in the Sturrock equivalent at Horseshoe Dam (90.3 m - 98.1 m). Ichnofauna of this facies, other than the common Ophiomorpha, include vertical Scolithos and the unnamed beaded trail trace fossil.

H. Bioturbated Sandstone

Occurrences of Bioturbated Sandstone Facies form the most massive and one of the most resistant facies within the Cardium, at the outcrops studied. Occurrences of this facies are at Seebe (38.6 m - 40.9 m) and at Horseshoe Dam (41.6 m - 46.9 m). These sandstones are light grey with rust coloured iron staining on their weathered surfaces. Some faint laminations may still be discernable but on the whole the sandstones are quite thoroughly bioturbated showing no sedimentary structures (Plate 13). Concretionary sheets may occur discontinuously along parting planes which in vertical section are generally 20 to 50 cm apart. Lower contacts tend to be gradational while upper contacts are quite sharp. On these top surfaces there may be veneers of pebbles. At Horseshoe Dam (46.8 m) there is a shallow scoured trough on the top surface which is oriented 140° - 320°, and has a veneer of pebbles on its surface.

In the discussion of the Amalgamated H.C.S. Sandstone Facies, evidence was given to show that hummocky cross stratified sediment was bioturbated sufficiently to locally destroy all sedimentary structures. I believe that this example can be extended to occurrences of Bioturbated Sandstone Facies. It is probable that occurrences of this facies were initially hummocky cross stratified but suffered extensive reworking after deposition and the formation of H.C.S.

Fauna present is a bivalve hash at Seebe (40.9 m). Ichnofauna are very well exposed on upper contact surfaces. These include both Rhizocorallium and Zoophycus in very high density as well as Planolites, Ophiomorpha and a trace which, being unnamed, will be referred to as "subway tunnels" (for a description and discussion of this trace see Chapter 5).

I. Bioturbated Silty Sandstone

Massive dark grey silty sandstone with extensive bioturbation is typical of this facies (see Plate 17 in Cycle Descriptions). Usually rocks of this facies appear to be quite homogeneous but on occasion parts of sandstone beds are preserved as laminated sandstone lenses. Preservation of these sandstone beds improves upwards within any one occurrence of the facies, giving the impression that an interbedded sandstone and siltstone facies has suffered thorough bioturbation. Preservation of sedimentary structures within the sandstones is poor. Both upper and lower sandstone contacts tend to be gradational. Rippled surfaces are present but, where exposed, are too weathered to determine their symmetry. Small sideritic concretions are scattered randomly throughout the facies and there is a general upward coarsening within any one occurrence of the facies. Fine sand size quartz grains occur within a large amount of silt size quartz grains and clays.

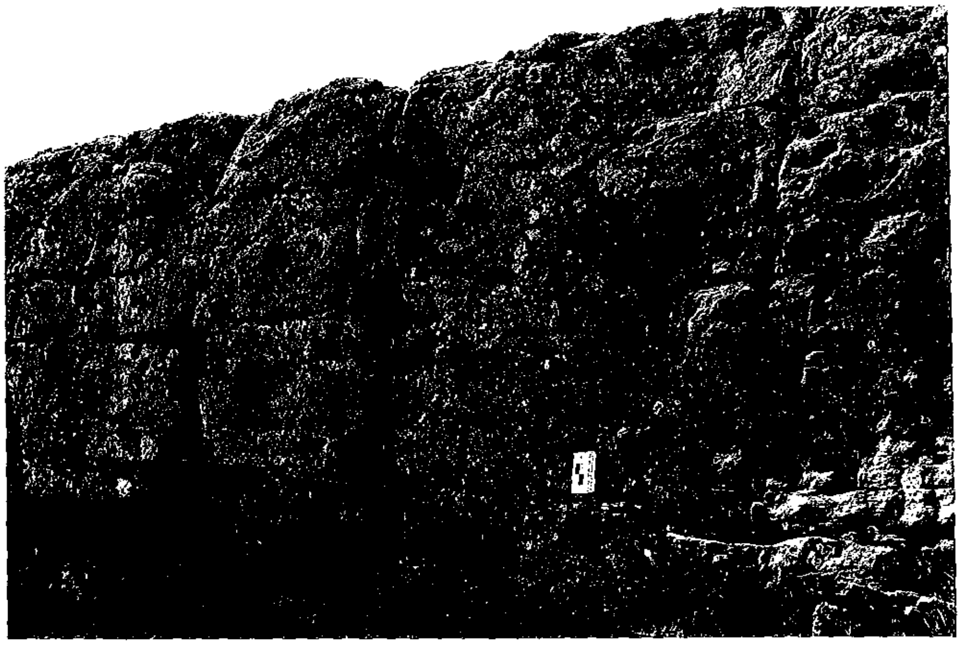

Plate 13: Bioturbated Sandstone Facies (Horseshoe Dam, 41.6 - 46.9 m).

Plate 14: Clast Supported Conglomerate Facies, beside book (Seebe, β_3, 21.8 - 22.1 m).

Recognizable ichnofauna include *Chondrites* and *Planolites*. This is not a common facies, occurring once at Seebe (35.8 m - 37.8 m) and twice at Horseshoe Dam (14.3 m - 17.5 m and 18.9 m - 21.3 m).

J. Clast Supported Conglomerate

This massive well cemented conglomerate occurs only once within the study area, at Seebe (21.8 m - 22.1 m in quartz). However, conglomerates like it are common in the Cardium throughout Alberta (Ainsworth, Duke, Walker, pers. comm., 1979) and are quite distinctive. Because of this, a separate facies has been assigned to this one occurrence.

A lack of sedimentary structures gives this 30 cm thick conglomerate a massive, homogeneous appearance (Plate 14). Weathered surfaces are iron stained and concretions often lie on the sharp upper contact. At β_3 of Figure 2 at the top of measured section iii (22.1 m) this upper surface displays symmetrical gravel waves with dips on both sides of the waves averaging about 14°. Wavelengths average 1 m and trough to crest heights average 7 cm (Plate 15). The crests of these gravel waves tend to strike in a north-south orientation. Figure 9 illustrates the orientations and vector-mean of these. Post depositional sideritic concretions have formed in the wave troughs (Plate 16).

Clasts are mostly well rounded chert pebbles, having an average diameter of 5 mm (range 2 - 20 mm, rarely 50 mm). The clasts are usually in contact with each other, with matrix filling the spaces. The matrix is composed of sand and silt size quart grains and clays. Locally, on the scale of a few centimetres, there is graded bedding but this is not

Plate 15: Symmetrical gravel waves in Clast Supported Conglomerate Facies (Seebe, β_3, 23 m).

Plate 16: Concretions in troughs of gravel waves (Seebe, β_3, 23 m).

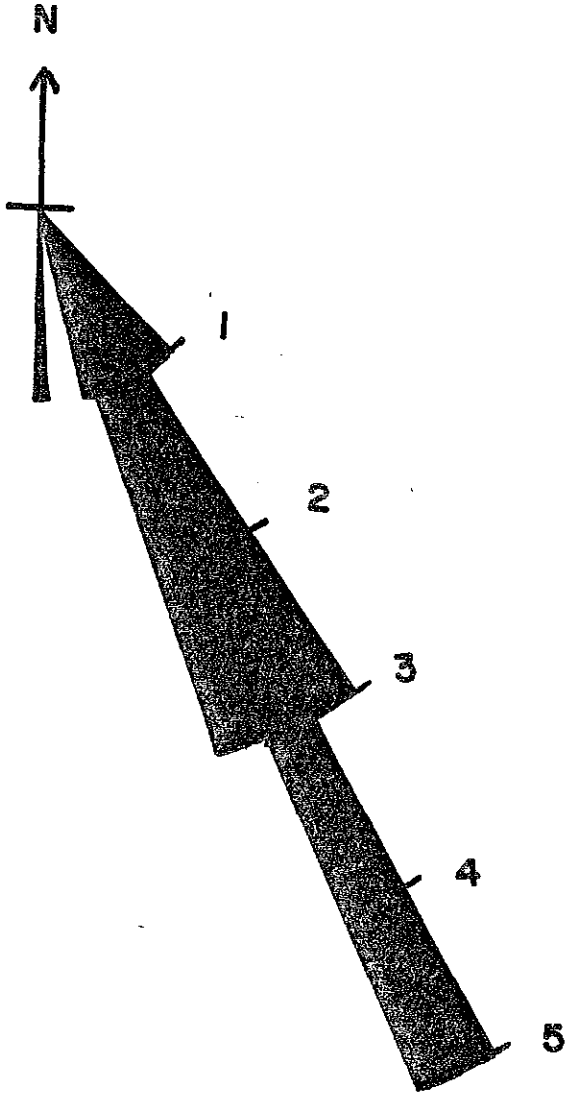

Figure 9. Rose diagram of gravel wave crests.

laterally continuous.

K. Matrix Supported Conglomerate

Seebe (22.1 m - 23.5 m) and Horseshoe Dam 24.8 m - 25.1 m) each have only one occurrence of this facies. Thicknesses are 1.4 m and 0.3 m, respectively. In outcrop the facies has a dark grey, rubbly appearance. Well rounded chert pebbles average 5 mm in diameter (range 2 - 10 mm, rarely up to 50 mm). These clasts are suspended in a very fine grained clay and silt matrix which is friable and poorly cemented (Plate 17). Sedimentary structures are absent. At Seebe the occurrence of this facies gradually grades upward into bioturbated siltstones by a steady decrease in the amount of pebble clasts present. Sideritic concretions occur randomly throughout the conglomerate and enclose chert pebbles within them (see Plate 30 in Chapter 6). The concretions occur as ellipsoid individuals or in very irregular, discontinuous sheets along the bottom contact.

L. Concretionary Conglomerate

This facies occurs once at Seebe (47.5 m) and twice at Horseshoe Dam (51.3 m and 54.9 m) forming a distinctively continuous concretionary layer (see Plate 3). Weathered surfaces are always an iron stained rust colour and stand out quite noticibly from the surrounding black shales and siltstones. The more massive nature and coarse grain size also allows occurrences of this facies to weather in a much less recessive manner than the surrounding shales. Sedimentary structures are absent. The distinguishing feature of this facies is a

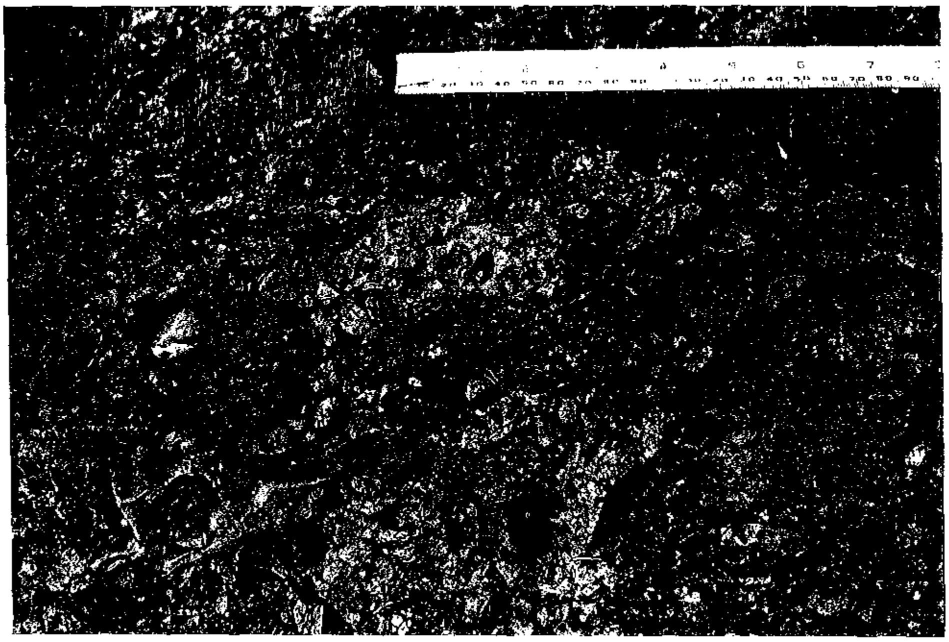

Plate 17: Matrix Supported Conglomerate Facies, plan view (Seebe, 22.5 m).

gritty mixture of silt, sand and chert pebbles which has been entirely enclosed by a laterally continuous sideritic concretionary layer. The whole thickness is seldom greater than 1 m.

Cycle Descriptions

There is a very distinctive development within the Cardium which can be seen by the vertical ordering of facies. The one feature common to all cycles is a coarsening and thickening upward within each cycle. The cycles follow a general pattern which begins with shales or siltstones and passes upward through various thin bedded, then thick bedded sandstone facies with massive sandstone facies above. These massive sandstone facies may or may not be capped by conglomerate facies or pebble veneers. The different cycle types are usually determined by the combination of facies which are present. Many of the facies of the general sequence may be missing.

In the Cardium of South and Central Alberta there exist six different cycle types (Walker, pers. comm., 1979). Data of my own as well as from Ainsworth, Duke and Walker (pers. comm., 1979) have been compiled in Table 1 to outline these cycle types. At Seebe and Horseshoe Dam the cycles present include TYPE 1, 2 and 6. The cycle types and ordering of cycles at the two outcrops is fairly similar. This is illustrated in Figure 10, as well as relating the terminology of Stott (1963) to this pattern of cycles.

Occurrences of TYPE 1 vary little from others in Alberta. Generally they consist of Less Bioturbated Shale Facies and are

Table 1

Cycle Types of the Cardium Formation, Alberta (after Walker, pers. comm., 1979)

Cycle Type	Description	Thickness (m) Mean	Range	# Samples
1	Less Bioturbated Shale Facies, followed by Bioturbated Siltstone Facies, terminated by very gritty Concretionary Conglomerate Facies, no sandstone facies present	7.0	3.6 - 23	10
2	Less Bioturbated Shale Facies overlain by Bioturbated Siltstone Facies, Rippled Interbedded Sandstone Facies or Thin Bedded H.C.S. Facies or Bioturbated Silty Sandstone Facies, Thick Bedded H.C.S. Sandstone Facies, then Amalgamated H.C.S. Facies	20.1	6 - 47	9
3	Thick cycles, Less Bioturbated Facies, followed by Bioturbated Siltstone Facies, then interbedded H.C.S. Sandstone Facies	35.6	21 - 48	5
4	Bioturbated Siltstones followed by interbedded H.C.S. Sandstone Facies then fading away into thinner H.C.S. Sandstone Facies	23.6	12.2 - 35+	2
5	Bioturbated Siltstones followed by interbedded H.C.S. Sandstone Facies then sandstone facies which have been interpreted as being shallower than H.C.S. Facies	30	27 - 30	2
6	As for TYPE 2, with Bioturbated Sandstone Facies in place of Amalgamated H.C.S. Sandstone Facies	19.6	7.8 - 35	12

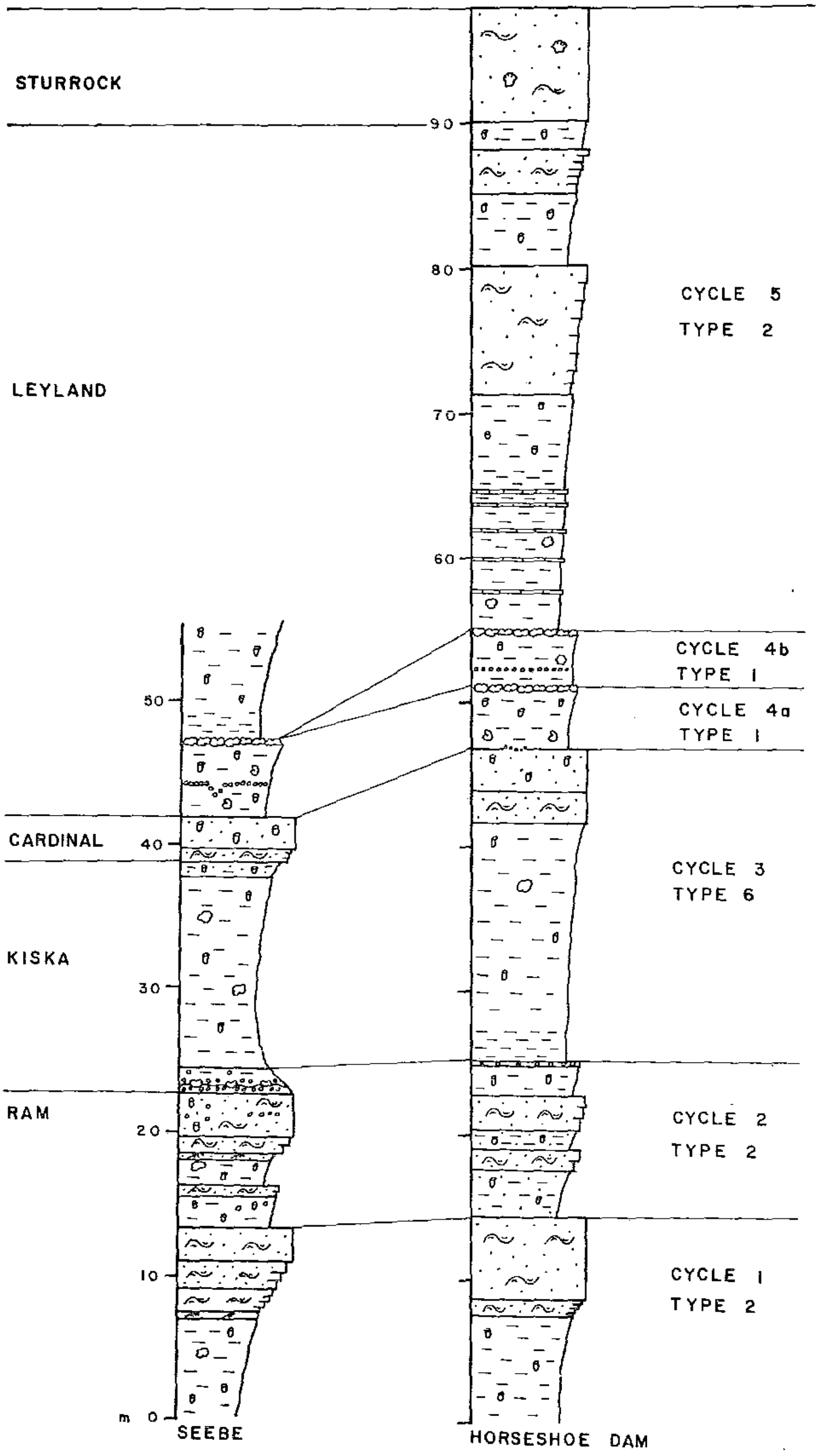

Figure 10. Cycle types and their relative ordering, with a key to the terminology used by Stott (1963).

terminated by sharp based Concretionary Conglomerate Facies. Cycle 4 at Seebe (see Plate 3) and Cycle 4b at Horseshoe Dam (Figure 10) each have a chert pebble horizon within the Bioturbated Siltstone Facies occurrences. Otherwise all three TYPE 1 cycles are quite consistent with the norm.

Cycle TYPE 2 begins with either Less Bioturbated Shale Facies or Bioturbated Siltstone Facies. These coarsen upward through different combinations of the interbedded sandstone and siltstone facies. This is always in such a way that the coarsening and thickening upward pattern is maintained. The interbedded facies are overlain by Amalgamated H.C.S. Sandstone Facies (Plate 18). These may or may not be capped by conglomerate occurrences or pebble veneers. This type of cycle has a great amount of internal variation. The presence of the different interbedded sandstone facies varies for each cycle of this type. At Seebe Cycle 1 of Figure 10 has no pebble veneer or conglomeratic upper termination. The Amalgamated H.C.S. Sandstone Facies occurrence in Cycle 2 at Seebe (Figure 10) is overlain by occurrences of Clast Supported Conglomerate Facies and Matrix Supported Conglomerate Facies, respectively. As the number of pebbles decreases this gradually fades into a Bioturbated Siltstone Facies of the next cyle. At Horseshoe Dam, Cycle 2 of Figure 10 has not developed an Amalgamated H.C.S. Sandstone Facies occurrence, thus appearing to be an incomplete cycle. Cycle 5 at this location is a much more expanded cycle than any others. It begins with an occurrence of Ribby Shale Facies and the cycle is terminated by a pebble veneer.

Plate 18: Cycle TYPE 2, Cycle 1 at Seebe. Note the well developed hummock above the book.

Plate 19: Cycle TYPE 6, Cycle 3 at Seebe. Top arrow = Facies H, middle arrow = Facies E, bottom arrow = Facies I which continues down, out of the picture.

TYPE 6 cycles are very much like TYPE 2 cycles except the former have Bioturbated Sandstone Facies where the latter have Amalgamated H.C.S. Facies (Plate 19). It is possible that these cycle types are actually equivalent, and post-depositional bioturbation has caused alteration of the terminating sandstone facies. At Seebe, Cycle 3 of Figure 10 has no conglomeratic termination. Cycle 3 at Horseshoe Dam (Figure 10) has a top surface pebble veneer within a surface scour.

CHAPTER 5

PALEONTOLOGY

Fauna

A study of the foraminifera within the occurrences of Bioturbated Siltstone Facies of Cycles 3 and 4 of Figure 10 at Seebe was done by myself for a paleontology term project. The text of this project is contained in Appendix 3. The microfaunal assemblage was both numerous as well as diverse. The assemblages were dominated by benthonic agglutinated species, with some calcareous benthonic and pelagic species present. The results are tabulated in Appendix 3, Table 1. A fairly deep water marine environment was indicated, requiring sufficient distance from shore influence for normal salinity and temperature with little turbidity.

Two specimens of the decapod Linuparus canadensis were found in a Bioturbated Siltstone Facies occurrence at Horseshoe Dam (53.2 m) (Plate 20). Identification of these specimens was by R. Feldmann (pers. comm., 1979). The dorsal surface of the thoracic region and part of the cephalic region were preserved. Evidence of appendages was visible but preservation was very poor. The size of the fossil is 8 cm in length and 4 cm in width. It was noted by Feldmann (in press) that "Linuparus canadensis is one of the most widely distributed decapods in Cretaceous rocks in North America". The specimens were found one

Plate 20: Linuparus canadensis; dorsal surface of the thoracic region and part of the cephalic region (Horseshoe Dam, 53.2 m). (Photo courtesy of Dr. R.G. Walker.)

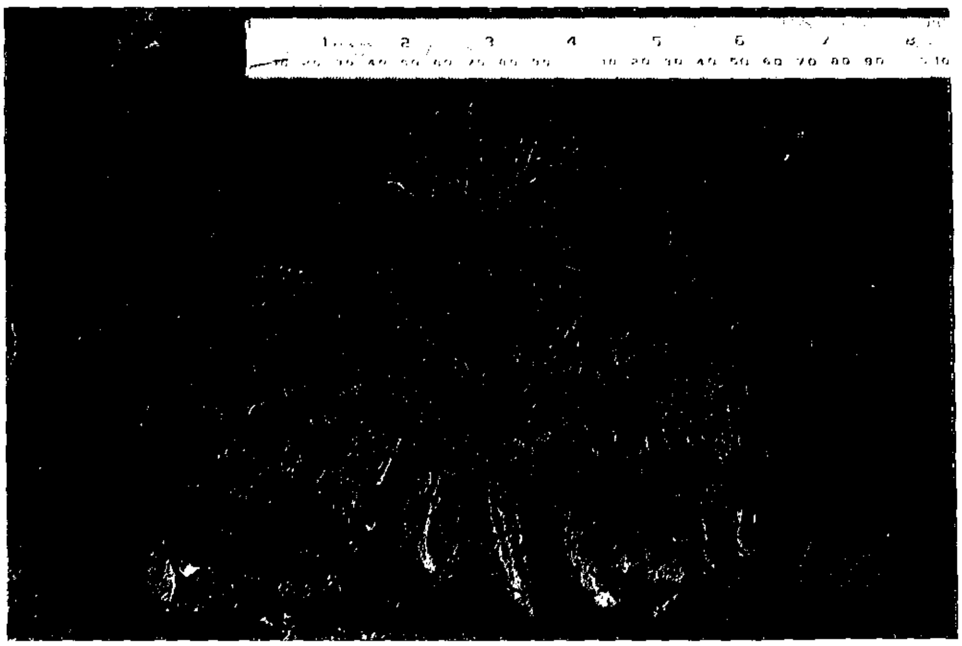

Plate 21: Acanthoceras sp.? (Horseshoe Dam, 47.0 m).

metre above a pebble horizon and both were within the same occurrence of Bioturbated Siltstone Facies. As previously noted, these pebble horizons are on occasion locally dispersed downward, presumably by bioturbators. Dispersal of these pebbles could very easily occur by the activities of so large a bioturbator as L. canadensis. At present too little is known about these decapods to determine if they were found in place or were swept in like the pebbles were (see Discussion, Chapter 6).

Cardium sp. was found only in the uppermost Sturrock sandstone at Horeshoe Dam (90.3 - 98.1 m). These specimens ranged in size from 4 mm to 15 mm and were found preserved as casts or molds along bedding planes.

Ammonites were found within the siltstones either preserved within the rock itself or enclosed by concretions. Two specimens of Scaphites sp. (identified by A. Bullock) were found within concretions at Seebe in or near Cycle 4 of Figure 10. Three samples of another genera, possibly Acanthoceras sp. or a similar genus, are exposed at Horseshoe Dam (47 m) at the base of Cycle 4 (Plate 21). Unfortunately these were so welded into the rock that identifiable samples could not be removed.

Ichnofauna

Zoophycos and horizontal Rhizocorallium are present together in extremely high densities within the Bioturbated Sandstone Facies (Plates 22 and 23). This occurs most notably in the upper part of the Cardinal Member which is underlain by H.C.S. Sandstone Facies. It

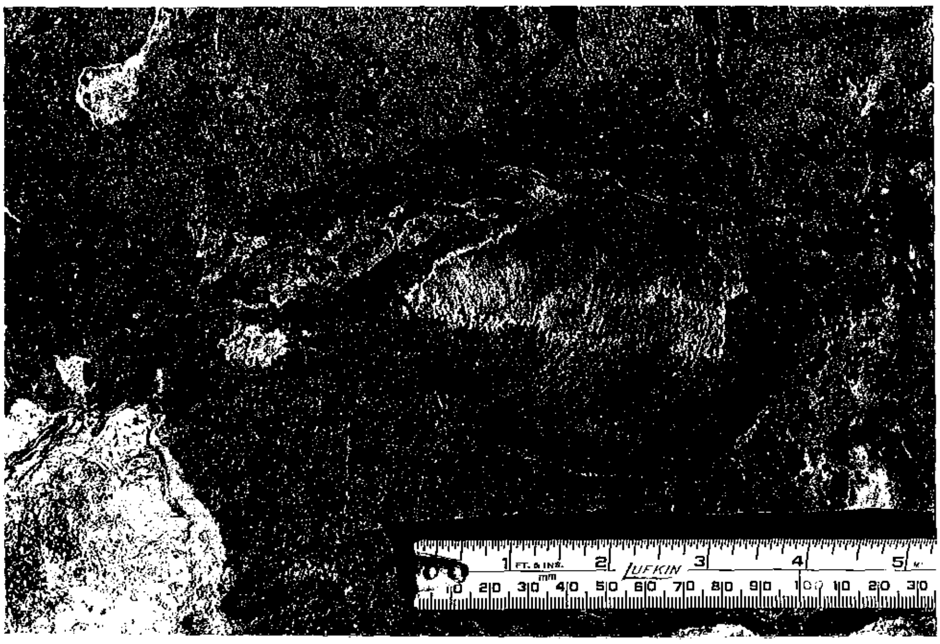

Plate 22: Zoophycos showing well preserved spreite and terminal burrows (Seebe, γ, of Figure 2, 42.0 m). (Photo courtesy of Dr. R.G. Walker.)

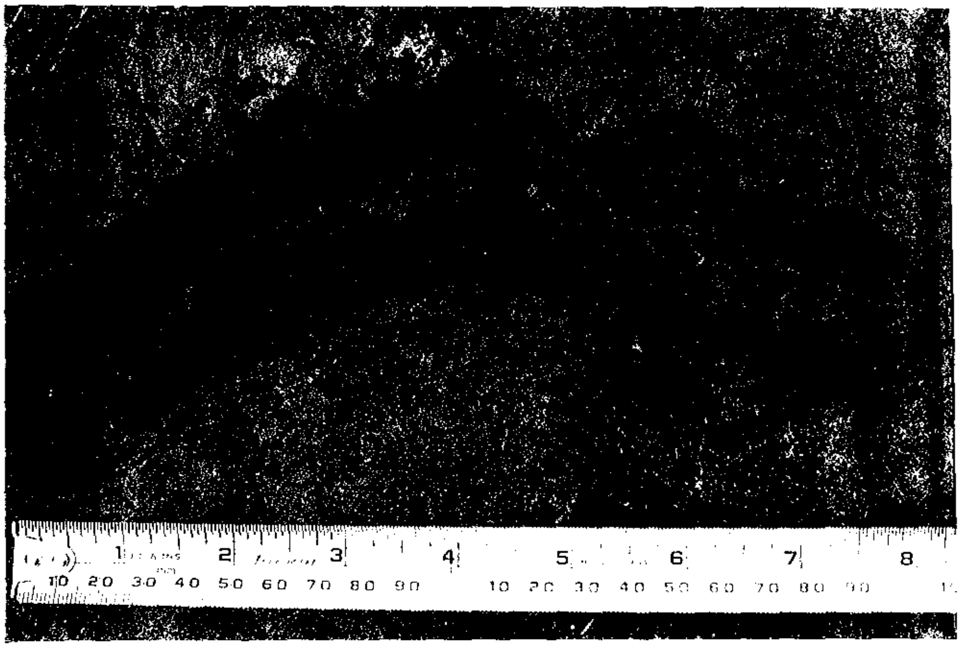

Plate 23: Rhizocorallium (Seebe, γ, of Figure 2, 42.0 m).

is thought that bioturbation by the trace forming organisms occurred by invasion of H.C.S. sediment after deposition, while quiet post-storm conditions prevailed. Evidence supporting this includes the close vertical association that the Bioturbated Sandstone Facies have with H.C.S. Sandstone Facies. The existence of local bioturbation within the upper Ram Member Amalgamated H.C.S. Sandstone Facies occurrence at Seebe (20 m - 21.8 m) also supports the idea of post-depositional invasion by bioturbators.

The occurrence of Zoophycos alone is not environmentally significant because it has been found in deep sea cores (Seilacher, 1967), shallow-water facies (Osgood and Szmuc, 1972) as well as its most common position in the intermediate to off-shore facies, designated the Zoophycos Ichnofacies by Seilacher (1967). Zoophycos is a mining trace distinctive of low energy, little oxygenated, quiet environments (Seilacher, 1967). The presence of this trace within the Zoophycos Ichnofacies reflects the most common occurrence of the organism's optimal environment. In Figure 11 this zone is located within the zone of infrequent mixing (Rhoads, 1975); that volume of water disturbed infrequently by storm waves.

Horizontal rhizocorallid burrows are representative of sediment mining programs and are found to be the farthest off-shore form of rhizocorallid burrow, because nearer shore forms tend increasingly toward the vertical (Seilacher, 1967). Usually horizontal Rhizocorallium is distinctive of the Cruziana Ichnofacies (Seilacher, 1967) (Figure 11).

Because Zoophycos and horizontal Rhizocorallium are present

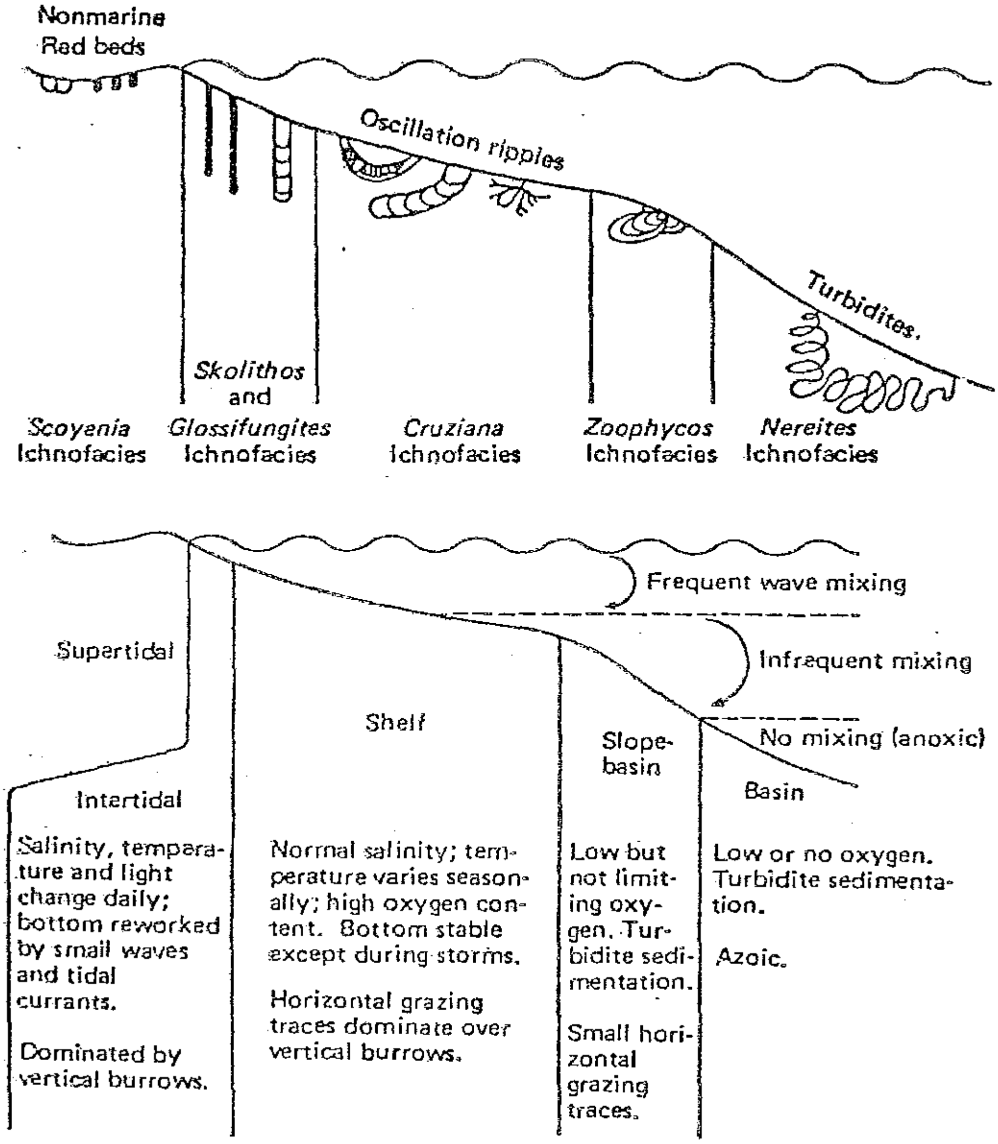

Figure 11. Cross section of geosynclinal shelf and basin showing (top) trace fossil assemblages (after Seilacher, 1967), and (bottom) gradients in imported ecologic parameters (after Rhoads, 1975). From Pemberton (1979).

together within the Cardium, it is apparent that the prevailing environmental conditions during deposition of Bioturbated Sandstone Facies can be represented by the interface between the Cruziana and Zoophycos Ichnofacies. These two traces occur most commonly within their respective ichnofacies (especially Rhizocorallium) and it is unlikely that they will be found together in any other environment. This places deposition of the invaded sandstones below fairweather wave base and to the shallow side of turbidite deposition (Figure 11). This is exactly the environment where H.C.S. is expected to be formed and preserved. The close vertical association of the Bioturbated Sandstone Facies with H.C.S. Sandstone Facies emphasizes this point. Hence, the Zoophycos-Rhizocorallium pair found in Bioturbated Sandstone Facies which overlie H.C.S. Sandstone Facies supports the off-shore deposition of H.C.S. Sandstone Facies followed by invasion by quiet water bioturbators.

The Bioturbated Siltstone Facies commonly contains traces of very high density Chondrites which were often accompanied by any of: Planolites, Teichichnus (Plate 24), Scolithos and possible Arenicolites. Pemberton (1979) has stated that "Chondrites is known to be a facies crossing form and is thus not restricted to any one environment". Because of this lack of restriction the presence of Chondrites and its accompanying assemblages has no environmental significance.

Ophiomorpha and the various species of Callianassa which are believed to form this trace have been reported from a variety of environments (Kern and Warme, 1974; Schnitt, 1921; Biffar, 1971;

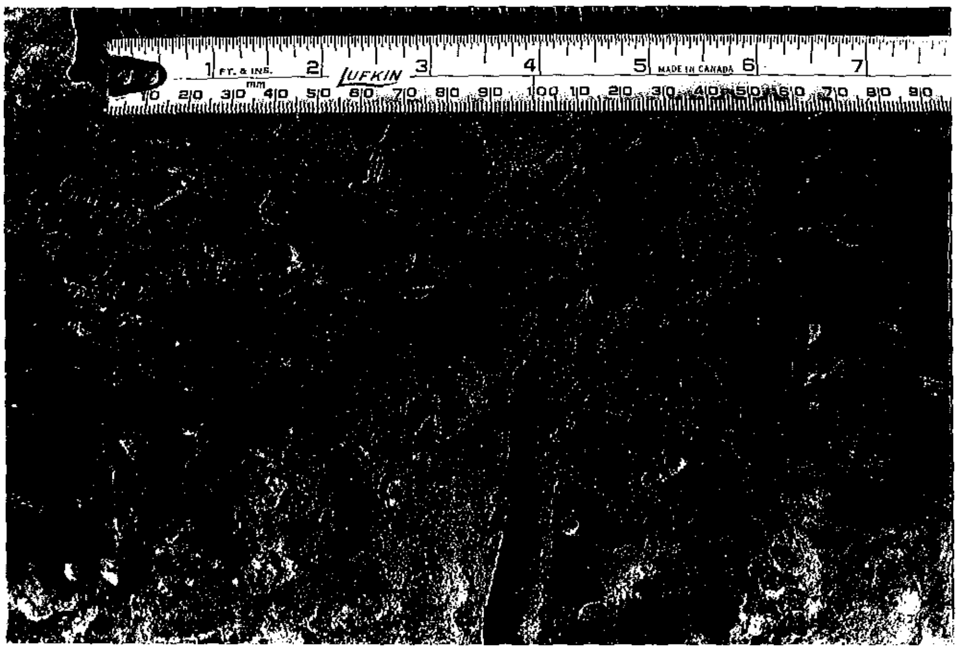

Plate 24: Teichichnus (Seebe, 17.0 m).

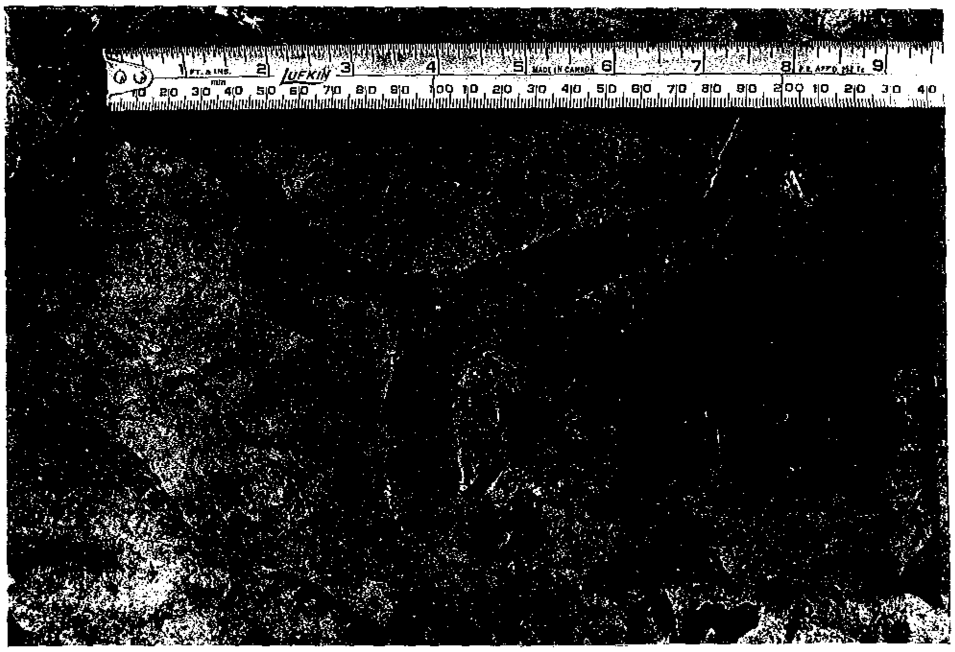

Plate 25: Ophiomorpha (Seebe, γ, of Figure 2, 42.0 m).

Frey et al., 1978; Pemberton, 1976; Stewart, 1978). What was once considered to be a shallow water shoreface indicator now has no environmental or depth significance. Hence occurrences of Ophiomorpha (Plate 25) within the Cardium, most notably in the Amalgamated H.C.S. Facies occurrences forming the Ram Member, are now considered to have no environmental implications.

A trace referred to as "subway tunnels" has been mentioned in the Facies Descriptions. These can be seen either on top surfaces or exposed bedding planes in occurrences of Bioturbated Sandstone Facies, most notably in the Cardinal Member (locations γ_2 and γ_3 of Figure 2). The traces are elongate depressions in the exposed surface of the sandstone, which may on occasion penetrate the rock to form a shallow tunnel. The depressions are usually 7 cm wide and up to about 5 cm deep, with a length ranging from a few tens of centimetres to a metre or so (Plate 26). Smaller cave-like hollows are rarely seen in the side walls of these depressions (Plate 27).

Before the L. canadensis specimens were found, Pemberton (pers. comm., 1979), a trace fossil authority, speculated that an organism like a "mud crab" could possibly have made such a trace. The L. canadensis specimens appear to be of a size to have made these burrows and Feldmann(pers. comm., 1979) agrees that this decapod could be responsible for these burrows. However, no body fossil has been found in direct association with these traces. The decapod specimens overlie the traces by some 6 m. Hence evidence is not conclusive enough to determine what organism formed the "subway tunnels" but it is a very good possibility that L. canadensis is the responsible

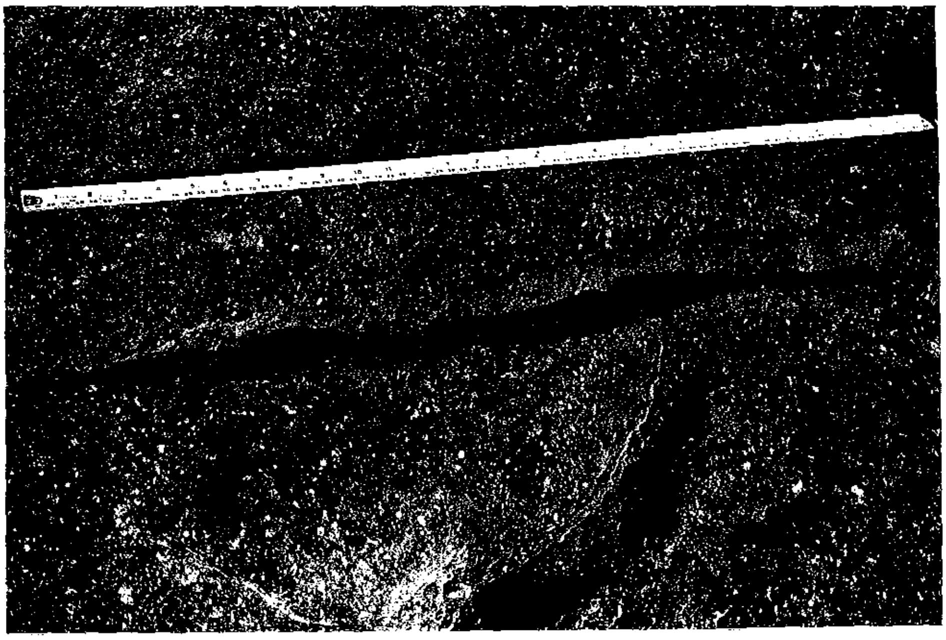

Plate 26: "Subway tunnel" (Seebe, γ of Figure 2, 42.0 m).

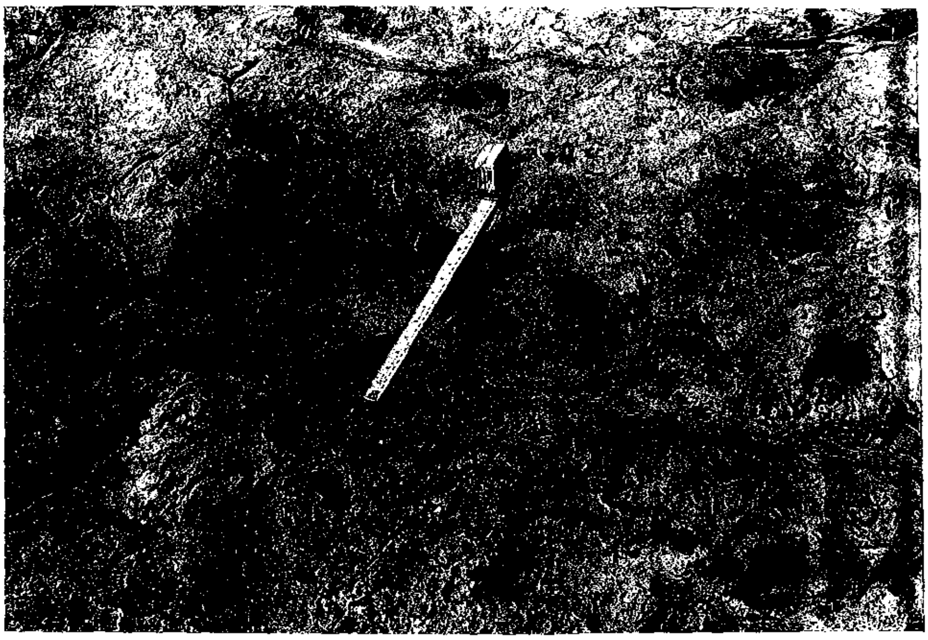

Plate 27: "Subway tunnel" with small hollows in the side wall. (Seebe, γ_2 of Figure 2, 42.0 m). (Photo courtesy of Dr. R.G. Walker.)

bioturbator.

Plate 28 is a photograph of the beaded trail trace which was mentioned in the Facies Descriptions. Each bead in the trail is a few millimetres in diameter and the trails seldom exceed a few tens of centimetres in length. They occur in sandstone but only rarely and have not, as of yet, been identified.

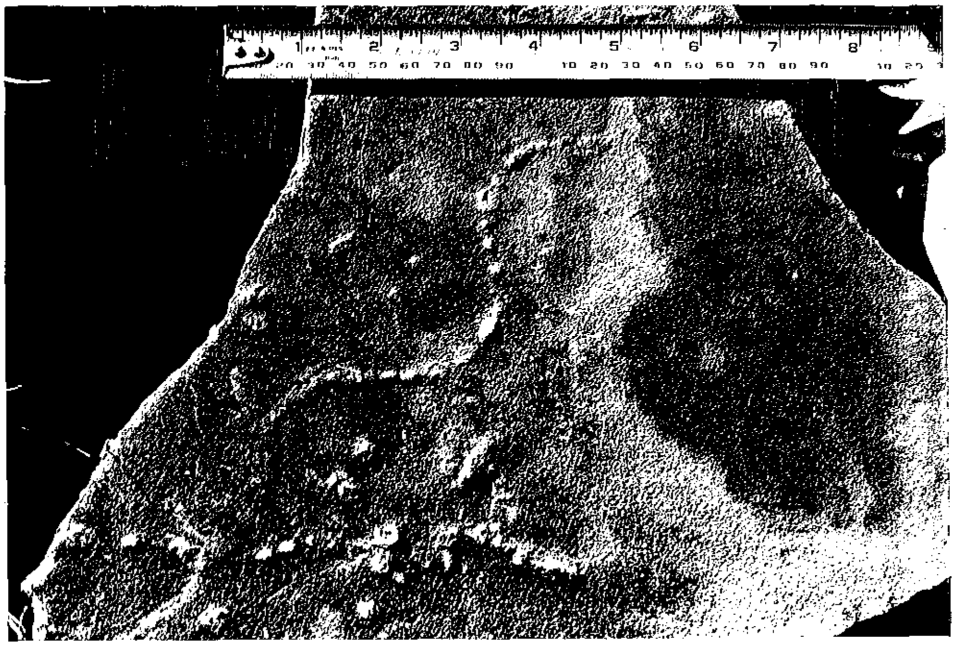

Plate 28: Beaded trail trace fossil (Seebe, within 8.0 - 13.5 m).

CHAPTER 6

CONCRETIONS

Both outcrops have abundant ironstone concretions which weather to a distinctive rust colour. These concretions have three common forms: small ellipsoidal to irregular individuals, thin laterally discontinuous sheets or thick laterally continuous units.

The ellipsoidal to irregular individual concretions occur scattered randomly within siltstones and shales. Their form can be quite smooth and ovoid (Plate 29) or very irregular with a churned up appearance. Average diameters are in the order of a few tens of centimetres. Occasionally these are found to enclose ammonite fossils.

The thin sheet concretionary form occurs along bedding planes either within sandstones or along the upper surface of sandstones or conglomerates which are overlain by siltstones or shales. Each laterally discontinuous sheet is a few centimetres thick and covers an average area of about a metre square. Some concretions of this type which overlie the Clast Supported Conglomerate Facies occurrence at Seebe (23 m) were found to enclose layers of chert pebbles (Plate 30).

The concretionary units are confined to coarser, gritty horizons of silt, sand and pebbles which occur occasionally within siltstones and shales. These occurrences have been described in Chapter 4 as a Concretionary Conglomerate Facies. This type of

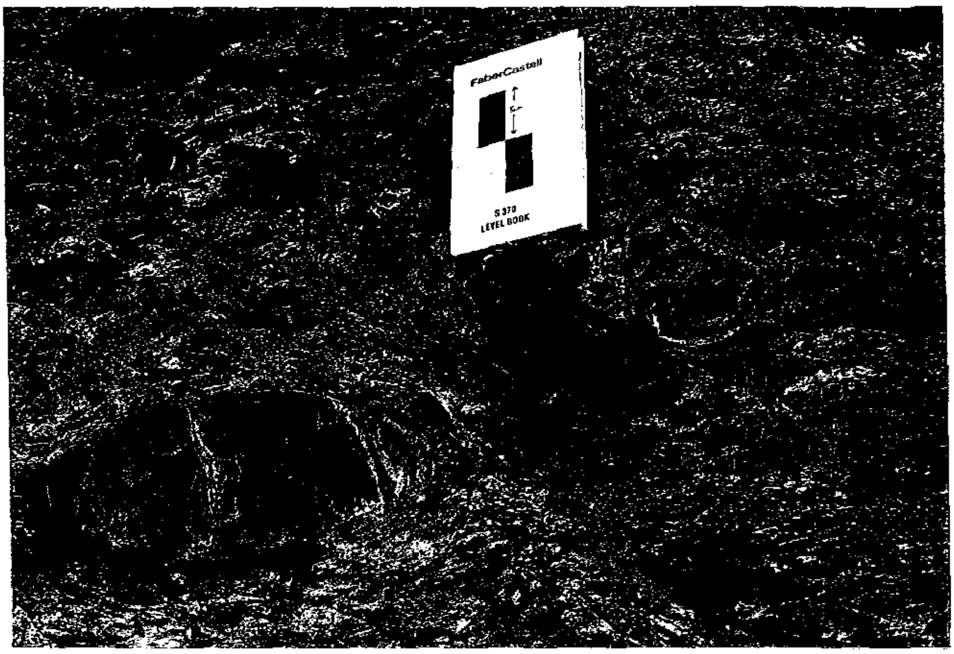

Plate 29: Ovoid concretions (Seebe, within 42.0 - 45.0 m).

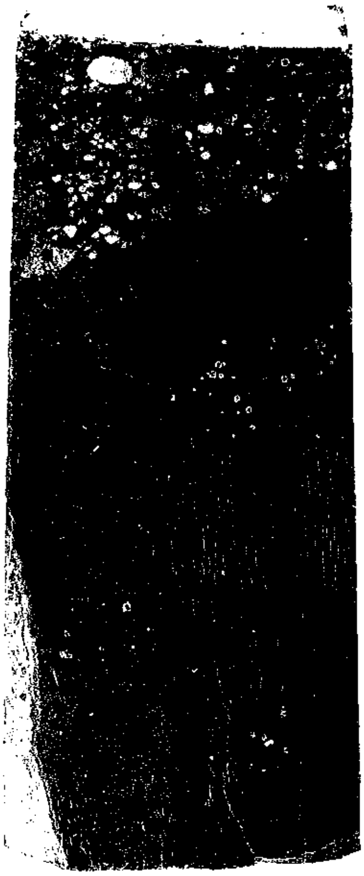

Plate 30: Concretion with chert pebbles. The original orientation is unknown (Seebe, β_3 of Figure 2, 9.0 m).

concretion is found to mark the top of a coarsening upward cycle (TYPE 1) within the study area and throughout much of Alberta (Ainsworth, Duke and Walker, pers. comm., 1979) (Plate 3). Because of the rust coloured weathering, these cycle tops are quite distinctive and easily seen within the surrounding siltstones and shales.

To determine the composition of these concretions, samples were analyzed for carbon, sulphur and ten major elements, as well as running X-ray diffraction scans. Experimental technique and results are given in Appendix 4. It can be seen from Figure 12 that the major minerals are siderite, quartz and chlorite. Composition analyses indicated that most iron and carbonate are tied up in siderite, with too little sulphur present to form pyrite. The identification of chlorite is in agreement with Thomas and Oliver (1979) who reported authigenic chlorite in an S.E.M. study of Cardium sandstones.

Occurrences of Concretionary Conglomerate Facies which mark the termination of TYPE 1 Cardium cycles are consistent throughout Alberta and serve as an excellent tool for identifying these cycles in the field (Ainsworth, Duke and Walker, pers. comm., 1979). The two other concretion types are fairly common diagenetic forms but the stratiform type has been interpreted by some as having a simple sedimentary origin rather than a diagenetic one (Curtis et al., 1975). It is important to determine the conditions under which siderite formed within these horizons for two reasons: 1) the concretionary conglomerates have a very conspicuous stratigraphic position and 2) the formation of siderite under surface conditions (nondiagenetic) is strictly

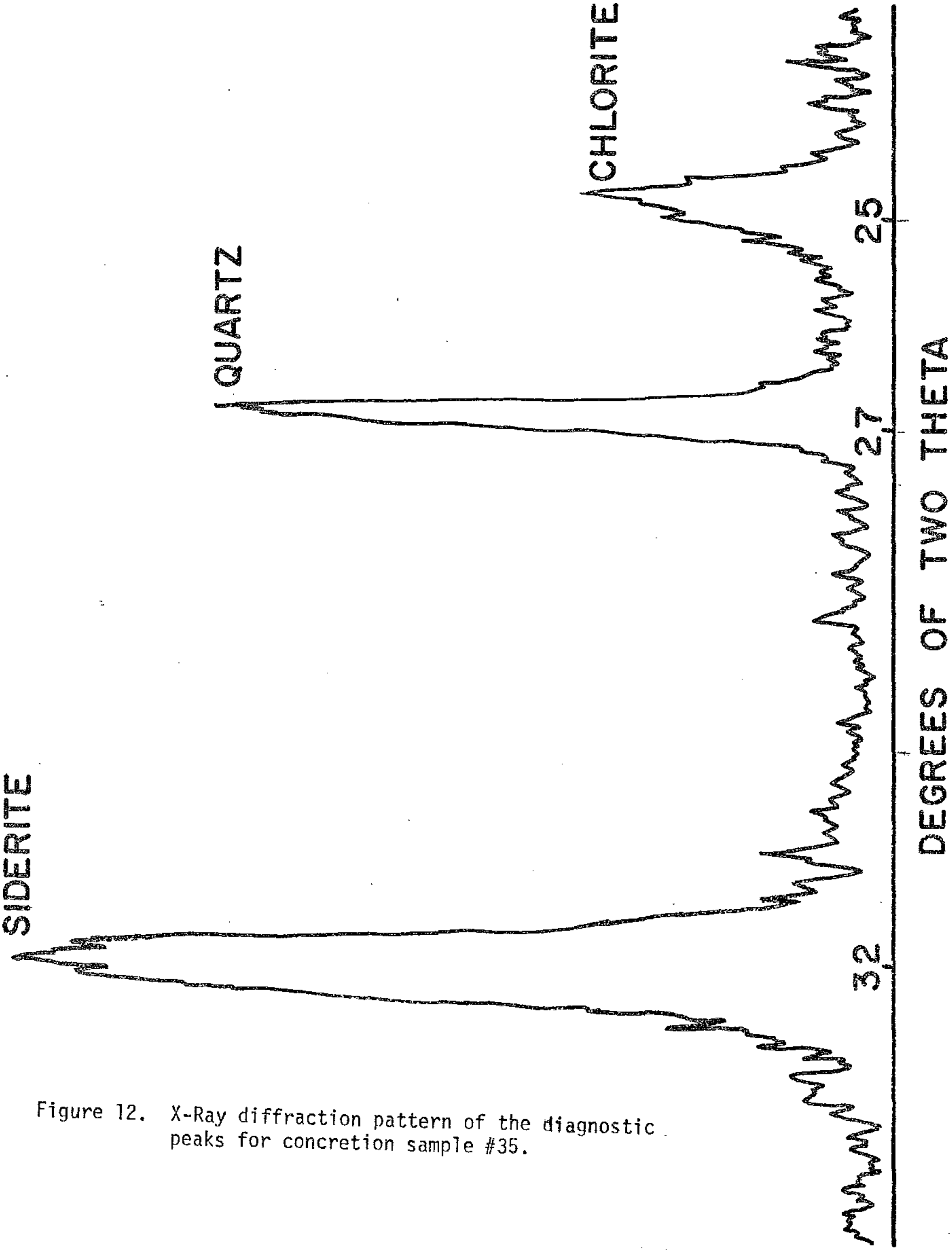

Figure 12. X-Ray diffraction pattern of the diagnostic peaks for concretion sample #35.

nonmarine (Berner, 1972).

The formation of siderite requires specific conditions of negative Eh, very low to zero sulphur, high carbonate and high carbon dioxide (Berner, 1972) which is commonly the case for sediment pore waters (Curtis and Spears, 1968), Curtis et al. (1975) attribute the stratiform character of this type of concretion to the coarser grain size of the horizon which allows for the channelling of pore water. Raiswell (1971) believes that it is the high porosity and permeability of the coarser sediment which keeps the horizon open to flow during diagenesis. In this way concretion growth is a cement replacement of porosity. At present there are two theories of diagenetic formation of siderite. Curtis (1967) and Curtis and Spears (1968) postulated that, in the absence of sulphate reducing bacteria, generation of carbon dioxide by other bacteria will react with precipitate ferric compounds to form siderite. Curtis and Spears (1968) also noted that, based on work done by Castano and Garrels (1950), it is possible to form siderite as a replacement of calcite by reaction with ferric solutions in a diagenetic environment where Eh values are negative.

Researchers who have studied this type of concretion have determined a diagenetic rather than non-marine environment of formation. One reason for this is the fact that the conditions conducive to siderite formation are common in the diagenetic environment. Another reason is the sandwiching of these horizons by marine siltstones and shales. It is believed that, under correct geochemical conditions diagenetic siderite concretions of the ovoid or discontinuous sheet type will form and when a coarser horizon is present the increased porosity and permeability will determine the distinctive form of the stratiform horizon type of concretion.

CHAPTER 7

DISCUSSION

General Interpretation of the H.C.S. Facies

The abundant occurrence of H.C.S. in the Cardium, combined with a marked absence of any medium scale cross stratification has some important implications. At present there are two somewhat different theories in the literature which attempt to explain the formation of H.C.S. The earliest interpretation was put forth by Harms et al. (1975, p. 88). In this model the formation of H.C.S. is believed to have resulted from the activity of storm waves reworking sediment in place. This reworking imprints H.C.S. on the sediment above storm wave base and preservation of the structure occurs below fairweather wave base. Scour marks result from the erosive action of the storm waves. Hamblin and Walker (1979) have suggested that H.C.S. is imprinted by storm waves upon sediment which is deposited below fairweather wave base by storm-surge-generated turbidity currents. H.C.S. facies are considered to be turbidite equivalents which are deposited above storm wave base and reworked by the storm waves of the same storm event. The resultant sedimentary structure is laterally continuous gently curving laminae which are both convex-downward and convex-upward. The most distinctive feature is the upward convexity which is not seen in other sedimentary structures (Walker, 1979, p. 81).

At present the model of Hamblin and Walker (1979) appears to be most applicable to the Cardium. Application of this model indicates that the formation of Cardium H.C.S. Sandstones, in the Seebe area, must have occurred below fairweather wave base and above storm wave base. The sharp based H.C.S. Sandstone beds which are interbedded with siltstones suggest that periodic storm-surge-generated bottom currents entrained coarser, nearshore sediment, moving it offshore as a turbidity current. Once deposited above storm wave base the still active storm waves feeling the bottom imprinted H.C.S. on these sediments. As the storm abated only oscillation ripples were formed on the top surfaces (Figure 13). Fairweather conditions are unable to rework the H.C.S. deposits but bioturbators might. Deposition during fairweather conditions represents the bulk of depositional time, producing only bioturbated siltstones and shales. Thick and Thin Bedded H.C.S. Facies represent one storm event per sandstone bed which is followed by a period of calm. Amalgamated H.C.S. Facies represent either successive storm events with insufficient time between them to accumulate fines or, more likely, the sweeping away of fines by the passing of the next turbidity current or the next storm feeling bottom. This has given rise to the stacked sets of H.C.S. Sandstone within this facies (up to 8 m, Sturrock Member, 90.3 - 98.1 m of Figure 8). Top surface symmetrical ripples represent the effect of the dying storm.

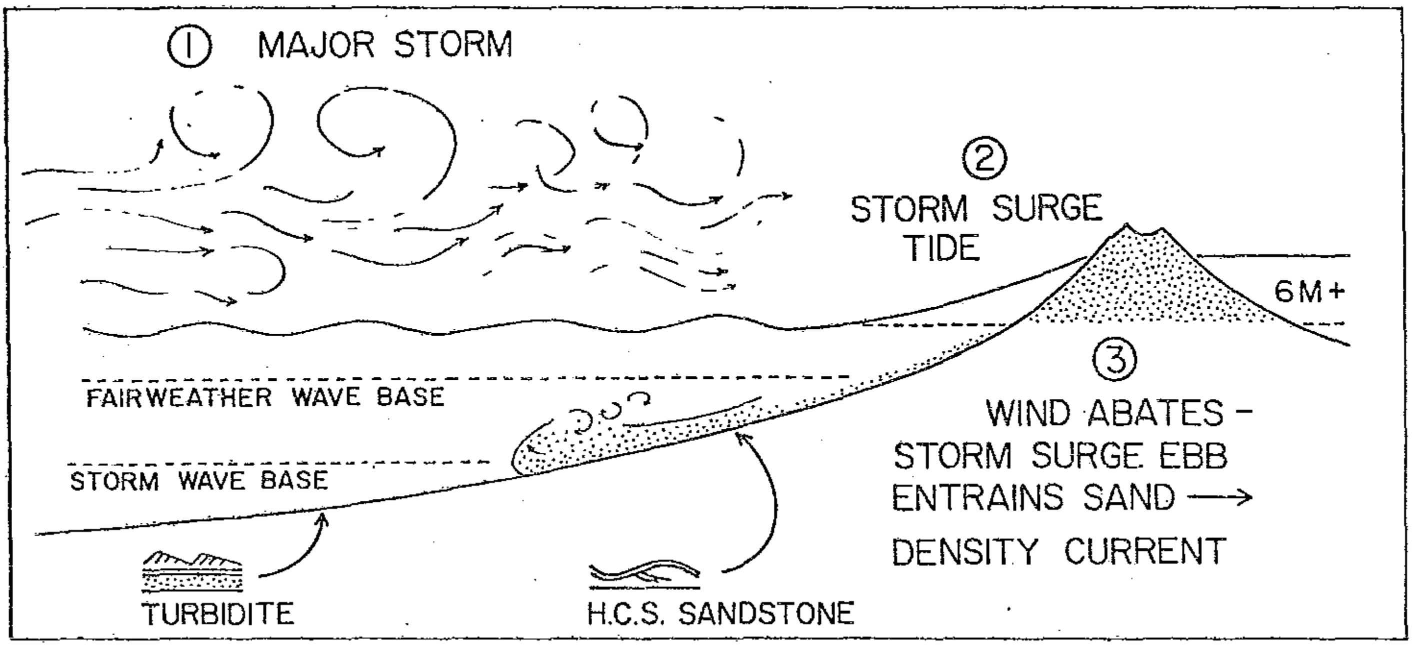

Figure 13. Conceptual diagram relating a major storm event to the formation of H.C.S. and a turbidite (from Walker, 1979b).

Conglomeratic Facies

Occurrences of conglomerate facies, pebble horizons and pebble veneers are also in keeping with the Hamblin and Walker (1979) model. Present day gravel bedforms, similar to those at Seebe (23 m, β_3 of Figure 2), have been reported by Gillie (1979) and Yorath et al. (1979) in inner shelf studies. Table 2 summarizes the dimensions for all three occurrences as well as the reported water depths of the two recent sediment studies. Minimum depths of occurrences were, for Gillie (1979) 17.3 m and Yorath et al. (1979) 85 m. Both Yorath et al. (1979) and Gillie (1979) reported that the average crest strike was parallel to shoreline. Both attributed formation of this bedform to storm generated wave trains. Gillie (1979) proposed that bedform creation occurred during the dying stages of the storm event, not during the peak of storm activity. He also noted that the size of this bedform is a function of the sediment grain size, making it essentially a large scale oscillation ripple.

These conclusions of water depth (17 m plus), storm wave formation and the association of occurrences of Clast Supported Conglomerate Facies with Amalgamated H.C.S. Sandstone Facies imply an off-shore environment of deposition. Both the Zoophycos-Rhizocorallium ichnofauna and the various H.C.S. Sandstone Facies indicate deposition between fairweather and storm wave base. The association of the gravel waves with these implies that they too were formed in the same environment. The reported formation of recent gravel waves in water deeper than 15 m illustrates the possibility that the Cardium Conglomer-

Table 2

Gravel wave dimensions from the Cardium Formation and two recent examples with reported observed water depths.

	Wavelength (cm)	Amplitude (cm)	Depth (m)
Cardium	90 - 130	4.8 - 7.5	-
Gillie (1979)	90	15	17.3 - 19.3
Yorath (1979)	15 - 30	15 - 30	80 - 105

within the Cardium. As mentioned in Chapter 6, the concretionary nature of the conglomerate is a diagenetic result of the relative increased porosity and permeability due to the larger grain size of the horizon within the much finer siltstones and shales. The pebble horizon at Seebe (44m) is locally disrupted. As explained in Chapter 5, the displacement of these pebbles is believed to be due to post-depositional bioturbation. In both of these cases deposition by turbidity current has been followed by post-depositional modifications.

Displacement by bioturbation does not appear to apply to the Matrix Supported Conglomerate Facies occurrence at Seebe (22 m - 23.5 m). This is because the pebble clast content decreases upward but bioturbators are known only to move large particles downward (Pemberton, pers. comm., 1979). This passage from well cemented clast supported conglomerate through muddy, matrix supported conglomerate, into siltstones cannot yet be interpreted in detail. This type of conglomerate transition does not appear to have any aspect of a beach conglomerate but, at present, its occurrence is not well understood.

Other Facies

Work by Hamblin and Walker (1979) on the Fernic-Kootenay Transition determined the existence of turbidites which were overlain by H.C.S. Sandstones. In the application of the Hamblin and Walker (1979) model to the Cardium it appears that the Ribby Shale Facies represents thin based turbidite deposits below storm wave base. It is probable that the sea floor topography in the area of Horseshoe

Dam was a locallized low, below the reach of storm waves, allowing the deposition of a turbidite in the area.

The Rippled Interbedded Sandstone Facies is very similar to the Thin Bedded H.C.S. Facies in all aspects except the absence of H.C.S. It could be that because of poor outcrop surfaces, detail of stratification or bioturbation could not be seen and these two facies might actually represent the same conditions of deposition.

The Bioturbated Silty Sandstone Facies was probably once one of the interbedded sandstone facies which suffered complete homogenization by bioturbators; very much like the reworking which occurred in the Bioturbated Sandstone Facies. As well as destroying the sedimentary structures within the sandstones, the interbedded facies suffered a complete mixing of two grain size types as well, yielding a much siltier composition than the sandstones.

Facies Sequence

The sequence of facies within the Cardium follows a distinct pattern which shows a degree of variation within it. Figure 14 shows a complete facies sequence. This is both the apparent facies ordering seen in outcrop as well as the ordering which would be predicted by the Hamblin and Walker (1979) model. Departure from the sequence of Figure 14 occurs in two ways: 1) as absences of some facies, and 2) as additions of conglomerates not at cycle tops. An extreme example of (1) is cycle TYPE 1 which consists of conglomerates capping a siltstone sequence. An example of (2) may include pebble horizons within siltstone facies occurrences. The absence of facies is probably due

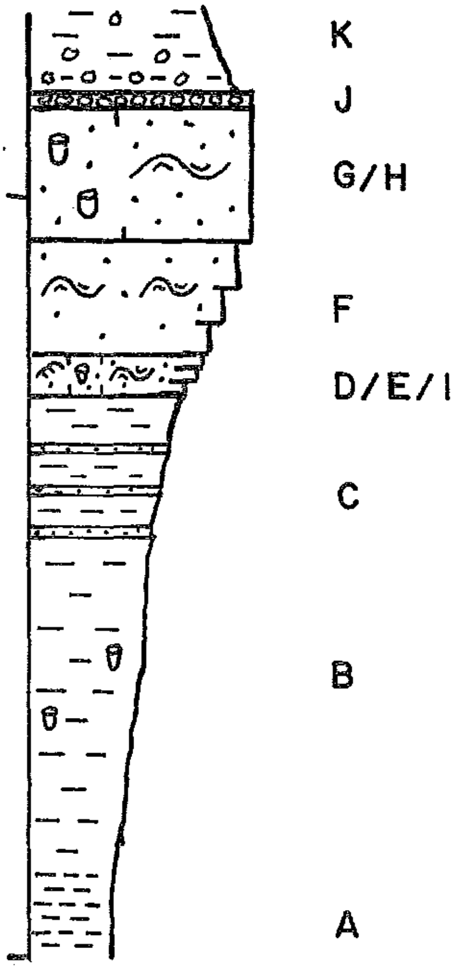

Figure 14. Facies Sequence.

to fluctuations of sedimentation conditions within the area as well as varying distances from the sediment source. The coarse clastic facies and horizons which are not at the top of a cycle are sudden coarse sediment injections occurring as a result of sediment source fluctuation. Much of this variation could result from the relative storm strengths combined with local progradation patterns.

Cycles

Cyclicity within the Cardium is seen by a coarsening and thickening upward pattern. Cycles begin with fine grained siltstones or shales. Each cycle type is a repeated facies combination from the basic facies sequence pattern of Figure 13. Conglomerate facies or pebble veneers may or may not terminate a cycle.

If this were a shoreline attached system then each cycle would represent local progradation. However, the environment of deposition of the Cardium in the study area appears to be several kilometres off-shore. For example, if a water depth of 15 m (just less than the 17.3 m minimum of Gillie (1979)) and an average epeiric sea slope of 0.1 foot per mile (0.001° slope) suggested by Shaw (1964) is used, then a distance from shoreline for deposition would be as much as 800 km. If the slope were as steep as 0.5°, the distance would be about 2 km. A 1° slope would be unexpected in an epeiric sea but even this would produce a distance of almost 1 km from shoreline. Hence, it appears more likely that the cycles are an off-shore response to shoreline progradation. Initiation of a cycle could result from active shoreline shifting which may change offshore depocentres (similar to delta lobe migration). Cycle initiation could also result from small eustatic sea level changes which result from orogenic activity in the west. These eustatic changes would have to cause relatively rapid rises in sea level which were followed by progradation. Uplift, due to igneous intrusion of the Omineca Crystalline Belt to the west, has been determined by K-Ar dating these igneous rocks to have occurred during the Late Cretaceous and Paleogene (20 - 95 Ma) (Monger and Price, 1979). These intrusions span the Turonian (absolute age 89 - 94 Ma (Van Eysinga, 1978)) during which the Cardium of Central Alberta was deposited.

Paleontology

The environment of deposition which has been suggested by the sedimentology is supported by the paleontology. The foraminiferal assemblage is considered to be distinctive of conditions far enough off-shore to maintain low turbidity, constant temperatures and normal salinity. The high density Zoophycos-Rhizocorallium ichnofossil combination found in Bioturbated Sandstone Facies is considered to be distinctive of sediment conditions well off-shore. Evidence indicates that these sandstones were invaded by fauna after deposition, while quiescent conditions allowed undisturbed mining of the sediment.

CHAPTER 8

CONCLUSIONS

1. The Cardium Formation within the study area can be subdivided into twelve different facies. Definition of these facies is based upon grain size, siltstone:sandstone ratios, bed thickness, sedimentary structures, and extent of bioturbation. Definition of facies in this manner provides a separate facies for each distinguishibly different rock type present allowing for a systematic mapping and description of the formation.

2. The sequence of these facies defines a cyclic development within the Cardium. The outcrops studied could be subdivided into three different cycle types. In all cases each cycle was typified by a coarsening and thickening upward. Cycle types show little variation within each occurrence of the same cycle type and the overall pattern of cycles at the two outcrops is quite similar.

3. H.C.S. tends to be the dominant sedimentary structure of the sandstone facies. This domination of H.C.S., combined with an absence of any medium scale cross stratification determines that the H.C.S. facies are the best indicators of depositional process. According to Hamblin and Walker (1979) this process involves storm-surge-generated turbidity currents moving shoreward sediment

offshore and depositing it between fairweather and storm wave base, while the storm waves feeling bottom are imprinting H.C.S. upon this sediment.

4. Occurrences of conglomerate facies are often associated with H.C.S. facies. This close association implies that these conglomerate facies occurrences were deposited in the same environment as the H.C.S. facies. This indicates an off-shore, below fairweather wave base environment.

5. The foraminiferal assemblage present within the Bioturbated Siltstone Facies at Seebe indicates marine environment far enough off-shore to eliminate most shoreline influences.

6. The ichnofauna combination of Zoophycos and horizontal Rhyzocarallium represents an off-shore marine environment at the interface between the Cruziana and Zoophycos Ichnofacies. This trace fossil combination makes a near-shore to beach interpretation of the Bioturbated Sandstone Facies unacceptable. A suitable location for these bioturbators is below fairweather wave base and above storm weather wave base.

7. The result of these conclusions makes it no longer acceptable to support a beach or near-shore model for the interpretation of the Cardium Formation in the Seebe area. It appears more plausible that deposition occurred a number of kilometres off-shore in water below the reach of fairweather, near-shore processes. The mode of emplacement suggested is that of storm-surge-generated turbidity currents.

APPENDIX I

PETROLOGY

Of the twelve different facies present, thin sections from eight of these facies were made and studied. Sample composition was determined for thirteen thin sections by performing a 400 grain point count for each slide. The results are summarized in Table A1. In this table all fractions were rounded up to the nearest percent, hence these percentages may not sum to 100. The sample labelled Facies G_2 is actually a sideritic concretion taken from within this facies.

The compositions were dominated by quartz, chert and clays. Quartz usually had undulose extinction, and polygonalized grains were common. Pressure solution was present within the sandstone and conglomerate facies. Siderite, silica and calcite occurred commonly as cement in the various sandstone facies. The clays were usually a dull brown colour and feldspars were noticably lacking.

Table A1. Petrographic Data

Facies	Quartz	Polygonalized Quartz	Silica Cement	Clay	Chert	Siderite	Lithoclast	Feldspar	Calcite	Other
	%	%	%	%	%	%	%	%	%	%
B	31	17		41	3	7		trace		2
	32	5	1	36	7	17		1	1	
D	35	20	11	18	6	8		1	2	1
E	56	6	5	22	8			trace	2	1
F	28	22	9	29	6			1	5	2
	35	22	11	22	2	7			2	trace
	33	14	2	38	8			1	2	2
G	32	28	12	22	2			2	1	2
	40	7	10	11	11	20	trace	1	1	trace
G2	40	4		5	3	48				
H	52	11	19	12	5			2	trace	
J	2	4		4	53	12	25			
K	5	2		15	57		19	1		1

APPENDIX II

GRAIN ORIENTATION

Oriented samples of the Clast Supported Conglomerate Facies occurrence at Seebe (23 m) were collected at β_3 of Figure 2. These samples were slabbed parallel to bedding and the long (a) axis orientation of pebbles larger than 2 mm was taken. A Tukey Chi-Square Test was then applied to these data using the program written by Martini (1965). A vector mean of 158° was determined having a Chi-Square value of 6.6 with two degrees of freedom. This is significant at the ninety-five per cent confidence level and hence is considered to be statistically significantly different from random. The data is summarized in Figure A1.

To determine if there was an a or b axis imbrication the samples were slabbed vertically along the 158° and 068° orientations. The dip of these pebbles was measured on the slabbed face and vector means were calculated. The resultant vector mean for the 158° plane is 87° and for the 068° plane is 86°. Rose diagram summaries of these data are given in Figure A2. From these diagrams, it can be seen that the vector means are not significantly different from ninety degrees (horizontal) and hence no preferred imbrication can be seen on either of the vertically slabbed faces.

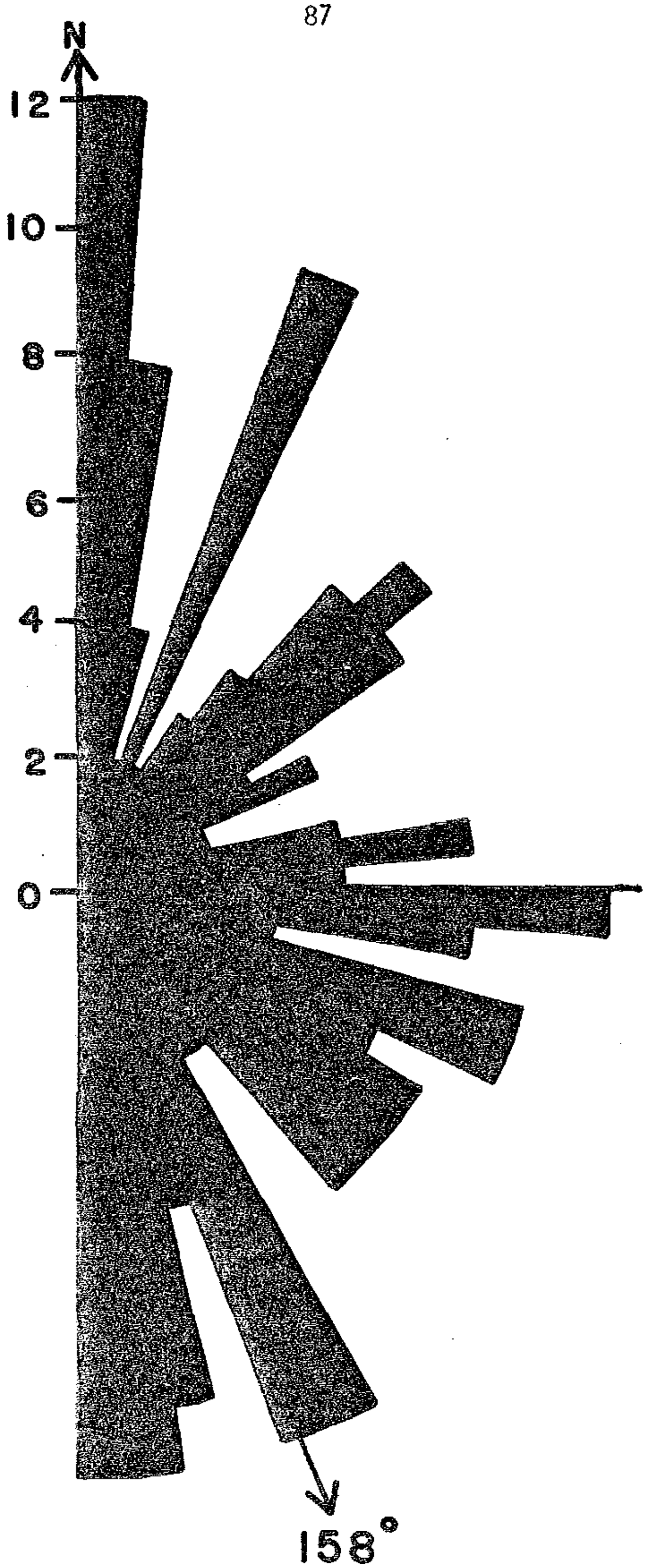

Figure A1. Rose diagram of the long (a) axis orientation of pebbles within the Clast Supported Conglomerate Facies.

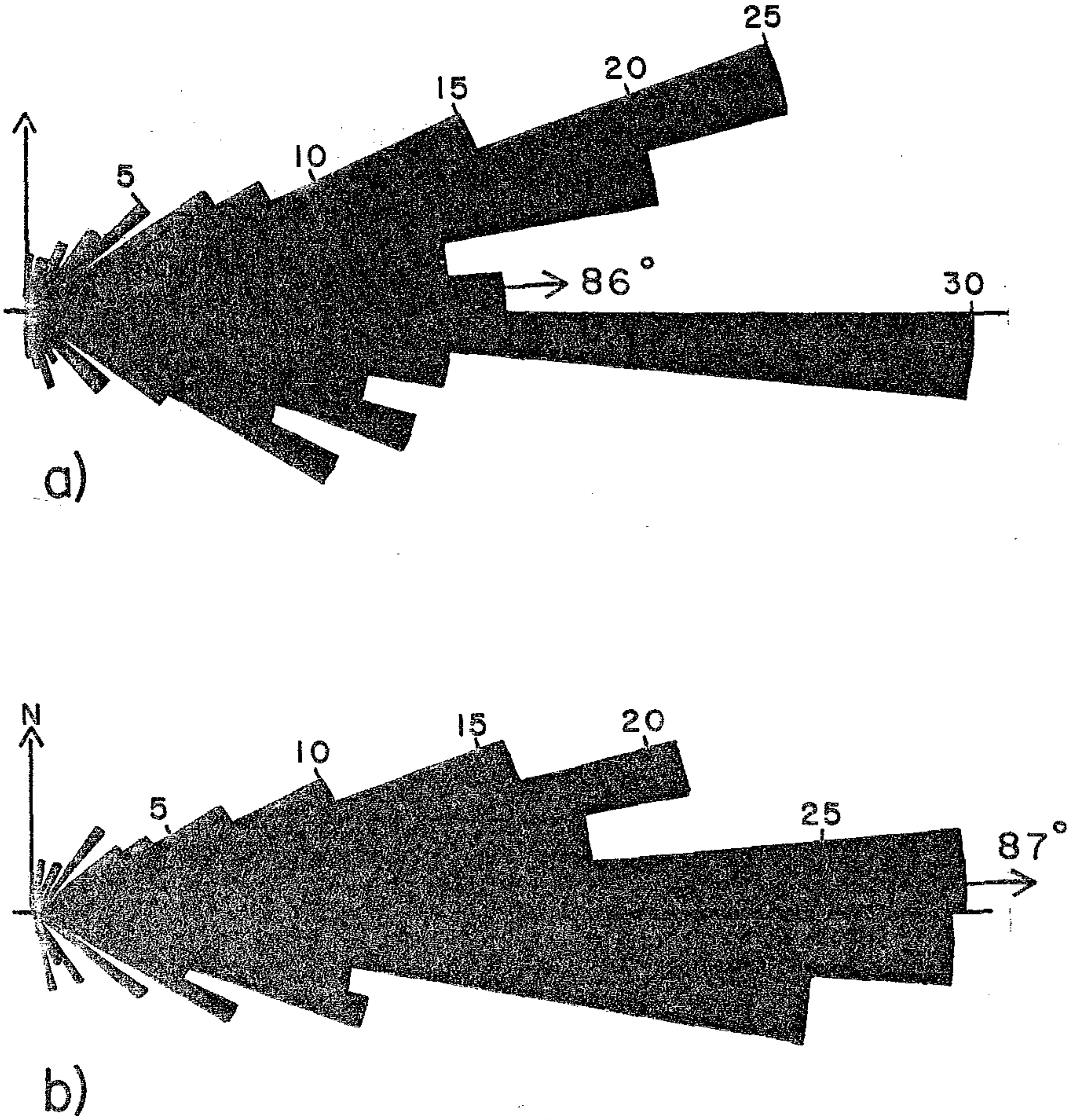

Figure A2. Rose diagram of imbrication of pebbles
(a) parallel to 68° (b) parallel to 158°

APPENDIX III

The Foraminiferal Assemblage and Paleoecology of the Cardium Formation at Seebe, Alberta

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For Dr. M.J. Risk
Geology 3D6 Term Project

Abstract

The Cardium Formation is predominantly a sand accumulation within the Upper Cretaceous Alberta Group of the central Foothills region of Western Canada. Within this formation are a number of shale and siltstone members. Study of the foraminiferal assemblage of these members is almost non-existant within the literature. The microfauna of the Cardium is not useful for fine zonations but can provide very valuable paleoecology indicators.

Samples taken of both Leyland and Kiska Members from outcrop below the Kananaskis Dam at Seebe, Alberta yielded a diverse and prolific foraminiferal fauna. Paleoenvironmental interpretation of this assemblage is based upon the guidelines as discussed by Wall (1967), because statistical techniques which are in popular use at the present time are inapplicable for the Cretaceous.

The assemblages from both members were very similar, including dominant agglutinated benthonic species with minor calcareous bethonic and pelagic species. This is interpreted as being consistant with a paleoenvironment located in an offshore marine position, removed from the activity of nearshore turbulent processes sufficiently to allow the existence of calcareous benthonic and pelagic species. These data provide the basis for a much more representative interpretation of the paleoenvironment of the Cardium Formation of the central Foothills area than that put forward by Wall (1967). In his study, due to a lack of data from the central Foothills, a more northern member was used and found to indicate agreement with the interpretation by Stott (1963)

which involved a nearshore to beach environment of deposition. The presence of a more offshore fauna which is consistent in two different members gives credence to alternative paleoenvironmental interpretations for the Cardium Formation.

Acknowledgements

I would like to thank C. Mahadeo for preparing and mounting the samples and for arranging for me to meet Dr. J. Wall. Both were very helpful in suggesting good references, explaining the basics for identification of agglutinated foraminifera, and answering many questions. Their help is much appreciated.

The Foraminiferal Assemblage and Paleoecology of the Cardium Formation At Seebe, Alberta

Introduction

The Cardium Formation is an Upper Cretaceous sandstone in the Alberta area. It is bounded above and below by thick sequences of black marine shales of the Wapiabi and Blackstone Formations, respectively. Together, these formations comprise the Alberta Group.

The Cardium was subdivided into members by Stott (1961). These are, in ascending stratigraphic order: the Ram, Moosehound, Kiska, Cardinal, Leyland and Sturrock. The Moosehound, Kiska and Leyland are siltstone members while the others are fine grained sandstones. The samples in this study were taken from the equivalent Kiska and Leyland members. The Moosehound Member is absent at this locality.

The study location is near the town of Seebe, Alberta which lies alongside the Trans Canada Highway between Calgary and Banff (Fig. 1). The Cardium Formation outcrops below the Kananaskis Dam which is situated at the confluence of the Bow and Kananaskis Rivers (Fig. 2). Sample locations are indicated on Figure 2.

The samples were prepared and mounted by Clarence Mahadeo of Amoco Canada Petroleum Co. Ltd.

Foraminiferal Assemblage

Agglutinated foraminifera are the dominant type found in Cretaceous rocks (Wall, pers. comm.). The Cardium is consistent with

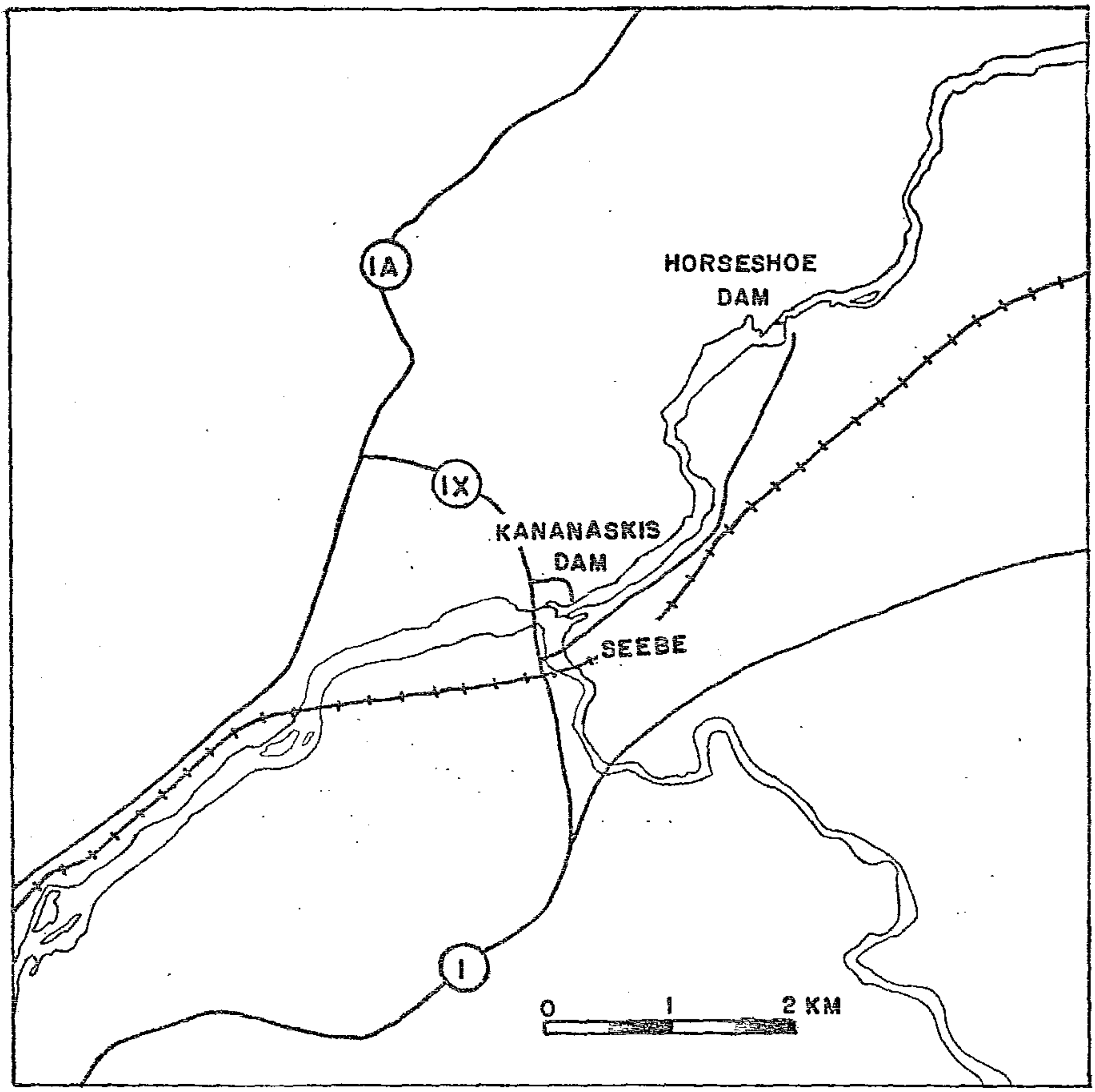

Figure 1. Outcrop Location Map

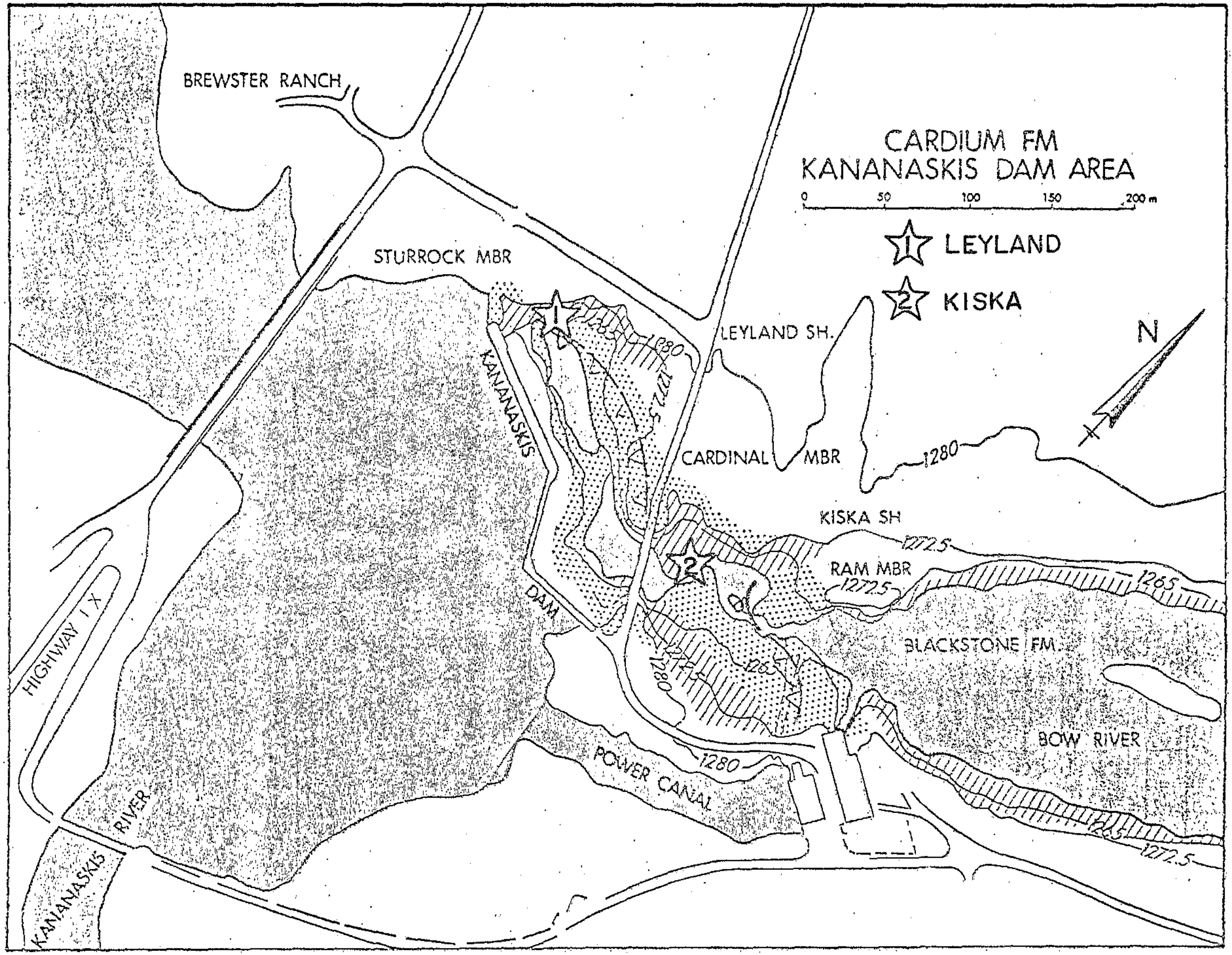

Figure 2. Location Map of Sample Collection Sites (de Wit, 1979).

this trend. Because of the indiscernable nature of this test form and the effects of diagenesis on it, few people choose to study these fossils. Those who do are, for the most part, petroleum geologists, and little of their expertise has been published. Dr. John Wall has published a Research Council of Alberta Bulletin (1967, #20) in which he has described and photographed many of the foraminifera of the Alberta Group. This has provided the basis upon which these specimens were identified.

The age of the Cardium, based upon foraminiferal fauna (Wall, 1967), is late Turonian. Determination of age for the Cardium cannot be based solely upon the microfaunal assemblage to be found within it. Although the microfaunal zones and rock stratigraphic units are concordant in the Blackstone (Wall, 1963), there are no fossil zones which are known to occur concordant with Cardium rocks (Wall, 1967). The Cardium acts as a time transition zone in which organisms distinctive of the microfaunal assemblages within the Blackstone and Wapiabi Formations occur together. Dating of the Cardium Formation must be done by dating of the two Alberta Group shales which over- and under-lie it, using both microfossils and megafossils.

The effects of dissolution and diagenesis on a microfaunal assemblage can result in a very selective removal of some species. This selective destruction and removal begins at the sediment-water interface with the dissolution of calcium carbonate by sea and connate waters as well as destruction by the activity of bioturbators. Dissolution may continue during diagenesis, and deformation can occur as the result of compaction. Hence selective removal will affect those species which are most fragile, entirely calcareous or agglutinated forms which have only small amounts of calcite cement. The well cemented, agglutinated varieties will best survive diagenesis (Douglas, 1979, p. 32). Thus the assemblage found in the rock record is not necessarily representative of the microfaunal assemblage that existed at the time of deposition of the enclosing rocks.

The fauna identified from the two Cardium Members are listed in Table 1. Description summaries and photographs can be found in the Formal Descriptions section of this paper.

Table 1: Identified Species

Type	Specimen	Sample*	
		Leyland	Kiska
Textulariina (benthonic)	Saccammima sp. cf alenandri	o	x
	Ammodiscus sp. 2		x
	Reophax sp. 1	o	o
	sp. 2		o
	sp. 3	x	
	Haplophragmoides crickmayi	o	o
	howardense	o	o
	howardense manifectum	x	
	sp. 2	x	x
	Ammobaculites fragmentarius	x	
	sp. 3		x
	Spiroplectammina sp. 2		x
	Pseudobolivina rollaensis	x	
	sp. 1	x	
	Trochammina ribstonesis	o	o
	sp. cf. ribstonensis		x
	rutherfordi	o	o
	wetteri		o
	sp. 1	o	
	Verneuilina canadensis		x
	Verneuilinoides bearpawensis	o	x
	kansansis	x	
	Dorothia glabrata		o
	smokyensis	x	
	sp. 1	x	
Rotaliina (benthonic)	Lenticulina sp. 1	o	x
Rotaliina (pelagic)	Bedbergella delrioensis	x	
Rotaliina (pelagic)	Praeglobotruncana sp. cf. coarctata	o	
Rotaliina (pelagic)	Anomalinoides		o

*x = present, o = abundant

Foraminiferal Ecology and Paleoecology

The use of foraminiferal zonation in the petroleum industry for stratigraphic identification, paleoecology and bathymmetry has proven to be extremely useful. This use has sparked much recent work with regards to the ecology and paleoecology of these organisms. Much of this research has been done in the recent, using multivariate techniques to obtain some very discriminating analyses of the data (Douglas, 1979). Properties such as temperature, oxygen, salinity, silica, phosphate, nitrate, alkalinity, carbon dioxide, and water depth have been used in these multivariate analyses.

Because a fossil assemblage lacks this information, results from analyses of organisms in the recent have been used to develop regression equations to determine the same properties from paleontological data (Douglas, 1979). To do this type of extrapolation requires assumptions that modern faunal distribution patterns are analogous, homeomorphs of modern species have similar environmental adaptations, and habitats have not changed (Douglas, 1979). Some of these extrapolations have proven useful within the Upper Cenozoic, but problems develop if extrapolation into the Cretaceous is attempted. Douglas (1979) has pointed out that evolution of the ocean and its benthonic populations has occurred since the middle Miocene. Isotopic paleotemperature analyses indicate that Cretaceous bottom waters were as warm as 10° to 13°C. This created only a weak vertical environmental gradient. It also must be noted that the inland seaway existing in Western Canada during the Cretaceous was much different from the continental shelves existing in the recent, where many foraminiferal ecology studies are being done. The Cretaceous sea was shallow, with low slopes and would doubtfully have developed a continental shelf morphology, as exists on continental margins today. These variables result in bathymetric zonations of the microfaunal assemblages of the Cretaceous being less distinct than those of the recent. The zonation which did exist will be representative of less diversified faunal assemblages.

Because of these problems of extrapolating into the ancient using the existing statistical techniques, multivariate analyses cannot be employed. It must be noted, however, that when dealing with a large number of samples and taxa, some multivariate analyses are well employed when attempting to determine unbiased biostratigraphical patterns (Hazel, 1977). Where only a few samples are involved, as in this case, it is unnecessary. The use of foraminiferal number, etc., to determine coastal shelf paleoenvironments, as illustrated in Figure 3, also is not relevant to this study. Instead much less elegant methods of estimating the paleoenvironment must be employed.

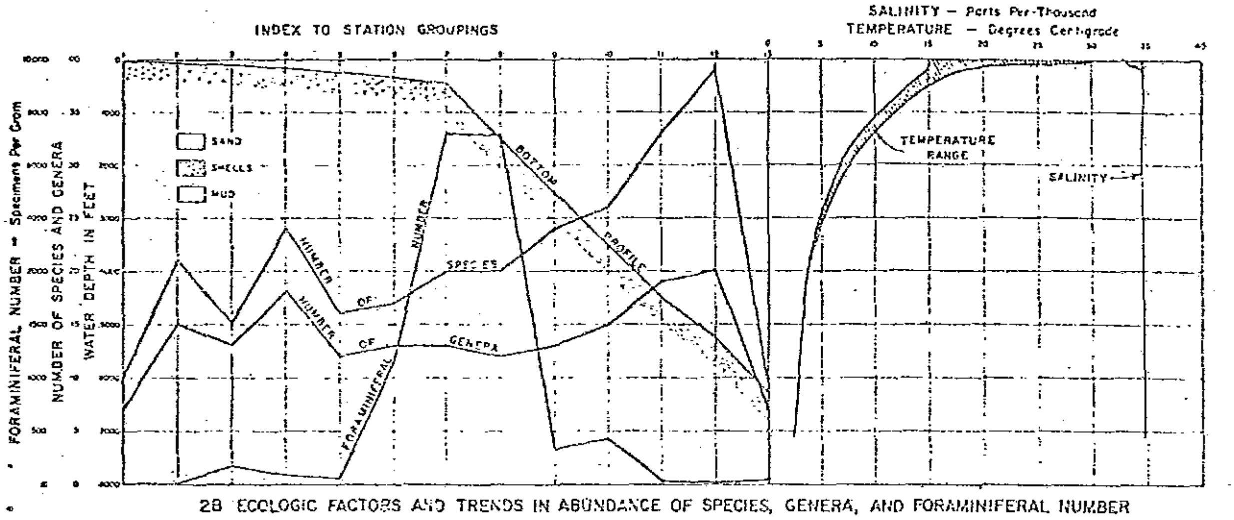

Figure 3. Trends in abundance of foraminifera across the continental margin off Central America (Bandy and Arnal, 1957; from Douglas, 1979).

Paleoecology of Alberta Group Foraminifera

The environmental indicators which Wall (1967) has used to interpret paleoenvironment of the Alberta Group are as follows. An entirely agglutinated assemblage is indicative of a shallow seaway having somewhat turbid waters and could possibly have subnormal salinity. High turbidity and low salinity are nearshore, coastal conditions. However, only very close to shore or restricted marine conditions are considered to be the case if both the population size and species diversity are low. The presence of Miliolids, nonmarine organisms, spores and pyritized diatoms will also support very near shore conditions (Mahadeo, pers. comm.) A combination of a dominantly agglutinated assemblage with calcareous forms suggests a deepening of water, lessening of turbidity, and near normal salinity. The preservation of calcareous tests as pyritic casts is an implication of restricted sedimentation. Hence the paleoenvironment was sufficiently removed from the activity of nearshore waves or currents as well as the discharge of rivers to allow fairly quiescent conditions. The addition of pelagic foraminifera to the above assemblage determines waters which are deeper still and free of excessive turbidity. A population consisting of twenty to thirty species is representative of water depths comparable to a middle shelf environment of the continental margins which are existing at the present time (Wall, pers. comm.). The presence of pelagic foraminifera, to the exclusion of all else, is considered to be distinctive of open sea conditions.

Interpretation of the Paleoecology of the Cardium Formation at Seebe

In the study by Wall (1967) of the foraminifers of the Alberta Group, results pertaining to the Cardium Formation are sparse. A number of localities sampled in the Leyland and Kiska Members yielded only Haplophragmoides sp., Dorothia sp. 1, D. sp. cf., D. sp. 1, one Quinqueloculina sphaera Nans, and a few marine ostracodes. Samples from the Moosehound Member were somewhat more prolific and diverse, yielding:

Reophax sp. 1
Haplophragmoides crickmayi Stelck and Wall
H. howardense
Ammobaculites sp. cf. A. fragmentarius Cushman
Spiroplectammina semicomplanata (Carsey)
Trochammina sp.
Verneuilinoides bearpawensis (Wickenden)
Dorothia smokyensis Wall
nonmarine ostracode (at base of unit)

The only interpretation of paleoenvironment of the Cardium Formation shale and siltstone members by Wall (1967) is based upon this assemblage. He suggests a brackish water, lagoonal type of environment of deposition, determined by the arenaceous assemblage combined with nonmarine ostracodes. On this basis the microfaunal assemblage is considered to be in agreement with a fresh- or brackish-water environment of deposition as suggested by Stott (1963) for the Moosehound Member. A nearshore, marine environment is inferred to be representative of the paleoenvironment of the Cardium generally.

At the outcrop at Seebe the nonmarine to restricted marine Moosehound Member is not present. An abundant population of diverse species was obtained from both the Kiska and Leyland Members. This population consisted of the majority being agglutinated benthonic forms, with both samples containing a number of calcareous benthonic forms and the Leyland sample containing a few pelagic forms. This indicates a much deeper water environment, which is farther removed from the shoreline than what has been indicated in the study by Wall (1967) for the Cardium Formation of the central Foothills.

Using the paleoenvironment indicators of Wall (1967) discussed in the previous section, it is possible to interpret the microfaunal paleoecology of the Cardium. The assemblages retrieved from both members are very similar. Twenty identifiable species were present in the Leyland sample, with eighteen from Kiska. Both assemblages were dominated by agglutinated forms but also had some calcareous benthonic as well as pelagic species. This implies fairly deep, marine conditions, sufficiently removed from the shoreline for normal salinity and very quiescent conditions of sedimentation. A depth comparison to the present day middle shelf environment is quite applicable to these samples. However, the small number of non-agglutinated species and a species diversity totalling near twenty will restrict the paleoenvironment to the shallower reaches of this domain.

These results are very significant because they offer very good faunal retrieval from the Leyland and Kiska Members which Wall (1967) did not have. Since the Moosehound Member is absent in the central Foothills it is not reasonable to imply a nearshore environment of deposition for the Cardium Formation using microfauna from the Moosehound Member. The deeper water, shore detatched paleoenvironment indicated by the samples of this study are in disagreement with a nearshore to beach interpretation put forth by Stott (1967) and supported by many others. However, recent sedimentological and ichnofaunal work done by the author at Seebe and by Walker, Duke and Ainsworth (pers. comm.) throughout Alberta has indicated an environment of deposition detatched from the shoreline and dominated by storm activity. These sedimentological data suggest an environment of deposition in close agreement with that indicated by the microfauna. Because of this close association it is no longer necessary to invoke changes of sea level to explain each of the siltstone and shale members within the Cardium. However, it certainly does not eliminated the possibility of transgression or regression occurring during the deposition of the Cardium Formation.

Summary

At the present time there is very little published work available about the foraminifera of the Cardium Formation. What has been done is unrepresentative of this formation in the central Foothills. The results of this study have shown that the paleoenvironment is farther away from the shoreline than was previously thought. This will require the bounding Cardium sandstone members to either have been formed equally away from the shoreline or have each member representative of a relative change in sea level. At present, the popular opinion supports that of transgressive-regressive cycles. However, recent evidence in support of a deeper environment of deposition for the Cardium has been rapidly becoming more prevalent. The distinctive similarity of the populations from both members sampled lends further support to the idea of a constant environment of deposition which is affected by a variation of depositional processes active within that environment.

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APPENDIX IV

CONCRETION ANALYSIS

Sample Preparation

Each sample had its weathered surfaces removed then the samples were powdered. This was done by passing the samples separately through a jaw crusher, disc pulverizer and shatter box. The samples were then hand ground using a mortar and pestle until the powder could pass through a 100 mesh screen. Samples for carbon, sulphur and oxide analysis were stored in glass vials. Samples for X-ray diffraction were prepared by making a slurry of the powder with acetone on a glass slide then levelling the surface by hand.

Analyses

Before X-ray diffraction was run chemical analyses were completed to help narrow the mineral possibilities which would need to be distinguished on the X-ray diffraction scan. This was to help eliminate the omission of carbonate minerals whose peaks overlap enough to make identification quite difficult.

The first analysis was for carbon content. The results are given in Table A2. Using the obtained carbon value, estimates of possible carbon bearing species were calculated. The possible amount of carbonate minerals was quite high, even if organic carbon is taken into account.

Table A2

Carbon and Sulphur analysis of Concretions, with calculated possible values of CO_2 and $CaCO_3$

Sample #	Weight	C Value	% C	% CO_2	% $CaCO_3$	% S
7	0.273	1.16	3.8	13.9	31.8	
9	0.276	1.32	4.4	16.0	36.5	
12	0.330	1.33	5.3	19.3	43.9	0.70
35	0.267	2.11	6.8	24.8	56.4	

The second analysis was for sulphur to determine if the iron species could possibly be pyrite. The very low value of 0.7% sulphur determined that very little iron could be present as pyrite.

After these two specific analyses were completed X-ray fluoresence was done for the ten most common rock forming oxides. These results are given in Table A3. The results of this suggested that: there was not enough magnesium or calcium to form significant amounts of carbonate other than siderite; iron did not appear to combine with any anions other than CO_3^- to form any other iron species; and quartz appeared to be the only significant mineral along with siderite.

Following these analyses, X-ray diffraction scans were run. A full scan was done from 5° to 60° of two theta for sample 35. Once the diagnostic peaks were isolated only abbreviated scans were run on the remaining samples for the interval 23° to 33° of two theta. For each sample, peaks of quartz, siderite and chlorite were identified as illustrated in Figure 12. Identification of these peaks was done by comparison to scan patterns obtained by Tihor (1978).

The peaks for quartz and siderite confirmed indications from the previous analyses. The presence of chloritic clays was not suggested by these analyses but is in agreement with work done by Thomas and Oliver (1979). Chlorite was identified in this study in samples of Cardium sandstone using the S.E.M.

Table A3

X-Ray fluorescence measurements of the ten most common rock-forming oxides in Sample # 12

SiO_2	52.50
Al_2O_3	3.24
Fe_2O_3	24.75
MgO	2.42
CaO	4.91
Na_2O	0.50
K_2O	0.40
TiO_2	0.15
MnO	0.23
P_2O_5	1.98
	91.08 %

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