UPPER CRETACEOUS WAPIABI AND BELLY RIVER FORMATIONS

THE STRATIGRAPHY, SEDIMENTOLOGY AND PETROGRAPHY

OF

THE UPPER CRETACEOUS WAPIABI AND BELLY RIVER FORMATIONS

IN SOUTHWESTERN ALBERTA

By

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Knowledge is proud that it knows so much;
Wisdom is humble that it knows no more.

William Cowper

ABSTRACT

The Upper Cretaceous Wapiabi and Belly River Formations are thick clastic units which are well exposed in the foothills along the southeastern margin of the Canadian Cordillera. The Wapiabi Formation constitutes the uppermost unit of a thick marine sequence known as the Alberta Group. The transition to the overlying nonmarine Belly River Formation marks the onset of a long period of molasse type sedimentation in the southern Alberta Basin.

The Thistle Member of the Wapiabi Formation is the lowermost unit studied and consists of marine shale with abundant siltstone and thin sandstone laminae which were probably introduced into the basin by turbidity currents. In the southern part of the study area, the overlying Chungo Member is characterized by a lower thick coarsening upward shoreline sandstone body which is overlain by approximately 60 meters of nonmarine coastal plain sediments. The coarsening upward sequence is dominated by turbidites and hummocky and swaley cross stratification. These structures are believed to record a significant storm influence in a shallow marine setting. In the central part of the study

area, nonmarine Chungo strata are absent. The nonmarine strata appear to have been replaced by thick sections of nearshore to shallow marine sandstones and mudstones which are organized into several coarsening upward sequences. Each sequence is capped by a thin transgressive conglomerate or pebbly mudstone. In the northern part of the study area, the Chungo Member is represented by a 5 meter interval of bioturbated sandstone which overlies an anomalously thick interval of bioturbated sandy mudstones of the Hanson Member. The Chungo interval is interpreted to have been deposited by a wave and storm dominated shoreline complex which prograded from south to north into the Alberta Basin.

The Chungo regression was terminated by the Nomad transgression which shifted the Cretaceous shoreline approximately 150 km to the south. This shoreline retreat is essentially nondepositional although the base of the overlying marine sequence is commonly marked by a thin pebbly mudstone or conglomerate. The transition from the marine Nomad Member to the overlying nonmarine Belly River Formation is typically abrupt and occurs across less than 5 meters of section. In the south, this transition is marked by a sharp based trough cross stratified sandstone unit approximately 5 meters in thickness which rests directly on bioturbated mudstone and which is overlain by rooted carbonaceous nonmarine strata. These fining upwards sandstone units are interpreted as low energy tidally influenced shoreline deposits. In the northern half of the study area, the Nomad to Chungo transition is marked by a thin coarsening and thickening upward sandstone-mudstone sequence. This sequence is capped by a trough cross stratified and parallel laminated sandstone which is thought to have been deposited by the progradation of a beach type shoreline.

Little paleocurrent data were available from this Nomad-Belly River regressive sequence but previous heavy mineral studies have indicated that the source area lay to the northwest and that major drainage systems flowed to the east and southeast.

Petrographic data suggest that the Chungo and Belly River Formation, were derived from different source areas. During Chungo time, much of the sedimentary detritus was derived from the Elkhorn volcanic field of west central Montana. During deposition of the lower Belly River sandstones much of the sediment was derived from erosion of uplifted sedimentary, volcanic, and metamorphic rocks in the rising Cordillera to the west and northwest.

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1. Introduction

The study of facies and facies sequences in clastic depositional systems has proven to be a powerful tool for unravelling the stratigraphic and tectonic history of a sedimentary basin and determining the depositional environments which existed within that basin. However, only in the last few years has this approach been employed on a systematic basis in the Western Canadian Sedimentary Basin. Despite excellent exposures afforded by the thrust belt, little is known of the sedimentology of many of the Cretaceous clastic units as little work has been done since the stratigraphic mapping was completed in the late fifties and sixties.

The object of this study was to describe and interpret a series of stratigraphic sections from the thrust belt of southwestern Alberta. These sections exposed the transition between the marine strata of the Wapiabi Formation and the nonmarine strata of the Belly River Formation. This interval, was chosen because previous, mostly single outcrop studies, reported conflicting stratigraphic and sedimentological interpretations and it was hoped that a systematic regional approach would resolve these problems.

The strata are interesting from a sedimentological point of view as previous investigators (Hunter, 1980; Bullock, 1981) have reported turbidites, and both hummocky and swaley cross stratification in the beds transitional between the Wapiabi and Belly River Formations. These features are considered to be indicative of storm dominated marine sedimentation. It was believed that a better understanding of the sedimentology and paleogeography of a unit that contained these structures would aid in the understanding of the processes active in an ancient storm dominated environment.

From a tectonic point of view, this transition is significant as it marks the end of a long period of marine sedimentation, which had resulted in deposition of 600-1500 meters of marine strata of the Alberta group. It also marks the beginning of a long period of nonmarine sedimentation which resulted in the deposition of approximately 1000 meters of Belly River strata. The massive influx of coarse clastic detritus into the basin was presumably due to increased orogenic activity in the rising Cordillera to the west. Thus a better understanding of the sedimentology of these molasse type deposits could be useful in resolving the problems of the timing and continuity of this orogenic activity.

In economic terms, the transition is also significant as the vast gas reserves (more than 5 trillion cubic feet recoverable) of the Milk River gas field, located 200 km to the east, are hosted in a unit which is stratigraphically equivalent to that studied in this thesis. Previous investigations have demonstrated that the trapping mechanism for the Milk River field is stratigraphic and related to a regional shaling out of the Milk River Sandstone. It was thought that a better understanding of the depositional processes that are observed in the foothills exposures should aid in the exploration and development of the relatively sparsely drilled area between the Milk River field and the foothills.

Format of the thesis

The data base for this thesis consists of 12 stratigraphic sections that were mapped in detail during the summer of 1981. A drafted copy of each section is located in the pocket in the back of the thesis. The first and second chapters are an introduction to the nature of the project and to the structural and stratigraphic setting of the study area. The third and fourth chapters review the nomenclature schemes and sedimentological models that have been previously developed for the units studied. Chapters five to nine present a summary of the data which is organized in terms of facies descriptions, facies sequences, paleocurrent measurements and petrographic descriptions. Chapter ten is a review of the micropaleontological studies that have been conducted on this interval and includes some additional data generated from the present study. Chapters eleven and twelve summarize the interpretations of the various facies and facies sequences and chapters thirteen and fourteen discuss source terrain, dispersal patterns and the nature of the diagenetic processes which affected the Belly River and Chungo Sandstones.

2. Geological Setting

(a) Structural Setting

Most of the outcrops examined in this study are located in the Foothills Structure Belt which forms the eastern margin of the Southern Canadian Cordillera. This belt is characterized by a series of subparallel, steeply westward dipping imbricate thrust plates in Cretaceous clastic sediments. The fault planes are the surface expression of relatively flat thrust faults in the Paleozoic carbonates at depth (Wheeler et al., 1972). The bulk of movement was translational and involved slippage along major listric thrust faults. However, rotational movement is significant at the steeply dipping upward terminus of the fault planes where concentric folds are formed (Dahlstrom, 1970). The boundary between the Foothills Belt and the Main Ranges, farther to the west, is defined at the first range where resistant cliff forming Paleozoic carbonates are thrust over the recessive Cretaceous clastic units (Price et al., 1972). The Coleman and Oldman River outcrops examined in this study are located west of the Main Ranges-Foothills boundary and thus are part of the Main Ranges structural

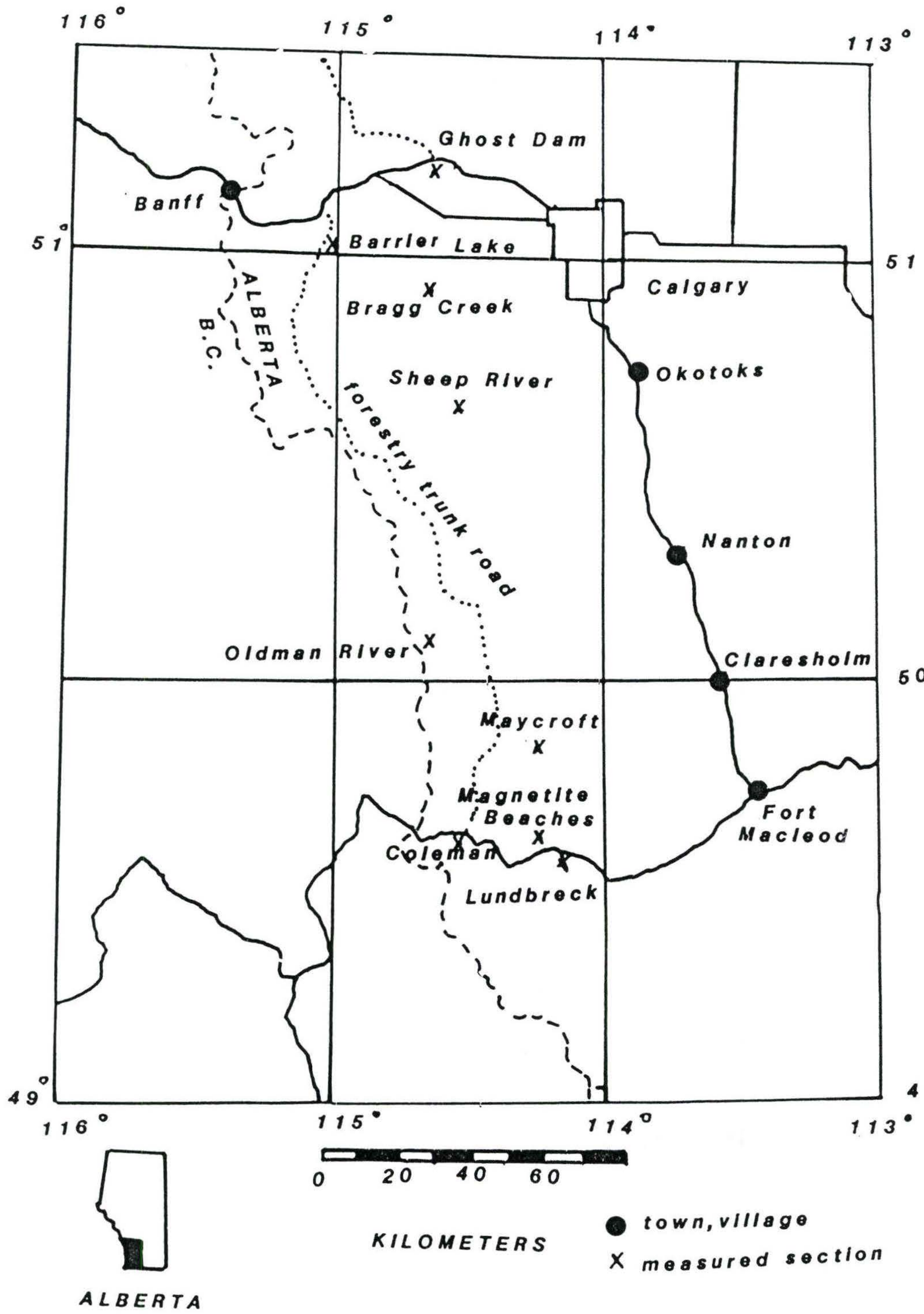


Figure 1 Section Location Map

domain. The Coleman outcrop is exposed in the footwall of the Coleman Thrust Sheet and the Oldman River outcrop is located in the footwall of the Lewis Thrust Sheet at the base of the Highrock Ranges (Fig. 1).

(b) Stratigraphic Setting

The sedimentary rocks that were examined in this study were deposited in the West Alberta Basin and comprise part of an eastward thinning Late Proterozoic to Tertiary sedimentary package which rests unconformably on Hudsonian crystalline basement (Fig. 2,3)(Wheeler et al., 1972; Jones and Workum, 1978).

The gross configuration of this West Alberta Basin was defined by the Precambrian Shield to the northeast, the continental margin or incipient Rocky Mountains to the southwest and the Peace River and Sweetgrass Arches to the northwest and southeast respectively (Fig. 4)(Stelck, 1975).

The oldest sediments exposed are the Middle to Late Proterozoic Purcell and Windermere Groups. These strata form a thick (to 13,000 meters) dominantly clastic miogeoclinal sequence that rests unconformably on the Hudsonian Basement and apparently prograded westward from the Proterozoic continental landmass (Wheeler et al., 1972). This sequence is unconformably overlain by the transgressive Middle Cambrian Gog Quartzite which is, in turn, overlain by a thick succession of Lower Cambrian to Lower Ordovician

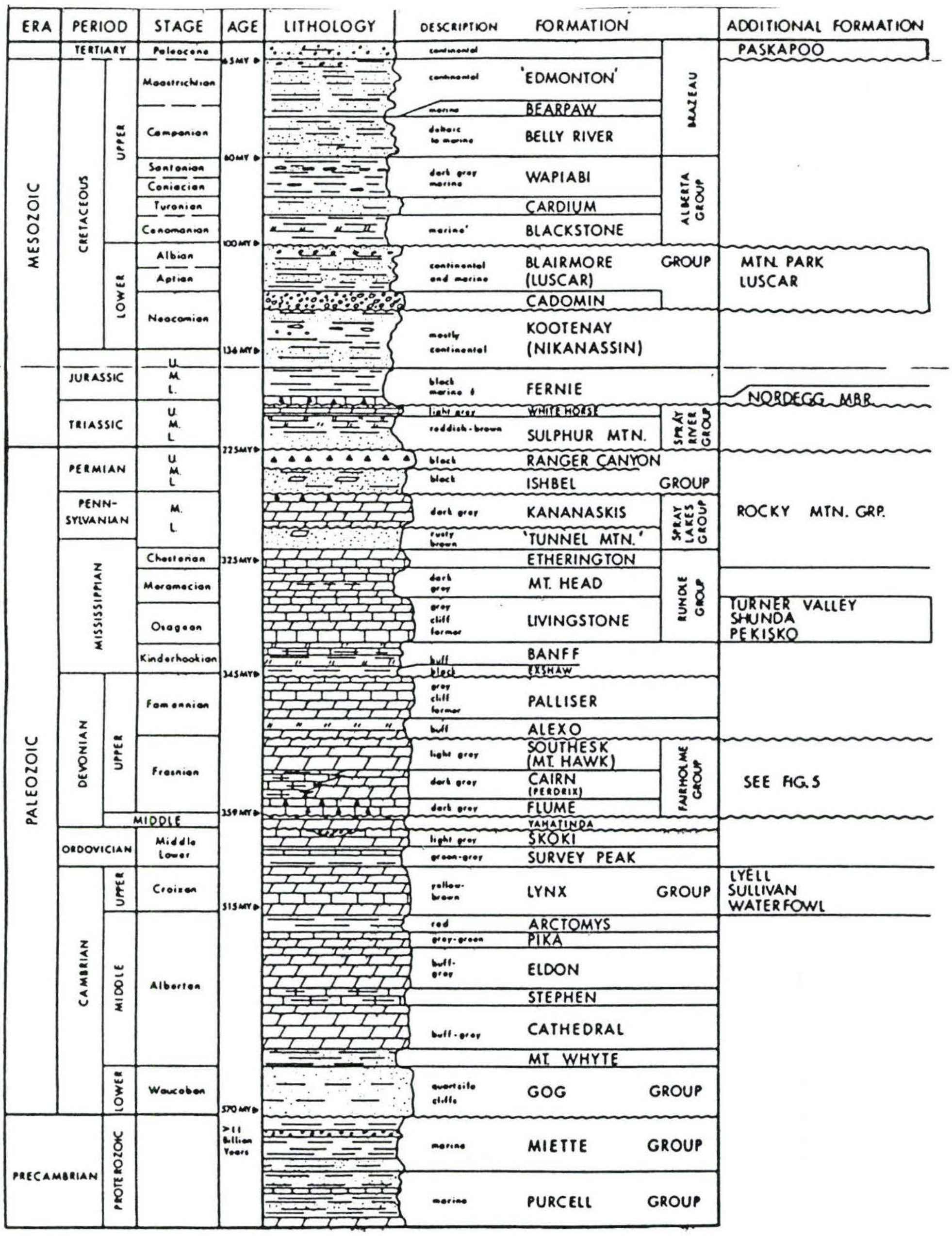


Fig. 2 Table of Formations (Jones and Workum, 1978)

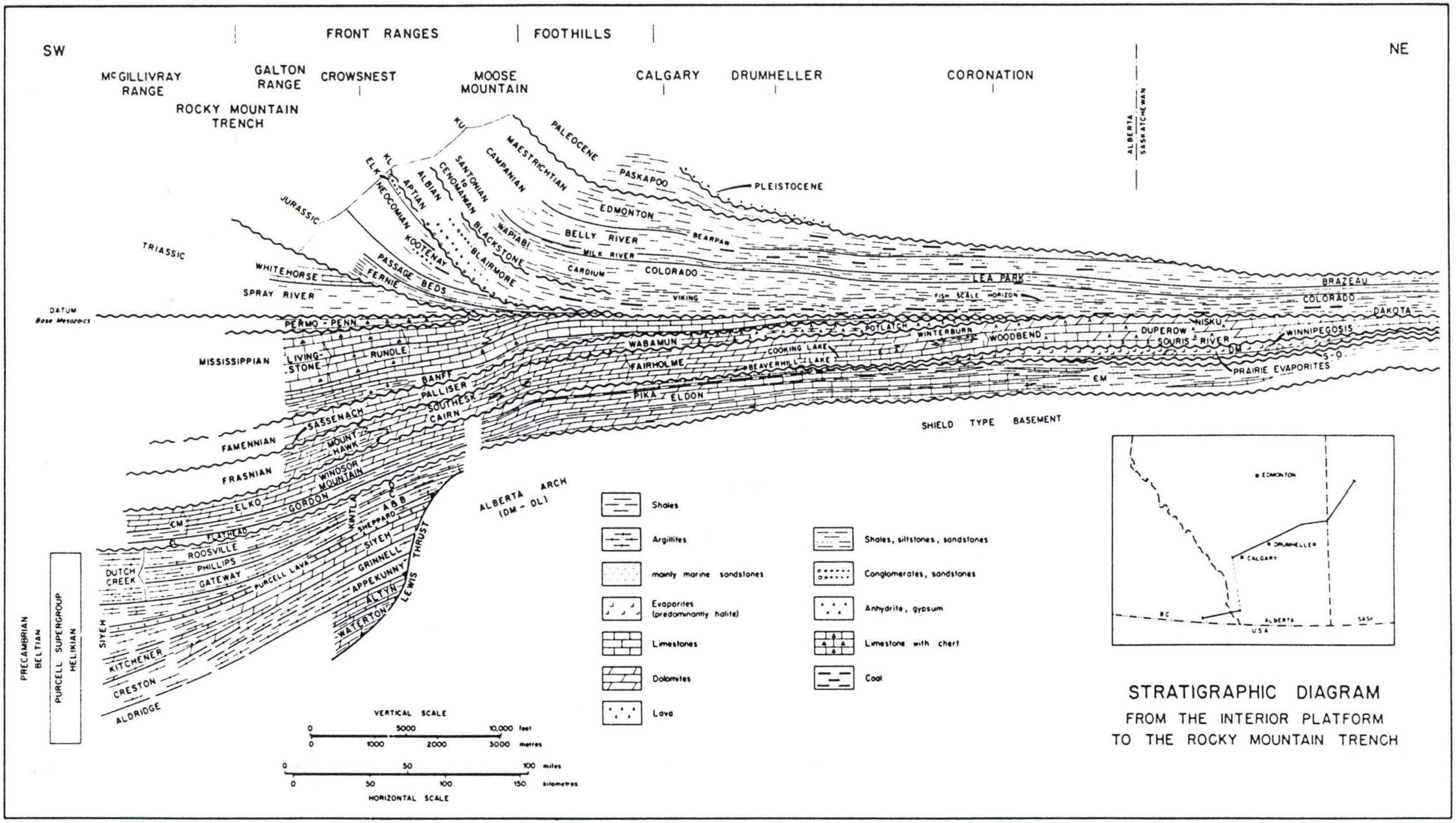
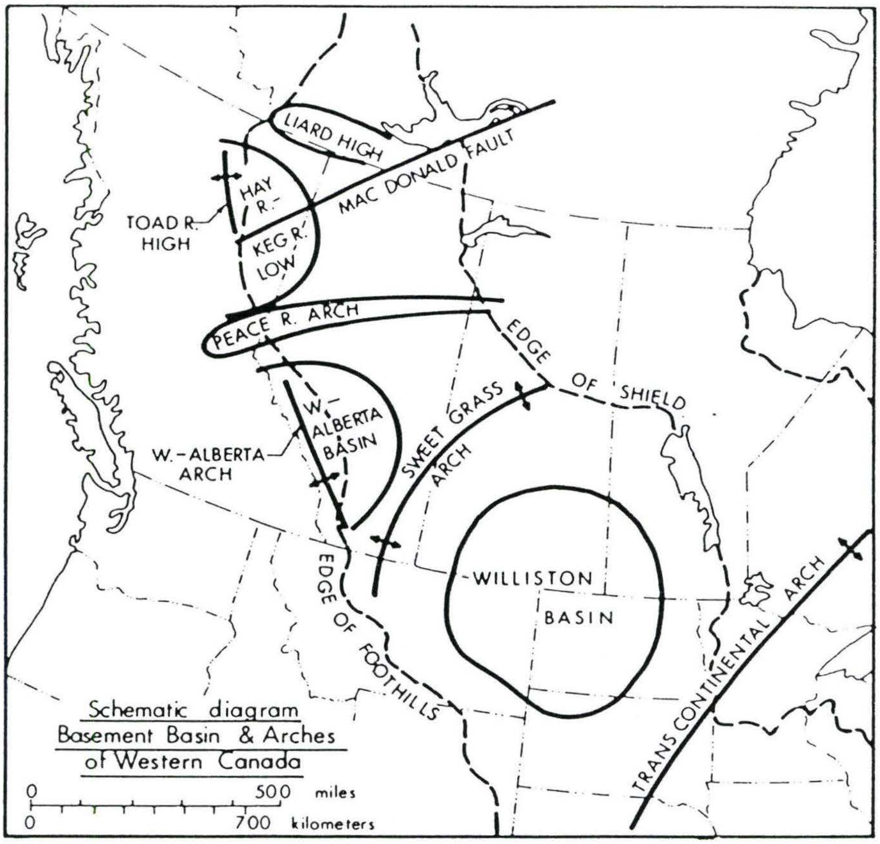


Figure 3 (from Wheeler et al., 1972)



Schematic diagram of Precambrian basement features of western Canada.

Figure 4 (from Stelck, 1975)

miogeoclinal shales and carbonates. A profound unconformity in the Early to Middle Devonian was followed by a major transgressive event. This resulted in shelf carbonate sedimentation across most of Alberta and development of major reef complexes during the Middle and Upper Devonian period (Belyea and Labrecque, 1972).

A minor unconformity at the top of the Upper Devonian was followed by an extensive transgression. This transgression resulted in the deposition of thick Mississippian shelf carbonate sequences across the entire Alberta Basin (Norris and Bally, 1972). This sequence gradually shoaled upward and became emergent during the Late Mississippian and Pennsylvanian eras.

The transition from the dominantly Paleozoic miogeoclinal carbonate depositional regime to the dominantly clastic Mesozoic and Tertiary exogeosynclinal "foredeep" regime occurred during a major transgression that spanned from Upper Pennsylvanian to Middle Jurassic time. The Late Jurassic to Early Tertiary clastic wedge that is preserved in the Alberta Basin is dominated by two clastic megacycles. These are termed the Kootenay-Blairmore assemblage (Jurassic-Lower Cretaceous) and the Belly River-Paskapoo assemblage (Upper Cretaceous to Tertiary) (Eisbacher _et al_., 1974).

The marine shales and siltstones of the Fernie Formation are the earliest record of sedimentation in the elongate foreland basin. Uplift and thrusting associated with the Late Jurassic to Early Cretaceous Columbian Orogeny provided a massive influx of coarse clastic material into the basin. This resulted in the withdrawal of the Fernie Sea and deposition of a thick regressive sheet of sandstone which was overlain by the dominantly nonmarine Kootenay and Blairmore Groups (Eisbacher _et al_., 1974; Hamblin and Walker, 1979).

A major unconformity separates the upper Blairmore group from the overlying marine shales, siltstones and sandstones of the Upper Cretaceous Alberta Group

(Blackstone, Cardium, Wapiabi Formations)(Stott, 1963).

A second pulse of uplift and thrusting in the western Cordillera occurred during the Late Cretaceous to Early Tertiary Laramide Orogeny. Concomittent erosion of the thrust sheets resulted in a second massive influx of coarse clastic material into the Alberta Basin. This resulted in the deposition of the Belly River, Edmonton, and Paskapoo Formations (Eisbacher, 1979). This sedimentological study was initiated to determine the nature of this transition between the marine Alberta Group and the nonmarine Belly River Formation. A more detailed discussion of the stratigraphy is presented in the next section.

3. Lithostratigraphic Nomenclature in the Upper Cretaceous South and Central Alberta

Lithostratigraphic nomenclature remains ambiguous and inconsistent for much of the Upper Cretaceous stratigraphy in southern Alberta, despite several recent attempts to clarify the various classification schemes that have evolved (Russell, 1970; McLean, 1971, 1977). Part of the confusion can be attributed to the construction of independent "local" schemes in different areas, each of which was developed before the correlations were understood. More importantly, detailed sedimentological studies reveal that the stratigraphy has a "non layer cake" geometry. Thus, simple "layer cake" lithostratigraphic classification schemes are of limited use.

To properly outline the evolution of the nomenclature system presently used in the southern foothills, some of the earlier regional studies will have to be discussed. In general, these studies include areas outside the study area of this thesis and encompass much larger stratigraphic intervals than this thesis is concerned with. They are included to clarify the use and limitations of the presently employed nomenclature system. The following discussion will be broken into four sections. The first two sections will describe the nomenclature of the surface and subsurface exposures for the southern plains and southern foothills respectively. The third section will discuss the nomenclature of the subsurface formations in central Alberta. The final section will describe the nomenclature system employed in this study and will relate this system to other nomenclature schemes.

(a) Nomenclature in the Southern Alberta Plains

The term Belly River Formation was first applied by Dawson (1883) to describe a series of continental beds that were exposed along the Belly River in southern Alberta along a reach of the river that has since been named the Oldman (McLean, 1971). Dawson (1883) had subdivided the formation into the upper "Pale and Yellow Beds " and the lower "Sombre Beds". These beds overlay a sequence of "Lower Dark Shales", which he incorrectly interpreted to be equivalent of the what is now termed the Alberta Group. The upper "Pale and Yellow Beds" were overlain by the marine Pierre Shale (Dawson , 1883)(Fig. 5). In this paper, Dawson correlated the Belly River Formation with sandstones along the Milk River but as seen in Fig. 5, he failed to recognize the presence of a marine tongue and sandstone unit below the Belly River Formation.

Evolution of Belly River Nomenclature
In The Southern Plains of Alberta

	Dawson 1883		Dowling 1915		Williams & Dyer 1930	Russell & Landes 1940
	Pierre Shale		Bearpaw Formation		Bearpaw Formation	Bearpaw Formation
Belly River Formation	Pale & Yellow Beds	Belly River Formation	Pale & Yellow Beds	Belly River Formation	Pale Beds	Oldman Formation
	Sombre Beds		Foremost Formation		Foremost Beds	Foremost Formation
	Lower Dark Shales		Pakowki Formation		Pakowki Formation	Pakowki Formation
			Milk River Formation		Milk River Formation	Milk River Formation

Fig. 5 (from Crockford, 1949)

Stanton and Hatcher (1905) concluded that the sandstones of the Milk River area were very similar to their Judith River, Claggett and Eagle Formations of northern Montana and they recommended that Canadian geologists adopt their nomenclature system. Stanton and Hatcher (1905) also recognized that the "Lower Dark Shales", as described by Dawson (1883), were actually part of a thin marine tongue that separated the Milk River from the Belly River sandstones.

Dowling (1915) introduced the name Milk River for the lowest sands outcropping along the Milk River and introduced the name "Pakowki" for the overlying marine shale. Dowling (1915) also changed the name of the "Sombre Beds" to the Foremost Formation and introduced the name "Bearpaw Formation" for the marine shale overlying the "Pale and Yellow Beds". He also recommended that the term "Belly River Formation" be used a general term to include the Milk River, Pakowki, Foremost, and the Pale and Yellow Beds (Fig. 5).

Williams and Dyer (1930) shortened the name of the Pale and Yellow Beds to "Pale Beds" and recommended that use of the term Belly River be restricted to include only the strata between the marine shales of the Pakowki and Bearpaw Formations (Fig. 5).

Powers (1931) and Slipper and Hunter (1931) recommended that the Foremost-Pale Beds terminology be employed in the subsurface studies. Irwin (1931) suggested that the Canadian classification was so ambiguous that it should be dropped entirely and that the American Eagle-Claggett-Judith River system should be adopted.

Russell and Landes (1940) introduced the name Oldman for the former Pale Beds. They also recommended that both the Oldman and Foremost receive formational status and that the name "Belly River" be discarded altogether. They defined a type section for the Milk River Formation and suggested that it should be divided into a Lower Member, consisting of massive sandstone, and an Upper Member, consisting of interbedded mudstones, lignites and sandstones.

Crockford (1949) pointed out that it was virtually impossible to pick the Foremost-Oldman contact and his views were later echoed by McLean (1971).

Tovell (1956) introduced a three part subdivision for the Milk River Formation in the southern Alberta plains. The Transition Beds (or Telegraph Creek Member) are transitional between the underlying calcareous shale of the Colorado Group and the overlying massive sandstone of the Virgelle Member. The Virgelle Member is sharply overlain by mudstones, lignites, and sandstones of the Deadhorse Coulee Member. The upper contact of the Deadhorse Coulee Member is marked by a thin layer of chert pebbles which is overlain by marine shales of the Pakowki Formation. The Pakowki Formation is, in turn, overlain by the Foremost and Oldman Formations (Tovell, 1956).

A later paper by Russell (1970) argued for retention of the classification of Russell and Landes (1940) and attempted to discount the adoption of the American system on the basis that significant differences exist between the stratigraphy of Alberta and Montana.

McLean (1971, 1977) conducted exhaustive comparisons of Alberta and Montana stratigraphy. He concluded that the Canadian system should be abandoned and that the Eagle-Claggett-Lea Park-Judith River classification system should be adopted by Canadian geologists for use in surface and subsurface studies. The Eagle Formation would include the Upper and Lower Milk River Members of Russell and Landes (1940) and the Transitional, Virgelle, and Deadhorse Coulee Members of Tovell (1956). The sandy shales extending beyond the depositional limit of the Eagle Formation, and the Pakowki Formation, would be grouped into the Lea Park Formation (McLean, 1971)(Fig. 6). McLean (1977) also recommended that the Belly River name be retained in the foothills exposures where no marine unit separates the Eagle (Milk River) Formation from the Judith River (Belly River) Formation. However, it will be demonstrated in this thesis that a marine tongue does exist throughout almost the entire foothills trend and thus, such a distinction would be of very limited use. Since the differences between the stratigraphy of the plains and the foothills are apparently not as obvious as McLean (1977) has presented, two different nomenclature systems may not even be required.

(b) Southern Foothills Nomenclature

The earliest stratigraphic mapping was attempted by Dawson (1883) who outlined the Fox Hills, Pierre and Belly River Formations as being part of the "Cretaceous Series" group. He incorrectly correlated these with units of a similar age in the northern United States (Stott, 1963).

Cairnes (1905) mapped exposures in the foothills just southwest of Calgary and introduced the terms Cardium,

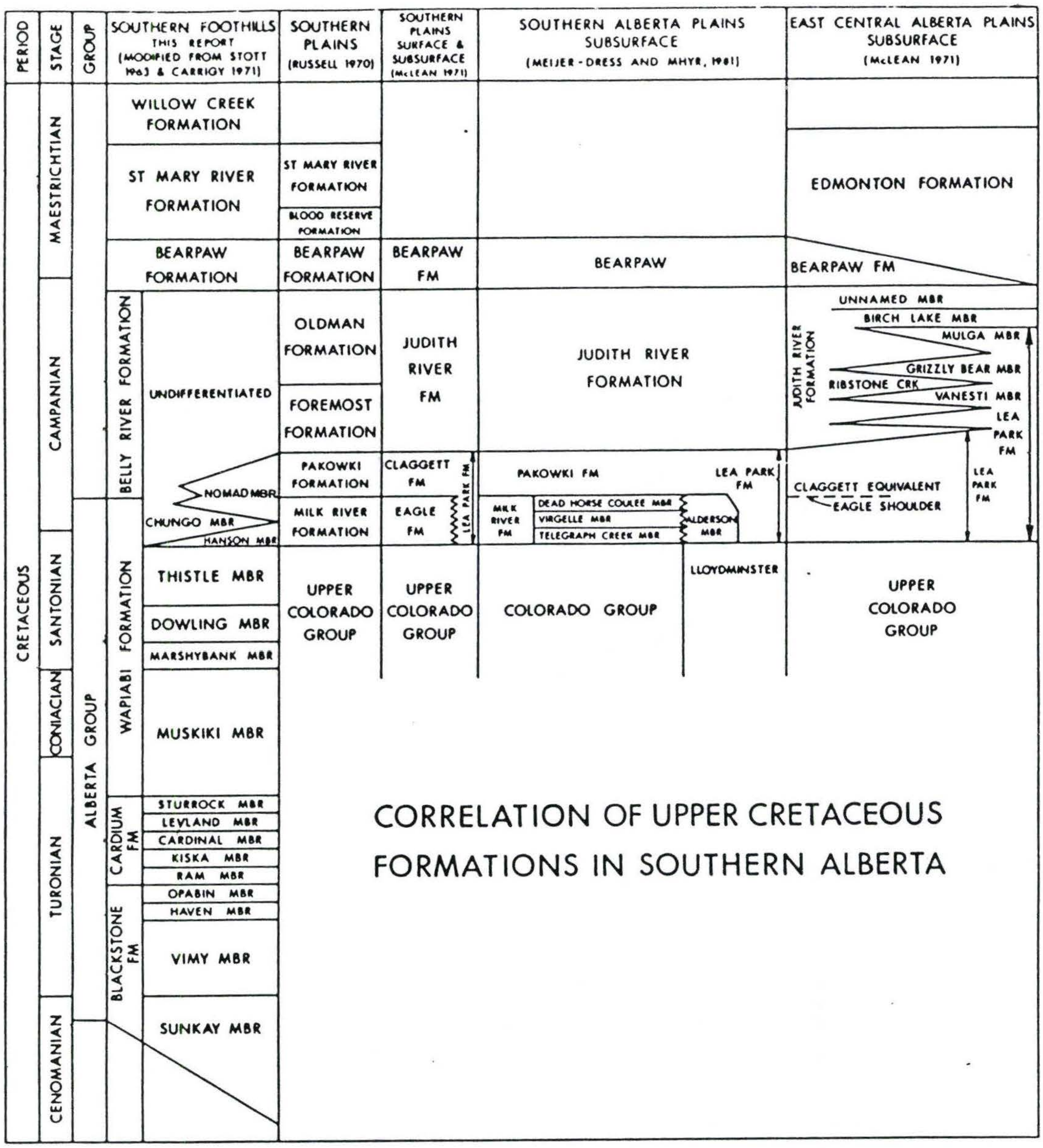

PERIOD
STAGE
GROUP
SOUTHERN FOOTHILLS THIS REPORT (MODIFIED FROM STOTT 1963 & CARRIGY 1971)
SOUTHERN PLAINS (RUSSELL 1970)
SOUTHERN PLAINS SURFACE & SUBSURFACE (McLEAN 1971)
SOUTHERN ALBERTA PLAINS SUBSURFACE (MEIJER-DRESS AND MHYR, 1981)
EAST CENTRAL ALBERTA PLAINS SUBSURFACE (McLEAN 1971)
CRETACEOUS
MAESTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBERTA GROUP
WILLOW CREEK FORMATION
ST MARY RIVER FORMATION
ST MARY RIVER FORMATION
BLOOD RESERVE FORMATION
EDMONTON FORMATION
BEARPAW FORMATION
BEARPAW FORMATION
BEARPAW FM
BEARPAW
BEARPAW FM
BELLY RIVER FORMATION
UNDIFFERENTIATED
NOMAD MBR
CHUNGO MBR
HANSON MBR
OLDMAN FORMATION
FOREMOST FORMATION
JUDITH RIVER FM
JUDITH RIVER FORMATION
JUDITH RIVER FORMATION
UNNAMED MBR
BIRCH LAKE MBR
MULGA MBR
GRIZZLY BEAR MBR
RIBSTONE CRK
VANESTI MBR
LEA PARK FM
PAKOWKI FORMATION
CLAGGETT FM
LEA PARK FM
PAKOWKI FM
LEA PARK FM
CLAGGETT EQUIVALENT
EAGLE SHOULDER
LEA PARK FM
MILK RIVER FORMATION
EAGLE FM
MILK RIVER FM
DEAD HORSE COULEE MBR
VIRGELLE MBR
TELEGRAPH CREEK MBR
ALDERSON MBR
WAPIABI FORMATION
THISTLE MBR
DOWLING MBR
MARSHYBANK MBR
MUSKIKI MBR
UPPER COLORADO GROUP
UPPER COLORADO GROUP
COLORADO GROUP
LLOYDMINSTER
UPPER COLORADO GROUP
CARDIUM FM
STURROCK MBR
LEYLAND MBR
CARDINAL MBR
KISKA MBR
RAM MBR
BLACKSTONE FM
OPABIN MBR
HAVEN MBR
VIMY MBR
SUNKAY MBR
CORRELATION OF UPPER CRETACEOUS FORMATIONS IN SOUTHERN ALBERTA

Fig. 6

Niobrara-Benton, and Claggett to describe a lower shale, an intervening sandstone and an upper shale unit which was overlain by sandstones and shales of the Judith River Formation. His correlation with exposures of similar sequences in the northern United States were also later proven to be incorrect (Stott, 1963).

Rose (1920) recognized that the Cardium Sandstone, as defined by Cairnes (1905) was not equivalent to the Eagle Formation as Cairnes (1905) has implied.

Malloch (1911) studied the stratigraphy in the central foothills near the North Saskatchewan River and introduced the terms Blackstone, Cardium and Wapiabi Formations to describe the marine sequence overlying the Dakota Formation (Blairmore Group).

In 1930, Hume proposed the use of the name Alberta Group to describe the largely marine section between the Blairmore and Belly River Formations. He recommended that the names Colorado and Benton be discarded since slightly different stratigraphic intervals are represented between the Canadian and American strata bearing the same name.

A comprehensive study by Webb and Hertlein (1934) recommended that the Alberta name be raised to group status which would be subdivided into (ascending order) the Blackstone, Cardium, and Wapiabi Formations. They recommended further subdivision of each formation, by which the Wapiabi would be subdivided into a lower concretionary zone, a platy shale, an upper concretionary zone, and an uppermost transition zone. Webb and Hertlein (1934) also recognized a discrete sandstone unit within the upper Wapiabi Formation around Highwood River which they called the Highwood Sandstone.

Lerbekmo (1961) demonstrated that the Milk River Formation of the southern plains is equivalent to the Lower Belly River Formation and that the Oldman-Foremost Formations are equivalent to the Upper Belly River Formation. Lerbe kmo (1961) stressed the Pakowki Formation is thin or absent in the foothills and thus the distinction between Upper and Lower Belly River Formation (or Milk River and Foremost Oldman Formations) was virtually impossible (Fig. 6).

The most comprehensive and widely accepted classification of the Alberta Group was presented by Stott (1963)(Fig. 6). He retained the basic Blackstone-Cardium-Wapiabi system of Malloch (1911) and further subdivided the Wapiabi Formation into seven members. These are, in ascending order, the Muskiki, Marshybank, Dowling, Thistle, Hanson, Chungo, and Nomad Members. The characteristics of each unit will be described in detail in a subsequent section.

(c) <u>Nomenclature in the Subsurface of East Central Alberta</u>

Subsurface studies have documented that the Milk

River Formation is absent in central Alberta. This interval is represented by sandy shales of the Lea Park Formation. In addition, the Foremost Formation (Lower Belly River) has "shaled out" into a series of alternating marine shales and deltaic-continental sandstone bodies, each of which had been given a member status (Fig. 6)(Shaw and Harding, 1949; McLean, 1971).

(d) Nomenclature Employed in this Study

This study proposes several changes to the basic nomenclature scheme developed by Stott (1963) for the Wapiabi-Belly River interval in the southern foothills. The basis for the nomenclature problems centers on attempts to impose a layer cake type nomenclature scheme onto a stratigraphic sequence of which the component units exhibit wedge shaped geometries. It can be seen in Fig. 17 that the Hanson, Chungo, and Nomad Members of the Wapiabi Formation exhibit dramatic thickness variations across the study area. It is suggested here that the stratigraphic implications of these thickness changes must be resolved before a nomenclature scheme can be constructed.

Stott (1963) considered the Nomad Member to be part of the Wapiabi Formation north of the Ghost River and part of the Belly River Formation south of the Ghost River. His reasoning for this distinction is apparently related to the fact that south of the river, the overlying Belly River strata are very similar, lithologically, to the underlying nonmarine Chungo strata. Thus the two intervals should be grouped as a single unit, separated by only a relatively thin marine shale. It will be demonstrated in a subsequent section of this thesis that this shale marks a very distinct depositional "break". Thus strata above the shale (Belly River Formation) and the strata below the shale (Chungo Member, Wapiabi Formation) should be considered as very distinct units. This Nomad Member is thin or absent in the extreme southern part of the study area but does serve as a convenient marker bed in the rest of the area. Where the Nomad Member is absent, the Chungo and Belly River strata would presumably be very difficult to differentiate. However, it will be demonstrated that the petrographic characteristics of the two units are markedly different and may thus aid in differentiating these two units where the Nomad Member is absent.

Throughout the study area, the Chungo interval should be considered to be a member of the Wapiabi Formation. The Chungo Member is overlain by a marine facies of the Nomad Member in the north and the nonmarine Belly River Formation in the south.

The concretionary bioturbated sandy mudstones of the Hanson Member are observed to thicken dramatically in the northern part of the study area apparently at the expense of the overlying Chungo Member.

A summary of the correlations between the various stratigraphic schemes and areas is shown in Fig. 6. Biostratigraphic support for these correlations remains weak, due primarily to the paucity of micro and macrofauna in the foothills exposures.

4. Previous Sedimentological Studies of the Wapiabi and Belly River Formations and Equivalent Strata

(a) Southern Plains Surface Exposures

The earliest environmental interpretations of the Upper Cretaceous sediments were made by Dawson (1884). He described the lower Sombre Beds (Foremost Formation) as brackish water deposits and the overlying "Pale and Yellow Beds" as dominantly fresh water deposits. The abundance of brackish water fauna and lignite seams in the Foremost Formation and the presence of dinosaur bones and fresh water faunal assemblages in the Oldman Formation has been recognized by many other workers (Slipper and Hunter, 1931; Russell and Landes, 1940; Crockford, 1949). McLean (1971) has identified brackish and fresh water fauna throughout the sequence. He has also noted that an upward decrease in marine fauna is accompanied by an upward increase in fresh water fauna. McLean (1971) has interpreted the Judith River Formation (combined Foremost and Oldman Formations) to represent the depositional record of Mississippi type delta that prograded into a shallow inland sea.

A comprehensive study of the Foremost and Oldman Formations in the Milk River Area was published by Ogunyomi and Hills (1977). They based their interpretations on sedimentary structures, grain size analyses, microfauna content and the field relationships between the various depositional units. They interpreted the entire Foremost Formation as being transitional between the underlying Pakowki Formation (marine) and the overlying (nonmarine) Oldman Formation. The Foremost Formation consisted of five discrete depositional cycles. Each cycle included offshore transition beds, barrier island foreshore and shoreface beds, lagoonal and salt marsh deposits, and fresh water marsh deposits. The Oldman Formation was interpreted as a coastal plain-meandering stream deposit (Ogunyomi and Hills, 1977).

(b) Southern Foothills

In the first significant sedimentological study on the Wapiabi-Belly River interval, Stott (1963) divided the Wapiabi Formation into seven members (Fig. 7). Outcrops of the upper five members were examined in this thesis and thus only these will be discussed in detail.

The Dowling Member is a sequence of dark grey to rusty weathering rubbly shales which contains abundant sideritic concretions and thin platy siltstone interbeds. The Dowling was reported in only one outcrop in the southern foothills (Highwood Sec. 7; Twp 18; R3W5) and was approximately 30 meters thick (Stott, 1963).

Table of Formations

Southern and Central Foothills				Description
Series	Group	Formation	Member	
Upper Cretaceous	Alberta 2,000'-4,100'	Wapiabi 1,043'-2,146'	Nomad 90'-130'	Rusty weathering, rubbly shales, grading upwards into greenish grey shales and fine-grained, thinly bedded sandstones. Base is marked by band of pebbles.
			Chungo 135'-416'	Fine-grained, thickly bedded, light brown weathering sandstones (lithic arenites to quartz wackes), and dark grey siltstone with reddish brown weathering concretions.
			Hanson 0-232'	Dark grey, rusty weathering, blocky to rubbly shales, with reddish brown weathering sideritic concretions.
			Thistle 384'-778'	Dark grey to black, calcareous, platy to fissile shales, weathers grey to light grey, with thin, dense, bluish grey dolomitic beds.
			Dowling 101'-351'	Dark grey, rubbly to platy shales, weathers rust, with reddish brown weathering sideritic concretions.
			Marshybank 41'-104'	Dark grey, massive, argillaceous siltstone, with large reddish brown concretions, siltstone grades into sandstone.
			Muskiki 144'-325'	Dark grey, rubbly to platy shales, weathers rust and has banded or striped appearance, some reddish brown sideritic concretions. Bed of coarse-grained, pebbly sandstone or pebble-conglomerate at base.

Fig. 7 from Stott, 1963

The Thistle Member is a thick sequence of platy calcareous shales and siltstones that conformably overlies the Dowling Member. Thick lenticular dolomitic limestone concretions and thin sandstone laminae are common in some sections. Complete exposures of the Thistle Member were recorded along the Highwood and Ghost Rivers where they were 170m and 143m thick respectively (Stott, 1963).

The Hanson Member is defined as a dark grey to rusty weathering sequence of blocky to rubbly shale which contains abundant rusty sideritic concretions. The basal contact is gradational with the underlying Thistle Member and the upper contact is marked at the base of the overlying Chungo Member. The thickness of the Hanson Member is variable and maximum and minimum values of 29m and 59m were recorded from two exposures along the Sheep River (Stott, 1963). Stott (1963) has also observed that the Hanson Member appears to disappear south of the Bow River.

The Chungo Member is characteristically a fine grained, thick bedded, light brown weathering sandstone that contains abundant interbedded concretionary siltstones. The thickness of the Chungo Member in the study area varies from 25m along the Highwood River to 127m along the Oldman River. The lower contact is gradational into the underlying Hanson Member and is marked at the base of the first massive sandstone bed. Stott (1963) has reported that nonmarine carbonaceous strata was found in the upper part of the Chungo Member south of the Bow River. He had also described a distinct sandstone unit, the Highwood Member, as being the Chungo equivalent on the Sheep and Highwood Rivers. Stott (1963) has also reported that the shale unit separating the Highwood Sandstone from the remainder of the Chungo Member appeared to thicken eastward (Stott, 1963).

Stott (1963) described the Nomad Member as a sequence of dark shales and siltstones of relatively uniform thickness which is generally separated from the underlying

Chungo Member by a thin chert pebble conglomerate. The upper contact with the overlying Belly River Formation is also generally quite sharp and is defined at the base of a channel form sandstone or an upward coarsening sandstone-siltstone sequence.

Stott (1963) has interpreted that the Dowling Member represents the transgressive phase of a basinal megacycle. He cited the abundance of siderite concretions as evidence for mildly reducing, slightly restricted nearshore conditions. The overlying calcareous shales, siltstones and sandstones of the Thistle Member are considered to have been deposited further offshore than the sideritic facies of the Dowling Member under inundative open marine conditions. The Hanson and Chungo Members were deposited during a rather short lived regressive stage. This regression was terminated by the major transgression which deposited the marine mudstones of the Nomad Member. The Nomad transgressive phase was terminated by the massive influx of coarse clastics generated in the rising Cordillera to the west (Stott, 1963). Stott (1963) has also outlined smaller scale cycles and subcycles which he interprets as being due to oscillatory sealevel fluctuations.

Mellon (1961) investigated the sedimentary magnetite deposits of the Crowsnest Pass area. He concluded that most of the magnetite deposits were located at the top of the thick, massive weathering, trough cross bedded, fine to medium grained "Basal Belly River Sandstone". He interpreted the heavy mineral accumulations as due to selective sorting processes along an ancient shoreline complex that formed during regression of the Late Colorado Sea (Mellon, 1961).

Chemical, optical, and x-ray diffraction methods were employed by Campbell and Lerbekmo (1963) who differentiated between Belly River sandstones and Milk River sandstones on the basis of surface textures of the component sand grains. They interpreted that the bulk of the Belly River Formation was deposited in a coastal plain environment (freshwater). However, the local presence of glauconite and brackish water fauna led them to interpret that marine incursions were common (Campbell and Lerbekmo, 1963).

A subsurface study of the Alberta Group strata in the vicinity of Waterton, Alberta led Herr (1965) to conclude that the Hanson, Chungo, and Nomad Members of the Wapiabi Formation, as defined by Stott (1963) were absent in the study area. He also concluded that the Muskiki, Marshybank, Dowling, and Thistle Members were very difficult to distinguish in the subsurface (Herr, 1965).

Wall (1967) employed Stott's (1963) classification of the Alberta Group and identified ten distinct microfaunal assemblages (Fig. 8) of which the last five represent the interval studied in this report. The Muskiki, Marshybank, and Dowling Members are associated with the early

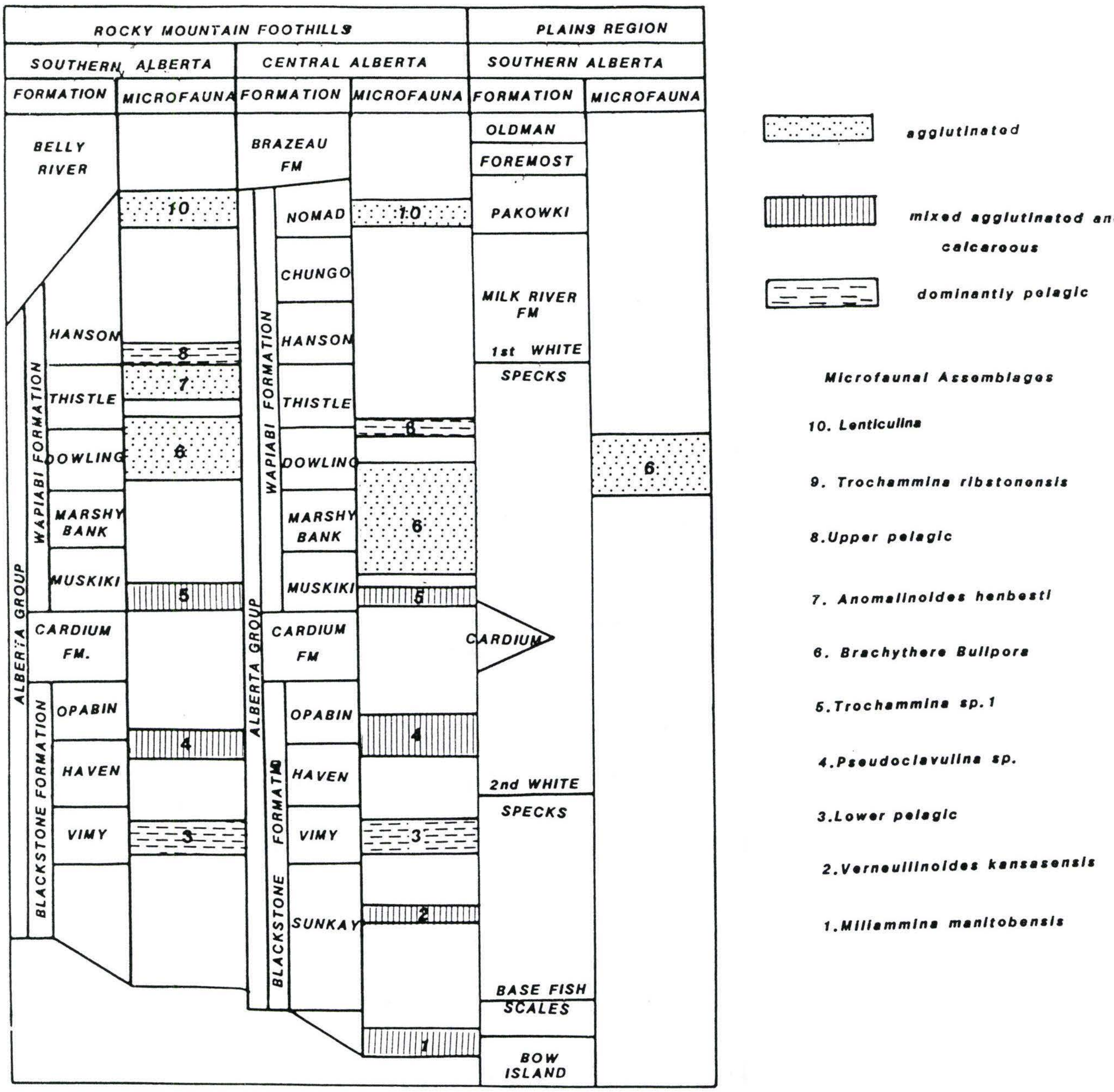


Fig. 8 Correlation diagram of the Upper Cretaceous stratigraphy and microfauna content in Southern Alberta redrafted from Wall, 1967

transgressive phase of the Wapiabi cycle and are represented by the number five and six microfaunal assemblage. The Thistle and Hanson Members record the maximum extent of the transgression and are represented by his number seven and eight assemblages. The Chungo regression is associated with a number nine assemblage and the final remnant of the Wapiabi Sea, the Nomad, is associated with assemblage ten. Wall (1967) also suggested that the Thistle Member became younger to the north and that the Late Cretaceous sea persisted longer in the northern and central foothills than in the south. This was demonstrated by the progressive disappearance of the younger faunal assemblages in the south.

Nelson and Glaister (1975) measured the lower part of the Trap Creek section and interpreted the coarsening upward sequence as a prograding delta sequence that was overlain by nonmarine channel sandstones and floodplain sediments. This section was recently reinterpreted by Walker et al. (1981) as a prograding storm dominated shoreline deposit.

The Lundbreck section was studied by Lerand and Oliver (1975) who interpreted the coarsening upward sequence as a distributary mouth bar deposit which was part of an eastward prograding delta complex. Lerand and Oliver (1975) cited the abundance of carbonaceous and micaceous laminae and the paucity of burrowing in fauna as support for a deltaic interpretation. This section was recently restudied by Bullock (1981). He pointed out the abundance of turbidites and hummocky cross stratification in the lower part of the sequence and the abundance of swaley cross stratification and plane lamination in the upper part of the sequence. Bullock (1981) interpreted the sequence as a regressive beach deposit and presented paleocurrent data which indicated that the shoreline prograded northward into the Cretaceous Seaway and not eastward as Lerand and Oliver (1975) had suggested.

Hunter (1980) recorded similar coarsening upward sequences in two exposures of the Wapiabi - Belly River transition along the Highwood River. The coarsening upward sequence was overlain by approximately 60 meters of nonmarine channel sandstone and floodplain deposits, which in turn were overlain by a thin marine shale unit. She suggested that both sections were deposited by a storm dominated shoreline system that prograded northward into the shallow Cretaceous sea. It will be demonstrated in this thesis that the marine shale is actually the Nomad Member of the Wapiabi Formation and not a previously unrecognized marine tongue, as she suggested (Hunter, 1980).

5. Facies Descriptions

A discussion of facies sequences and facies models was presented by Walker (1979) and this thesis has borrowed heavily from his approach. The concept of facies, as employed by de Raaf et al. (1965) has both descriptive and genetic implications. In this study the various sections were described in detail and particular attention was paid to the sandstone to shale ratio, the grain size, the type and degree of bioturbation, and the presence or absence of various sedimentary structures. When all the data were collected, the characteristics of the various units were compiled and 12 distinct facies were defined. This chapter is a summary of the descriptive parameters of the various facies. The genetic implications of each facies and the facies sequences overall will be discussed in subsequent chapters.

(a) Facies 1 Shale with interbedded siltstone and thin (less than 5cm) sandstone beds

Facies 1 forms the bulk of the Thistle Member although the facies is also observed in some of the other members of the Wapiabi Formation. This facies consists of an interbedded sequence of recessive weathering shales, siltstones and thin sharp based (less than 5 cm) sandstone beds. The color of the weathered surface varies from black to light grey and is related to the relative proportions of the shale, siltstone, and sandstone. The shale dominated sections are dark grey to black whereas the siltstone-sandstone dominated units are light to medium grey. Facies 1 strata is also important because the majority of ripple foreset orientations were measured from this facies.

Facies 1 has been divided into 3 subfacies, based on the relative proportions of shale, siltstone, and sandstone, as estimated visually in the field. These relative proportions can vary considerably across short stratigraphic intervals (less than 50 cm) and in many cases the contacts between the subfacies are gradational and very difficult to determine. It is generally difficult to distinguish between siltstone and very fine sandstone beds in the field, and in most instances, they were grouped together.

i <u>Subfacies 1a</u> Shale with fewer than 10% discrete siltstone and sandstone beds

Subfacies 1a is essentially a clean black mudstone containing 90% shale and up to 10% combined siltstone-sandstone (Plate 1A). This subfacies is generally a minor component of the section studied but, where found, it commonly forms relatively thick (5 to 15 meter) continuous sections. The unit typically has a micro blocky weathering texture, where, on a 1 to 2 cm scale, the rock appears to be non fissile and breaks with a splintery angular fracture pattern. The preservation of continuous very fine (less than 1 mm) silt laminae in the samples indicates that there is a planar fabric to the rock but the fracture and weathering patterns are only weakly influenced by this layering. However, in other exposures, subfacies 1a is very fissile and weathers into thin (0.1 to 0.3 cm) chips.

This unit commonly contains thin laminae and interbeds of siltstone and very fine sandstone from 0.5 to 1.5 cm thick. A few fine grained sandstone beds were also noted but they are relatively rare. The discrete beds generally retain their sharp base and top and are laterally continuous across several tens of meters. Internally the discrete beds retain very fine parallel laminations and small scale current ripple foresets with an amplitude of 0.5 to 1.0 cm and a wavelength of 5 to 20 cm.

Subfacies 1a is generally non to very weakly bioturbated. The microblocky weathering may suggest that the unit is massive and well bioturbated but the abundance of very fine silt laminae testify that the unit is non bioturbated.

The shale is not calcareous or dolomitic but some of the siltstone and sandstone interbeds are slightly dolomitic. The section may contain discrete rusty red concretions from 4 to 15 cm thick (average 10 cm) and 15 to

25 cm in length. These concretions may be randomly distributed and comprise from 1 to 2% of the total section, or they may be concentrated along discrete concretionary horizons.

ii <u>Subfacies 1b</u> Shale with fewer than 50% combined siltstone and thin (less than 5 cm) sandstone beds

Subfacies 1b is defined as a thinly bedded sequence of shale, siltstone, and thin (less than 5 cm) sandstone beds. In this facies, the shale comprises 50 to 90% of the section and the combined siltstone-sandstone interbeds made up the remaining 10 to 50% (Plates 1B and 1C).

In the exposures that were examined in detail, it was found that the ratio of discrete siltstone to sandstone beds averages 1:1. However, this ratio is very variable and the shale may contain only siltstone beds or only sandstone beds or any combination of the two.

The siltstone beds are very thin (0.05 to 0.8 cm) whereas the very fine sandstones are thicker (0.5 to 3.0 cm). The siltstone beds are typically parallel laminated and ripple foresets are absent or rare. The sandstone beds are sharp based and may retain parallel laminations, overlain by ripple laminae but these are extremely rare. The ripple foresets are similar to those in Subfacies 1a and have an amplitude of 0.5 to 1.0 cm and a wavelength of 5 to 20 cm.

The extent and nature of bioturbation is difficult to estimate. However the persistent preservation of very fine silt laminae in the shale indicates that it is non or very weakly bioturbated. The discrete sandstone and siltstone beds are typically sharp based but the upper contact of the beds may be non to well bioturbated. No systemic variation in the bioturbation was noted for all examples of this facies. In certain exposures all the very fine sandstone beds may be bioturbated across the top 0.4 to 1.0 cm whereas in other exposures the tops are not disturbed at all. Commonly, the thicker (1.5 cm) beds are undisturbed while the thinner less than 1.5 cm beds are weakly to moderately bioturbated across the top 0.5 to 1.0 cm.

Inoceramus fragments are the only macrofossils observed in the section.

Overall, concretions are rarely found in Subfacies 1b although minor buff to rusty red weathering concretions from 6 to 10 cm in thickness and 10 to 20 cm in diameter are present. These concretions may be randomly distributed or they may be concentrated along discrete horizons. Several concretionary horizons pinched out laterally into a thin (0.1 to 0.5 cm) rusty zones which were continuous across several tens of meters.

iii <u>Subfacies 1c</u> Shale with more than 50% thin (less than 5cm) siltstone and sandstone beds (Plate 1D)

Subfacies 1c is defined as a thinly bedded sequence of shale, siltstone and sandstone beds in which the sandstone forms the bulk of the section and the shale forms a smaller component. It is the most frequently observed unit in the Thistle Member.

The ratio of sandstone to shale is difficult to estimate but it varies from 1:1 to 4:1 and averages approximately 3:1. The ratios of the shale, siltstone and sandstone components may show pronounced variations across narrow stratigraphic intervals.

The sandstone beds vary from 0.5 to 5.0 cm in thickness and are generally thicker than those found in Subfacies 1a or 1b. The sand is very fine grained and may retain parallel lamination, ripple foreset lamination, or, rarely, parallel lamination overlain by ripple lamination. In general, parallel lamination is much more common than ripple lamination. Many of the thicker beds which retain this primary lamination also contain carbonaceous and micaceous partings which are best developed at the base and top of the discrete beds.

Subfacies 1c is more highly bioturbated than Subfacies 1a or 1b and it is characterized by moderately bioturbated siltstone and shale beds and weak to moderately bioturbated discrete sandstone beds. Generally the silt and shale is more highly bioturbated than the interbedded sandstone. The base of most of the sandstone beds is a mold of the upper surface of the underlying siltstone or shale.

Subfacies 1c has a more diverse trace fauna than both 1a or 1b. Rhizocorallium, a bedding plane U-shaped trace approximately 4 cm wide and up to 35 cm long, is present in several sections and is particularly well exposed at Sheep River. A narrow bilobate trail from 0.5 to 1.0 cm in width was observed forming irregular traces across the upper surfaces of discrete sandstone laminae and was interpreted as Gyrochorte. Reticulated crustacean burrows up to 1.5 cm in width and 25 cm in length are observed in a few sections. An unknown cone shaped burrow 5 cm long and tapering from 2 cm to 1cm in diameter is also observed in a few sections.

Inoceramus fragments are commonly found in this Subfacies and are concentrated in the concretionary layers. Poorly preserved molds of unidentifiable ammonites were also found in a few concretionary layers.

Buff to light grey dolomite concretionary lenses were commonly observed in Subfacies 1c. The individual lenses comprise less than 1% of the section and vary from 5 to 20 cm in thickness and 0.5 to 20 meters in lateral extent. Very commonly, the concretions contain molds of ammonite tests, oyster shells, and fish teeth. These concretionary horizons are commonly well developed at cycle

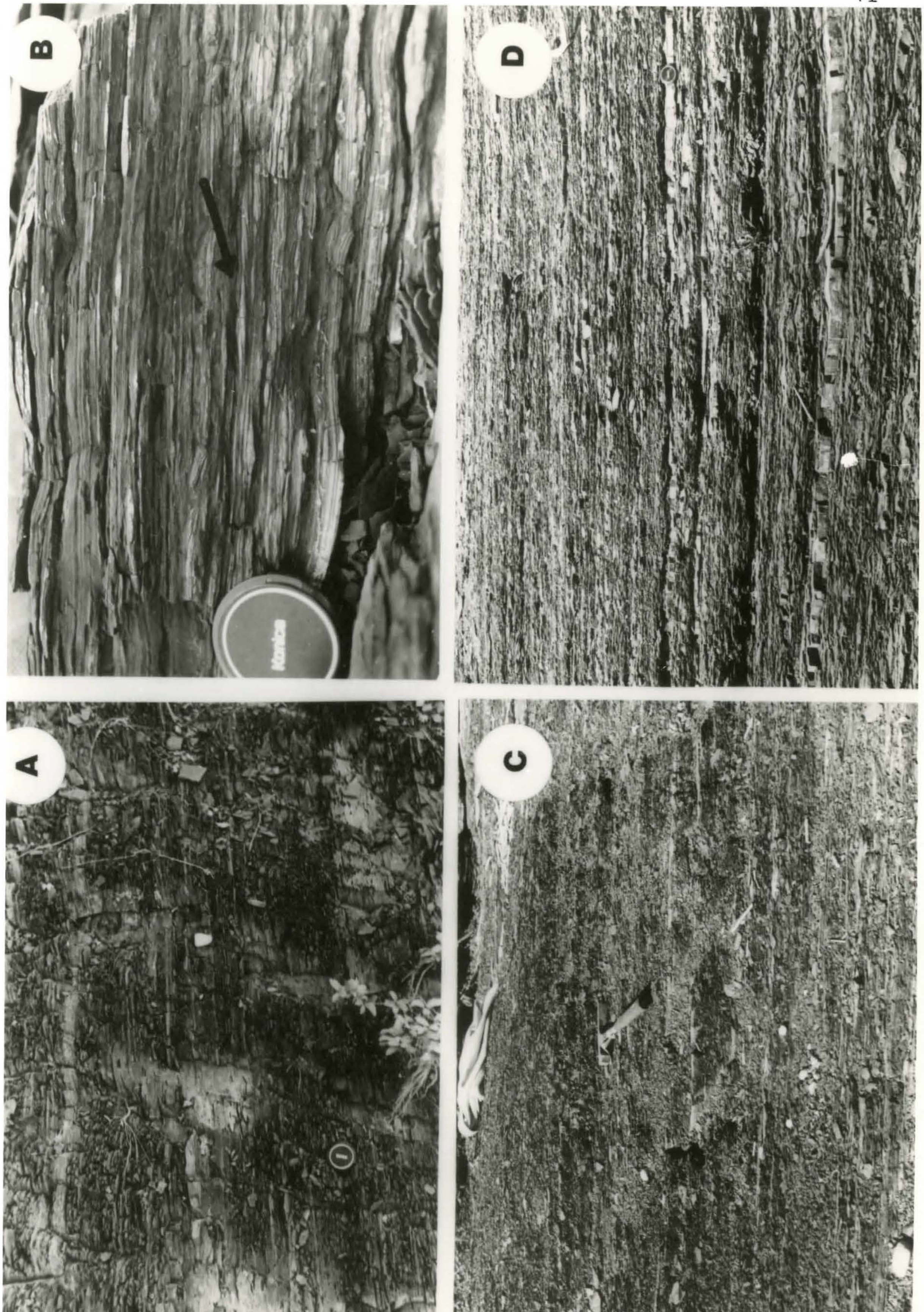
Plate 1

A. Photo of Facies 1a. Shale with fewer than 10% discrete sandstone and siltstone beds. Photo taken 48 meters above base of Barrier Lake section.

B. Close up photo of Facies 1b. Shale with 10 to 50% discrete sandstone and siltstone. Note ripple foreset lamination (see arrow). Photo taken 73 meters above base of Barrier Lake section.

C. Outcrop photo of Facies 1b. Shale with 10 to 50% discrete sandstone and siltstone. Note lateral continuity of discrete laminae. Photo taken 150 meters above base of Ghost Dam section.

D. Outcrop photo of Facies 1c. Shale with more than 50% discrete sandstone and siltstone beds. Note all beds less than 5 cm thick. Photo taken 140 meters above base of Ghost Dam section.


A
B
C
D

tops (see facies sequences Chapter 6) where they may contain a few scattered chert pebbles.

(b) Facies 2 Siltstone with interbedded thin (less than 5 cm) sandstone beds Plate 2A

Facies 2 is defined as a sequence of light to medium grey weathering interbedded siltstone and thin sandstone beds. It is very similar to Subfacies 1c except Facies 2 units contain no discrete shale beds whereas Subfacies 1c can contain significant proportion of interbedded shale (up to 50%).

The proportion of discrete sandstone beds in the section varies from 10 to 90%. The beds vary from 1.0 to 5.0 cm and average 2.5 cm in thickness. The sandstone is generally very fine grained although some of the thicker beds contain fine grained sand. Normal size grading was observed in a few beds. Parallel lamination was preserved in a number of beds and was accentuated by carbonaceous and micaceous partings at the top and base of some of these beds.

The siltstone beds are typically thin (.2 to .5 cm) bedded and are markedly sandy and argillaceous in the more highly bioturbated sections.

The siltstone beds are generally more heavily bioturbated than the adjacent sandstone beds. Thicker sandstone beds are less bioturbated than adjacent thin

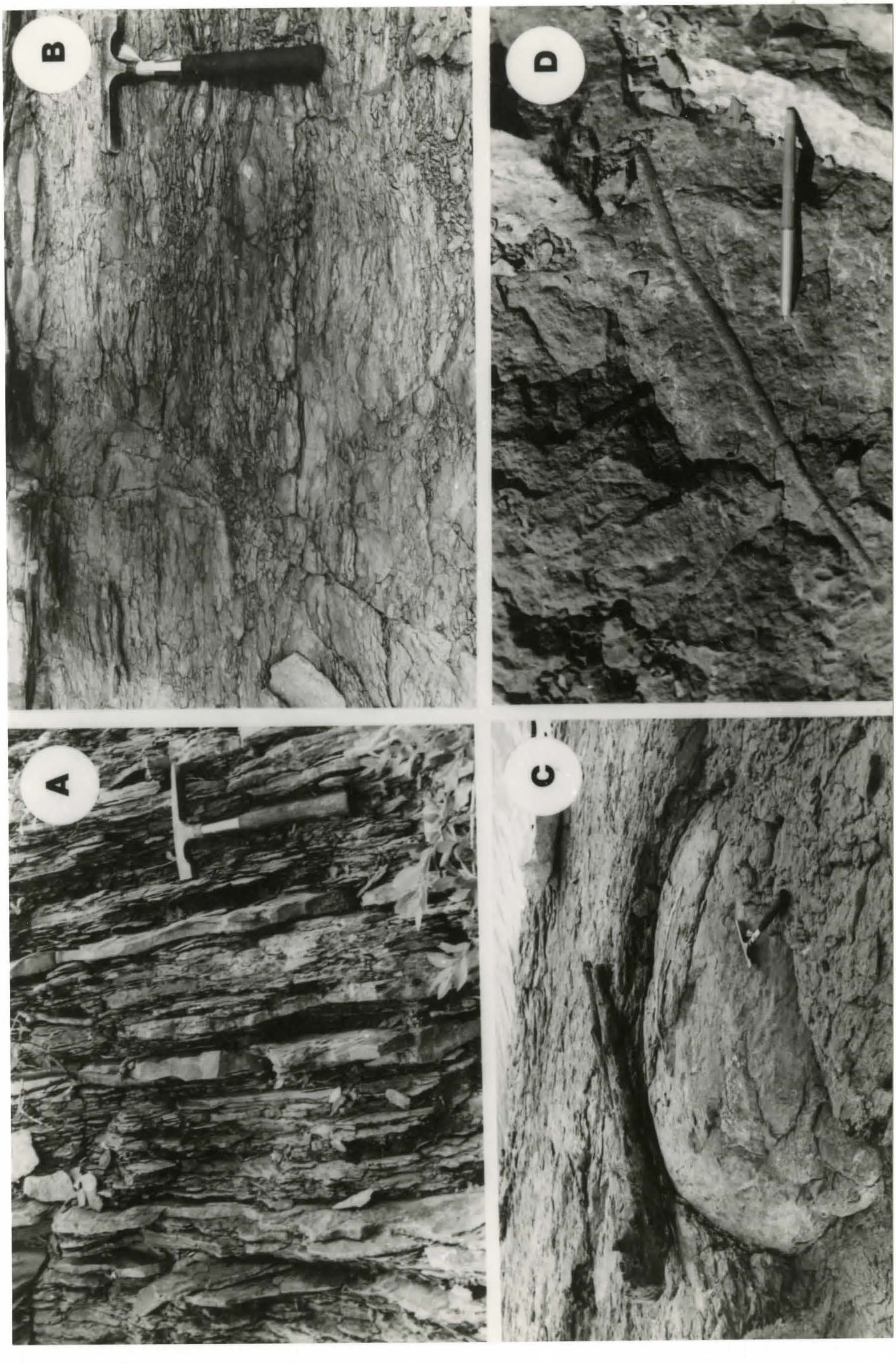
Plate 2

A. Facies 2. Siltstone with discrete, thin (less than 5 cm) sandstone beds. Note general absence of discrete shale laminae. Photo taken 15 meters above base of Sheep River section.

B. Facies 3. Bioturbated sandstone. Note almost complete absence of bedding and irregular crumbly weathering. Photo taken 91 meters above base of Sheep River section.

C. Facies 4. Bioturbated sandy mudstone. Note giant concretion. Photo taken at top Chungo Member 308 meters above the base of the Ghost Dam section.

D. Facies 4. Bioturbated sandy mudstone. Note reticulated crustacean burrow along bedding plane. Photo taken 24 meters above base of section.


A
B
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sandstone beds. In the thicker sandstone beds the base and top of the beds are preferentially burrowed and the core may not be disturbed by burrowing.

The only trace fossil identified was Cosmoraphe, a thin vermiformis trail approximately .2 cm wide. This trace was found along relict bedding planes within the siltstone and sandstone.

(c) Facies 3 Bioturbated sandstone Plate 2B

Facies 3 constitutes a relatively small proportion of the Upper Wapiabi section and consists of moderately to well bioturbated sandstone.

Sandstone units containing thick (greater than 5 cm) discrete sandstone beds are assigned to Facies 5.

This unit is typically light to medium grey brown and has an irregular blocky weathering surface. In most exposures, the sandstone is completely bioturbated and only discontinuous lenses of discrete beds are preserved.

The discrete beds, where preserved, vary from .8 to 5.0 cm in thickness and consist of very fine grained to fine grained sandstone. Parallel lamination is common while ripple foreset lamination is rare to completely absent. The sandstone enclosing the discrete beds is argillaceous and silty and retains little or no primary bedding.

Many of the discrete sandstone beds are preferentially bioturbated at their top and base but retain primary lamination in their central "core". Most of the beds are discontinuous along strike due to local differences in the intensity of burrowing.

The only lebenspurren identified in Facies 3 is Cosmorhaphe a narrow (.2 cm) vermiformis trace that is common on many bedding planes in the sandstone.

(d) Facies 4 Bioturbated sandy mudstone
Plates 2C,D,3A

Facies 4 is defined as a medium to dark grey, massive to blocky weathering, completely bioturbated sandy mudstone. It is restricted to the northern and central parts of the study area and it is the type lithology of Stott's (1963) Hanson Member. Thick sections of Facies 4 are exposed in the Ghost Dam and Barrier Lake sections.

Due to the high degree of bioturbation, it is very difficult to estimate the relative proportions of sand, silt, and shale within any particular outcrop. It appears that there is considerable variation in the proportions of these components as the sandier and siltier sections are light colored and resistant weathering whereas the argillaceous units are dark grey and very recessive.

The outcrops are generally very recessive and the rock crumbles into fragments .5 to 2.0 cm in size. In a few exposures at Barrier Lake, discontinuous lenses of sandstone up to 15 cm thick are present. These lenses are moderately bioturbated at their top and base and pinch out laterally, due to more intense bioturbation locally. A few of the lenses retain parallel lamination internally but this is rare and most of the lenses are bioturbated throughout.

Buff to rusty colored concretions are common in Facies 4 and typically comprise 1 to 2% of the entire section. They may be randomly distributed throughout the section but generally they are concentrated in discrete layers. The concretions vary from 5 to 100 cm in diameter and are typically 5 to 20 cm thick. In some exposures they are amorphous while in others they have well defined ovoid shapes. The concretions are generally massive internally. However in the Ghost Dam section, many of the concretions have a Baculites test at their center and it appears that the concretion formed around the shell.

Much of Facies 4 consists of alternating concretionary and non concretionary units from 2 to 10 m in thickness. The concretionary units may be sandier than the non concretionary units but the difference is very subtle. In the Ghost Dam and Barrier Lake sections, concretionary units containing scattered chert pebbles cap two distinct coarsening upward cycles (see facies sequences, Chapter 6)

It is very difficult to identify the trace fauna associated with this highly bioturbated unit. Reticulated crustacean burrows approximately 1.0 cm wide were observed in the concretionary zone which caps a coarsening upward cycle at Ghost Dam (Plate 2D).

On the same surface described above, a small cone shaped burrow approximately 8 cm long and tapering from 2 cm to 1 cm in diameter was observed.

(e) <u>Facies 5</u> <u>Interbedded sandstone and mudstone facies.</u>
(Discrete sand beds thicker than 5 cm).
Plate 3B,C,D

Facies 5 is characterized by a medium grey to buff weathering sequence of discrete sharp based sandstone beds (thicker than 5 cm) which are interbedded with shale, siltstone or bioturbated sandstone. This facies is generally restricted to the lower parts of the Chungo Member. It is typically underlain by thinly bedded mudstones and sandstones (Facies 1 to 4) and is typically overlain by a hummocky cross stratified section. Many of the ripple foresets and most of the solemark orientations that were measured in this study were gleaned from exposures of Facies 5.

The discrete sandstone beds are typically very fine to fine grained but a few of the thicker beds have a thin (less than 5 cm) clay pebble lag at their base which contains clay pebble clasts up to 1.0 cm in diameter. Apart from this abrupt change in grain size, which only exists in a few beds, normal size grading is very rare. Concentrations of very finely comminuted carbonaceous and micaceous material are found at the base of a few beds while other beds retain carbonaceous and micaceous partings throughout. The discrete sharp based beds commonly exhibit parallel lamination and ripple foreset lamination. Very rarely the beds exhibit parallel lamination overlain by ripple foreset lamination, analogous to Bouma Tbc beds of classical turbidites. To a certain extent the paucity of ripple foreset data may reflect their limited preservation potential as the ripples are generally found at the tops of beds where bioturbation is more pronounced. Hummocky cross stratified beds (Facies 6) are occasionally interbedded with Facies 5 lithologies but these were generally rare. In certain exposures many of the discrete sandstones beds were capped by low amplitude (0.5 to 1.0 cm) short wavelength (5 to 20 cm) straight crested symmetrical wave ripples. In general, the orientation of the long axes of these ripples in stratigraphically juxtaposed beds were subparallel. However in some cases the long axes diverged by as much as 50 degrees.

Facies 5 was subdivided into two subfacies, based on the lithology of the beds which are interbedded with the discrete sandstone beds.

i Subfacies 5a

This subfacies consists of sharp based sandstone beds which are interbedded with shale or siltstone. The proportion of discrete sandstone beds ranges from 20 to 80% and averages approximately 50% of the section. The discrete beds vary from 1.0 to 30 cm and average 10 cm in thickness.

In general the beds are very continuous along strike (across several tens of meters). However, in some exposures, extensive bioturbation has destroyed the continuity of the beds.

The siltstone and shale beds which separate the discrete sand beds vary in thickness from thin (less than .1 cm) partings to silt-shale interbeds up to 25 cm thick. The siltstone and shale is typically light to medium greenish grey and recessive weathering. It is generally moderately to well bioturbated although in the Lundbreck section, the shale and siltstone beds retain fine lamination and are non bioturbated.

Subfacies 5a contains a diverse trace fauna. Irregular bilobate trails approximately 0.5 cm wide were commonly found on the top of discrete sand beds and are identified as Gyrochorte. Thick (1.5 to 2.5 cm) burrows with very rough nodular inner walls form complex networks within some bedding planes. These are interpreted as Ophiomorpha, a burrow of the callianassid shrimp family. A thin vermiformis trail on many bedding surfaces in the shale and siltstone is tentatively identified as Cosmoraphe. In outcrops at Sheep River and Longview where bedding planes were well exposed, abundant subcircular depressions approximately 10 to 15 cm in diameter and 1 to 3 cm deep were observed but they could not be identified.

With the exception of a few Inoceramus fragments, no body fossils were identified in Subfacies 5a.

ii Subfacies 5b

Subfacies 5b is characterized by tan to light grey sharp based sandstone beds which are interbedded with argillaceous, silty, well bioturbated sandstone. The discrete sandstone beds vary from 1 to 15 cm and average 8 cm in thickness. In the Lundbreck section, the sandstone beds are markedly thicker (15 to 30 cm) than in other sections studied. The beds are generally continuous across several tens of meters.

The sandstone present between the discrete sand beds is light grey, , tan or rusty colored and typically has a very irregular blocky weathering habit. This sandstone is moderately to well bioturbated but in a few exposures, it retains thin (less than 5 cm) discontinuous lenses and layers of sandstone.

The trace fauna observed in Subfacies 5b is very similar to that observed in Subfacies 5a. Gyrochorte is commonly found on top of discrete sand beds and is particularly abundant at Sheep River. Ophiomorpha is found in both the discrete sand beds and in the enclosing sandstone. These burrows are generally parallel to bedding and in some cases form a network of interconnected burrows. Cosmoraphe is commonly found in the argillaceous silty sandstone. A few reticulated crustacean burrows approximately 1.0 cm wide and 15 cm long are exposed at Longview. Also, the argillaceous "matrix" sandstone at Longview contains several unidentified conical tube burrows which are 5 cm long and tapered from 2 cm to 1.0 cm in diameter.

At Sheep River, some of the discrete sandstone beds contain vertical escape burrows which cut across a single 12 cm thick bed. The burrows are very abundant and in places comprise up to 30% of the cross sectional area of the bed. These vertical burrows have a horizontally ribbed internal wall and are commonly terminated at the base by a small "blob" of sediment that protrudes into the underlying shale (Plate 3C).

In the Lundbreck section a single sandstone bed in subfacies 5a contains a vertical burrow which consisted of a series of concave upward concentric halfround rings, each approximately 5 mm wide, which are oriented normal to bedding. This burrow is tentatively identified as Teichichnus (Plate 3D)(G.Pemberton, pers. comm. 1983).

No macrofossils were identified in Subfacies 5b.

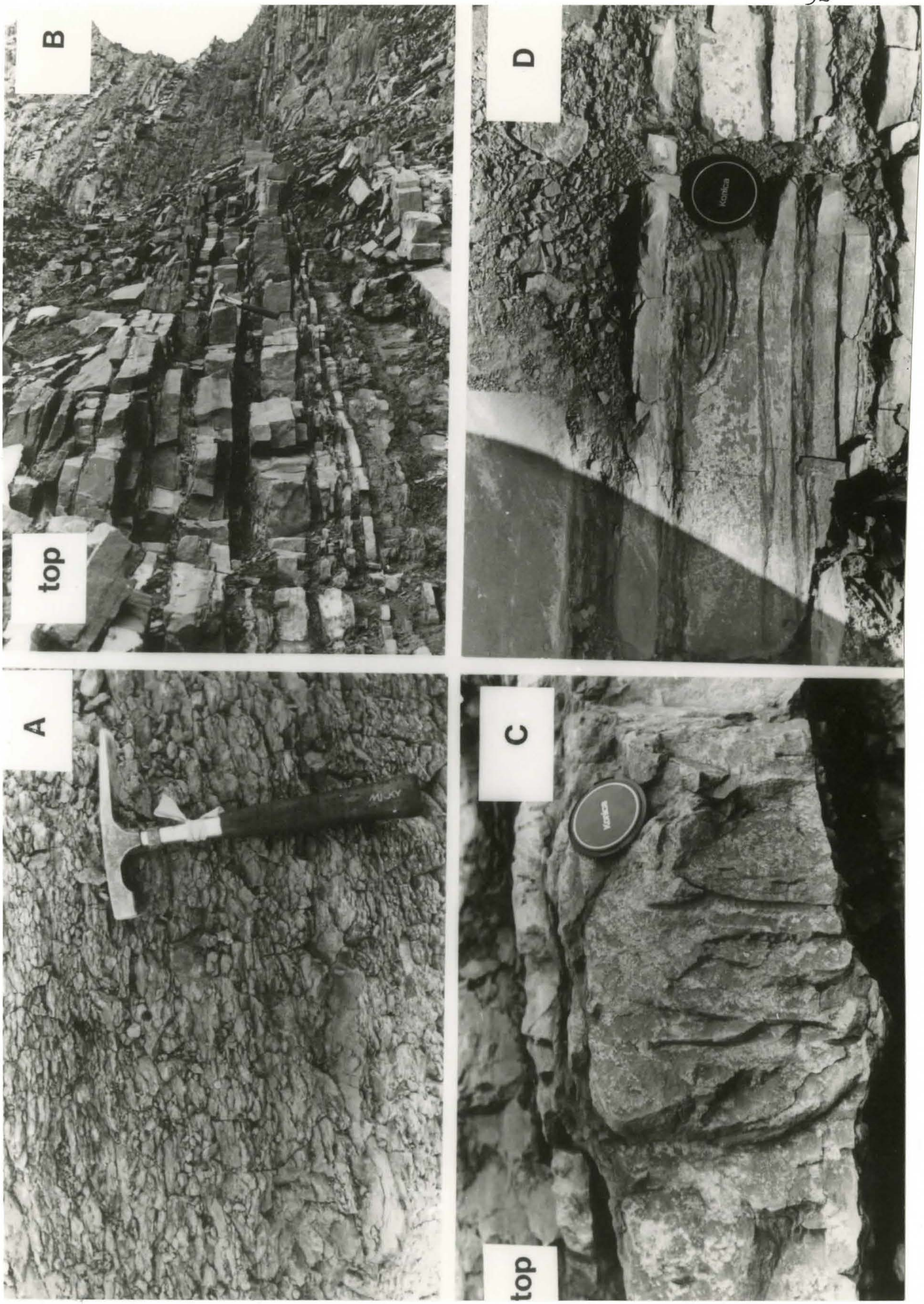
Plate 3

A. Facies 4. Completely bioturbated sandy mudstone. Note crumbly weathering pattern and complete absence of bedding. Photo taken 240 meters above base of Ghost Dam section.

B. Facies 5a. Interbedded sharp based sandstone beds and shale. Note the lateral continuity of the beds. Stratigraphic tops at base of the photo. Note offsetting small displacement fault in the background. Photo taken 100 meters above the base of Sheep River section.

C. Facies 5a. Note the ribbed vertical escape burrows in discrete sandstone beds. Photo taken 101 meters above base of the Sheep River section. Possibly *Stipsellus*.

D. Facies 5a. *Teichichnus* trace fossil. Photo taken 62 meters above base Lundbreck section.


A
B
C
D
top
top

(f) Facies 6. Hummocky Cross Stratified Facies

Facies 6 is characterized by a sequence of thick sharp based sandstone beds exhibiting hummocky cross stratification which are interbedded with shale and thin sandstone and siltstone beds. The term hummocky cross stratification (HCS) was first introduced by Harms et al. (1975) and the reader is directed to this paper and others by Hamblin and Walker (1979), and Dott and Bourgeois (1982) for a more complete discussion of this bedform.

This facies is restricted to the upper portion of the coarsening upward cycles. The HCS facies is typically underlain by Facies 5a or 5b and overlain by a loaded sandstone unit of Facies 7. The thickness of the hummocky cross stratified facies within a single coarsening upward cycle varies from a maximum of 24 meters in the Lundbreck section to a minimum of 4 meters in the Barrier Lake section.

The sharp based sandstone beds typically comprise approximately 60% of the HCS facies but this proportion is very variable. In some cases, an isolated HCS bed may be present in an otherwise continuous section of Facies 5. On the other extreme, the discrete HCS beds may constitute the entire section and no shale or siltstone laminae are observed between the sand beds (amalgamated HCS).

The discrete HCS beds vary from 8 to 240 cm and average approximately 30 cm in thickness. Generally the thicker discrete beds are found in the upper portion of the HCS interval. The beds are generally continuous across several tens of meters, particularly those in the lower portion of the HCS section. However, in the Lundbreck, Coleman, and Oldman River sections, the beds in the upper portions of the hummocky section are very lenticular and pinch out from 50 cm to 5 cm in thickness across a lateral interval of less than 10 meters.

The base of the sand beds is typically sharp and may retain flutes and toolmarks. More commonly, the base of the bed is a mold of the burrowed upper surface of the shale or siltstone underlying the hummocky bed.

Internally, the discrete beds contain parallel and weakly convergent laminae which are bounded by low angle (<10°) truncation surfaces (Plate 4A). A pattern of convex upward domes or hummocks and concave upward swales is well developed (Plate 4B). The amplitude of these undulations varies from 2 cm to 30 cm. Within the Lundbreck and Oldman River sections, the thick, complete hummocky sections that are exposed display a more pronounced hummock/swale topography in the upper part of the HCS interval. The angle between the convergent laminae also increases in the upper part of the hummocky cross stratified interval.

Most of the beds are flaggy weathering and break into .8 to 1.5 cm slabs which are separated by thin (<.1 cm) carbonaceaous, micaceous partings containing abundant wood fragments up to 2 cm in length. Some of the thicker discrete beds (>50 cm) are massive weathering at the base and become flaggy with carbonaceous partings in the uppermost 20 to 30 cm of the bed. Straight crested symmetrical wave ripples with an amplitude of .4 to .8 cm and a wavelength of 25 to 40 cm were observed at the top of a few HCS beds.

Most of the beds consist of fine grained sandstone throughout the bed. Some of the thicker beds have a thin (<2 cm) clay pebble layer at their base which contains clay pebbles up to 2.0 cm in diameter. No graded sequences were observed in the section.

The lithology of the section between the discrete hummocky beds is very variable and may consist of shale, siltstone or "turbidites" of Facies 5a or 5b. The interval between adjacent hummocky beds varies from 0 to 100 cm and averages 15 cm in thickness. In the amalgamated HCS sections, adjacent hummocky beds are superimposed directly on each other and no intervening siltstone or shale is present.

Bioturbation is not pronounced in the HCS facies sandstones although the top 1 to 10 cm of some of the discrete HCS sand beds may be moderately bioturbated. Narrow (.5 cm) bilobate Gyrochorte trails were found on the upper bedding surfaces of a few HCS beds. An unidentified narrow (.2 cm) burrow with a shallow U-shaped structure was

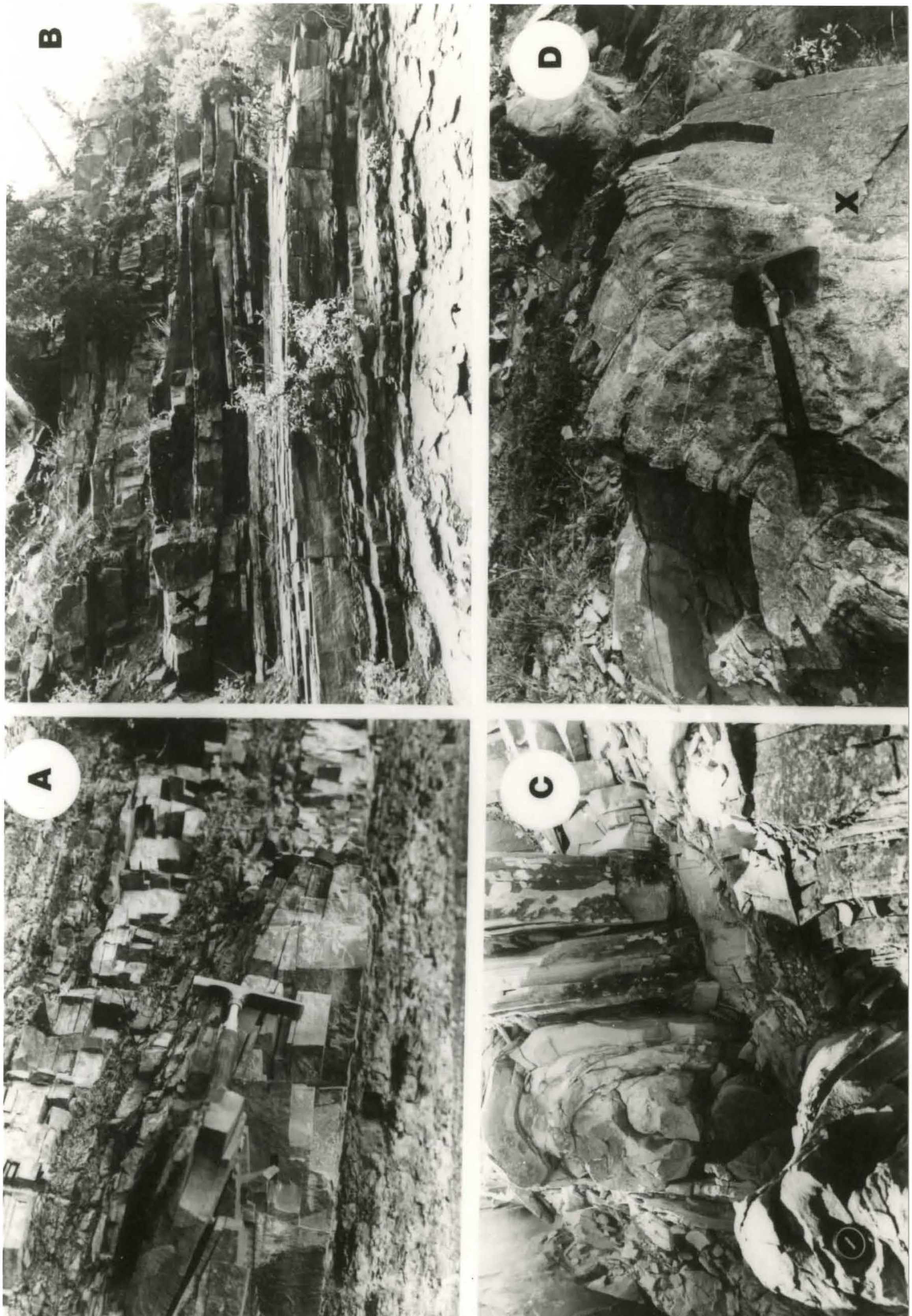
Plate 4

A. Close up of convergent laminae in Facies 6, hummocky cross stratified sandstone. Note flat base and undulating top. Photo taken 99 meters above base of Lundbreck section.

B. Facies 6. Hummocky cross stratified sandstone. Note gently undulating upper and lower surface to discrete hummock marked with X. Photo taken 152 meters above base of Sheep River section.

C. Facies 7. Loaded sandstone, top to left of photo. Photo taken 123 meters above base of Sheep River section.

D. Facies 7. Loaded sandstone. Note the curved or deformed laminae are truncated at upper bedding surface marked X. Photo taken 257 meters above base Trap Creek section.


A
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found at the top of a few beds in the Maycroft section. Large "pock marks" or bowl shaped depressions approximately 2 cm deep and 15 cm in diameter were found at the top of many hummocky beds but these could not be identified. The Longview section contained hummocky sand beds with good Thalassinoides traces on the base, but this trace fauna was generally very rare.

(g) Facies 7. Loaded Sandstone Facies. Plate 4C,D

The loaded sandstone facies is characterized by buff to tan colored massive weathering sandstone beds which contain abundant soft sediment deformation structures. In some exposures, successive loaded units may be stacked directly on top of each other (e.g. Trap Creek). In other exposures, the loaded units are separated by intervening units of interbedded sandstone and mudstone (Facies 5a or 5b). Exposures of Facies 7 were only observed within the Chungo Member. The loaded facies consistently forms the base of the massive weathering "main" Chungo sandstone and is generally underlain by a hummocky cross stratified unit and is typically overlain by a swaley cross stratified unit. The thickness of the loaded unit is variable and a maximum of 15 meters of loaded facies sandstone is present in the Trap Creek section.

The basal contact of this facies is defined at the first exposure which contains beds with soft sediment deformation structures. The upper contact of the loaded zone may be gradational into the overlying swaley facies or it may be separated from the swaley facies by a sharp contact.

The discrete loaded units vary from .5 to 4.5 meters and average 1.5 meters in thickness. The beds are commonly very lenticular and can pinch out from 3.3 to 1.0 m in thickness across a lateral distance of less than 40 meters. This thickness change is related to the undulating basal contact of the bed which appears to load to various depths into the underlying units. This contact is very sharp and no deformation structures exist in the underlying beds. In the Trap Creek section, some of the loaded beds have a thin (<5 cm) basal layer which contains abundant clay pebbles.

The upper contact of the beds is flat to slightly undulating. In some cases, this surface appears to truncate deformed laminae within the bed itself. This surface commonly contains scattered chert pebbles up to 1.2 cm in diameter and round coal balls up to 1.0 cm in diameter (Plate 4D). In addition, this surface is commonly covered with symmetrical wave ripples which exhibit amplitudes of .5 to 1.0 cm and wavelengths of 10 to 25 cm.

The internal deformation structures are generally confined to the base in the thickest (greater than 1.0 meter) beds but continue throughout the entire bed in the thinner (less than 1.0 meter) beds. The deformation has folded a pre-existing (1-4 cm) lamination within the sandstone into narrow synclinal forms which commonly have an amplitude of 5 to 40 cm. To determine whether these fold structures had a preferred orientation, the fold axes of the best exposed structures were measured and plotted on a rose diagram, after correction for regional dip (Fig. 9). No consistent orientation is recognizable on the diagram although there are obviously an insufficient number of measurements to support or contradict the presence of a preferred orientation.

The upper portions of some of these beds are either massive or they can retain parallel to weakly convergent laminae from .8 to 1.0 cm in thickness which is similar to the lamination found in the overlying swaley section.

In most exposures the sand in the deformed portion of the bed is identical to that in the upper laminated portions of the bed. However, in the Trap Creek section, the sandstone in the upper laminated part of the discrete loaded beds is very fine grained, siliceous, and "tough" whereas the sand in the lower deformed part of the bed is fine grained and relatively friable.

Bioturbation is not pronounced in the loaded facies. Gyrochorte and Planolites traces are observed on the top surface of a few loaded beds. Also, the top of the beds may contain bowl shaped depressions up to 20 cm in diameter and 5 cm deep. These appear to be organically formed but

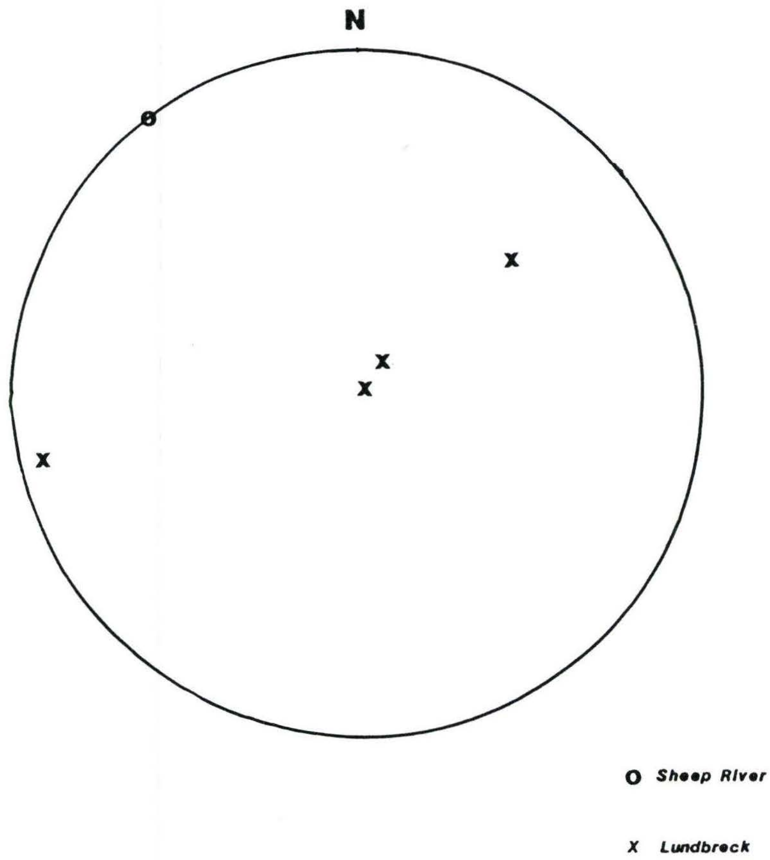


Fig. 9 Orientation of fold axes in the loaded sandstone facies

they could not be identified.

(h) Facies 8. Swaley Cross Stratified Facies. Plate 5A,B

This facies is characterized by a light grey, orange, or buff colored sandstone which displays swaley cross stratification (SCS). This stratification is defined as a series of thin (0.5 to 5 cm) parallel and weakly convergent laminations (maximum dihedral angle of 15°). These laminations are arranged in bedsets which are broadly concave upward (Leckie and Walker, 1982). This arrangement forms interlocking swales or trough like depressions from 0.3 to 2.0 meters wide. These swales are filled with sandstone laminae which drape or parallel the lower surface of the swale in most cases and which may also exhibit weak convergence towards the margin of the swale.

The SCS facies was only observed in strata of the Chungo Member and was best developed in the southern part of the study area. The thickness of the SCS interval was variable and a maximum of 39 meters was recorded in the Lundbreck section. The SCS facies is restricted to the upper portions of the Chungo coarsening upward cycle. This facies is always underlain by a loaded sandstone unit and is generally overlain by trough cross stratified and parallel laminated sandstone of Facies 9.

The thin laminations which characterize this unit are not pronounced and in most exposures, the swaley unit is massive weathering and shows only traces of bedding or lamination. The Lundbreck and Sheep River exposures, however, are superbly exposed and most of the descriptive information on this facies was gleaned from these outcrops.

In the Sheep River exposure, there is a gradational change from massive and thick (10-25 cm) flaggy weathering beds at the base of the section to thin (0.5 to 1.0 cm) flaggy weathering beds at the top of the section. The sandstone is fine grained overall but clay pebbles up to 2.0 cm in diameter are scattered throughout the section.

In the lower part of the swaley cross stratified section at Lundbreck, the sandstone laminae are discontinuous and the angle between adjacent intersecting laminae is generally less than 5° (Plate 5A). In the middle part of this swaley cross stratified zone, thinly laminated accretionary bedforms up to 60 cm thick are well developed and can be traced across 20 to 30 meters of outcrop. In the upper most part of the Lundbreck outcrop on the south side of the river, angle of repose planar tabular cross stratification with sweeping asymptotic toesets are well developed (Plate 5B). At Lundreck the section above this lower 22 meter interval is covered on the south side of the river. On the north side of the river, the correlative overlying units become essentially parallel laminated and only very low angle truncation surfaces are noted.

Rose diagrams plotting the direction of maximum dip

Plate 5

A. Close up of Facies 8. Swaley cross stratified sandstone. Note low angle (less than 15 degrees) convergent laminae and flaggy weathering characteristics. Photo taken 114 meters above base Lundbreck section.

B. Facies 8. Angle of repose planar tabular foresets in a swaley cross stratified sandstone unit. Photo taken 129 meters above base Lundbreck section.

C. Facies 9. Parallel laminated sandstone. Photo taken 6 meters above base Magnetite Beach section.

D. Facies 9. Parallel lamination and low angle convergent lamination. Photo taken 140 meters above base Lundbreck section.


B
D
A
C

of swaley lamination are shown in Fig. 10. The swaley beds at Lundbreck have a predominantly eastward dip (mean 113°) while those at Sheep River have a westerly dip (mean 252°).

No bioturbation features or macrofossils are observed in the SCS sections.

(i) Facies 9. Trough Cross Bedded and Parallel and Low Angle Convergent Laminated Sandstone

Facies 9 is characterized by a buff to light grey resistant weathering sandstone unit which contains abundant small scale trough cross stratification and abundant parallel to low angle convergent planar laminations. This facies is restricted to the uppermost portions of some of the coarsening upward sequences. Facies 9 is generally underlain by a SCS or HCS sandstone unit and is overlain by carbonaceous mudstone and sandstone (Facies 10) or a sharp based trough cross stratified sandstone unit (Facies 11). This facies is typically 10 to 12 meters in thickness but in most exposures, the upper or lower contacts are poorly or non exposed. In the Ghost Dam section the Facies 9 unit is only 3.5 meters thick.

The sandstone is typically medium to fine grained and micaceous. The unit is generally flaggy weathering and breaks into slabs 5 to 15 cm in thickness. The internal stratification is dominated by planar laminae which intersect each other at low angles (less than 10°) but trough cross stratification is also common. The troughs are

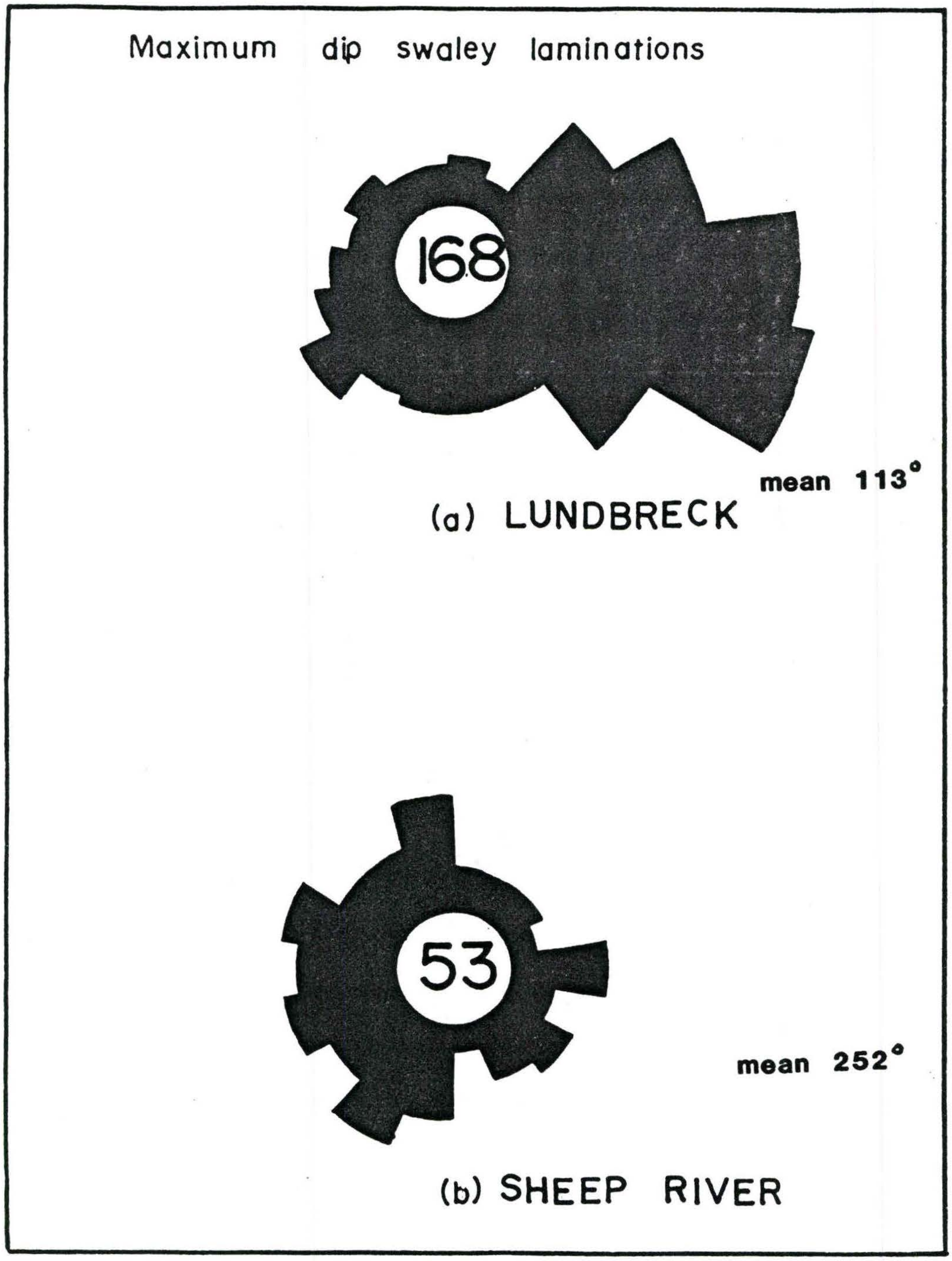


Figure 10 Direction of maximum dip of swaley lamination (a) Lundreck (b) Sheep River

typically 15 to 50 cm deep, and where exposed, appear to be 3 to 4 meters wide. In the Highwood 2 section, Facies 9 includes five meters of trough cross stratified sandstone in which juxtaposed foresets are oriented 180° to each other (bipolar)(Foldout F-5). In outcrop, this looks like herring bone cross stratification and a rose diagram of foreset orientations shows a weak SW-NE directional trend for the currents which formed these bedforms (Foldout F-5). In Ghost Dam section, after correction for regional dip the lamination retained a consistent southwest dip (Fig. 11).

The Magnetite Beach section is capped by two discrete layers of heavy mineral concentrations. The beds are 0.6 and 1.0 meters thick and consist of parallel laminated sandstone which contain 50 to 100% dark minerals. These beds are separated by 1.8 meters of parallel laminated sandstone which contains between 5 and 20% dark minerals. The upper beds are apparently dissected by a sharp based channel form sandstone but these beds are poorly exposed and the exact nature of the contact is not clear.

Exposures of Facies 9 are commonly capped by a rusty carbonaceous rooted zone. In some cases, no roots were observed in the rusty zone but they were identified in the mudstones of Facies 10 directly overlying the Facies 9

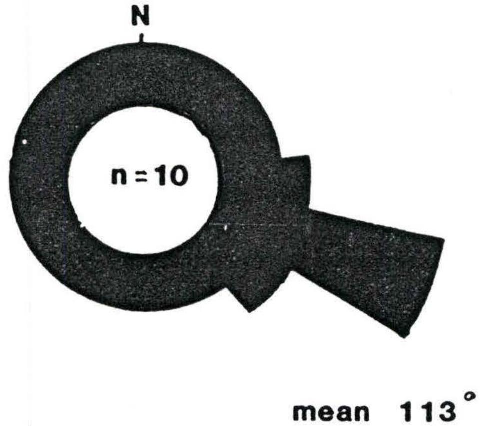


Fig. 11 Direction of maximum dip of parallel and low angle convergent laminae measured 355 meters above the base of the Ghost Dam section.

sandstone. No other bioturbation features were noted in this facies.

(j) Facies 10. Rooted Carbonaceous Mudstone/Sandstone Facies. Plate 6A

This facies is characterized by very recessive weathering olive green to grey mudstone which contains minor intercalated sandstone and siltstone beds. This facies is generally associated with trough cross stratified sandstone (Facies 11) although it may be underlain by parallel and trough cross stratified sandstones (Facies 9). This facies

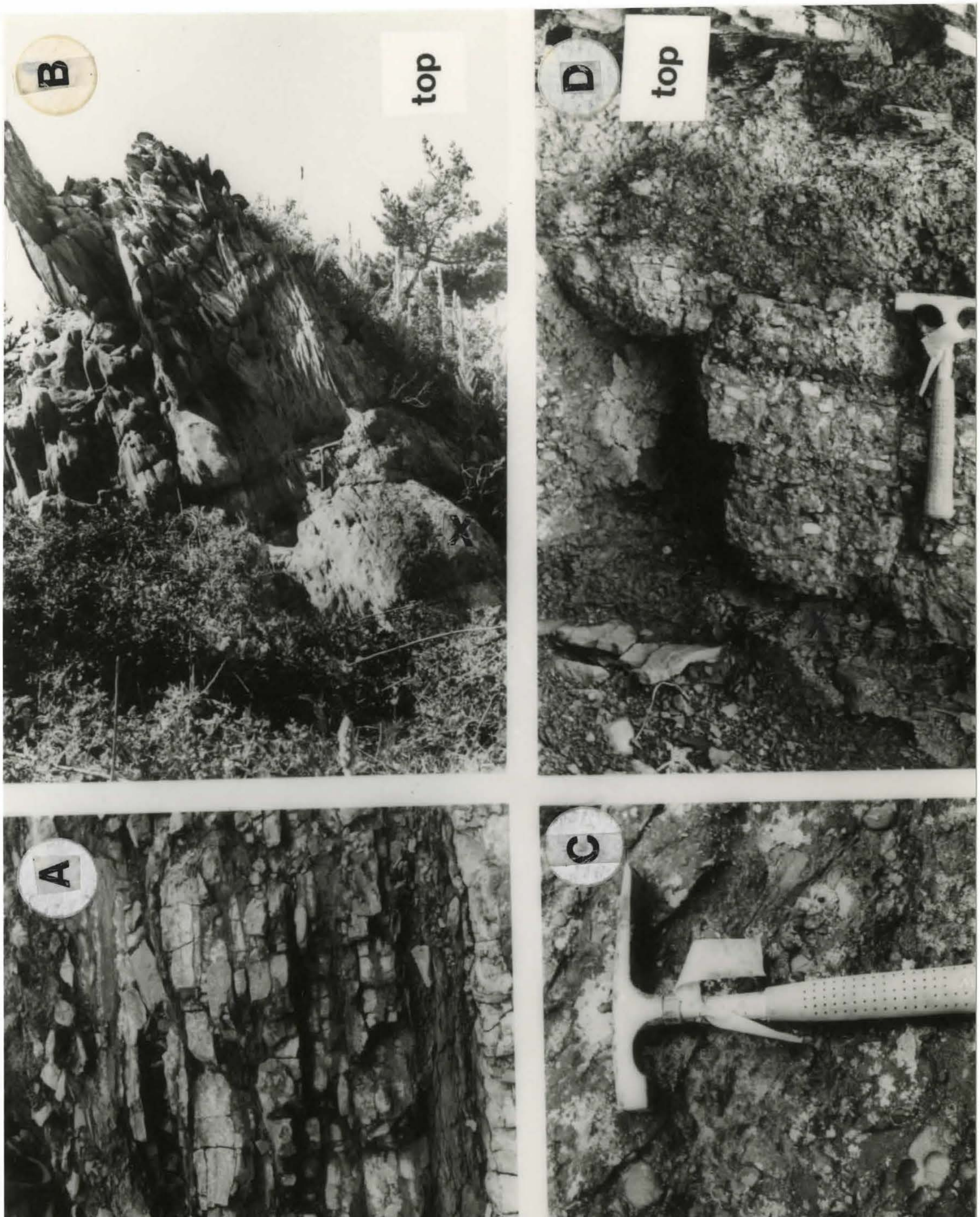
Plate 6

A. Facies 10. Rooted, carbonaceous mudstone with abundant discrete sandstone beds. Note the discontinuos nature of the beds. Photo taken 172 meters above base Highwood 2 section.

B. Facies 11. Resistant, trough cross stratified sandstone. Stratigraphic top of the ledge is marked with an X. Photo taken 174 meters above base Lundbreck section.

C. Facies 12. Exhumed surface on top of conglomerate beds capping swaley cross stratified Chungo sandstone. Photo taken 130 meters above base Sheep River section.

D. Facies 12. Cross section of sharp based clast supported conglomerate bed, 35 cm thick capped by 10 cm thick pebbly mudstone. Base of conglomerate bed marked with an X. Photo taken 140 meters above base of Sheep River section.


B
top
X
D
top
A
C

is very poorly exposed in most sections.

The olive to green grey mudstone which forms the bulk of the section is typically very sandy, carbonaceous, and micaceous. It is massive to very poorly bedded overall but may retain small scale current ripples and undulating to parallel lamination in a few exposures. The recessive shale overlying the Facies 9 sandstone at Trap Creek is dark grey, very carbonaceous, and contains a few pyrite nodules.

The dark green to brown weathering sandstone beds included with this facies typically comprise 10 to 20% of the section and vary from 5 to 50 cm in thickness. The beds consist of very fine to medium grained sandstone which is very silty, carbonaceous, and micaceous. In several exposures the thicker beds (greater than 40 cm) exhibit fining or coarsening upward trends across the thickness of the bed. The bases of the beds are generally sharp and are commonly loaded into the underlying mudstone. The beds commonly retain layering from .5 to 1.5 cm in thickness which is accentuated by carbonaceous and micaceous partings. Current ripples and small scale (less than 10 cm) trough cross beds were found in a few sections.

The tops of the discrete sandstone beds are commonly disturbed by shallow (less than 5 cm) vertical and oblique root systems. No other bioturbation features were documented.

(k) Facies 11. Trough Cross Stratified Sandstone.

This facies is characterized by thick, buff to light grey colored sandstone units which are very resistant and massive weathering. These units are invariably sharp based and frequently exhibit trough and planar tabular cross stratification. Facies 11 sandstones are very commonly interbedded with carbonaceous rooted mudstones and sandstones (Facies 10) in units where they comprise approximately 50% of the section. In addition, this facies was observed capping the lower upward coarsening Chungo sandstone unit in the Sheep River, Maycroft, and Barrier Lake sections. The individual trough cross bedded sandstone units vary from 3 to 8 and average 6 meters in thickness.

The base of each sand unit is typically floored by a coarse lag which contains clay pebbles and cobbles up to 15 cm in diameter and logs up to 60 cm in length. This lag varies from 0 to 40 cm and averages 25 cm in thickness. The bulk of the sandstone units consist of a sequence of stacked beds each of which is sharp based, trough cross stratified and floored by a clay pebble lag. These beds vary from 30 to 300 cm and average 75 cm in thickness.

The grain size distribution is very variable within each sandstone unit. In most exposures, the grain size variations are non-systematic. However, in some sequences, there is a gradational change from medium and coarse grained sandstone at the base to very fine and fine grained sandstone at the top of the sand body.

On most sequences, trough cross stratification is dominant in the lower part of the sandstone and parallel lamination and small scale ripple lamination is dominant towards the top of the sandstone unit.

(1). Facies 12. Pebbly Mudstone/Pebble Conglomerate.

Thin units of pebbly mudstone and pebble conglomerate were observed in the Maycroft, Highwood 2, Sheep River, and Longview sections. The units varied from 5 to 500 cm in thickness and consisted of either structureless mudstone containing 1 to 40% chert pebbles or discrete sharp based clast supported conglomerate beds up to 40 cm thick. The basal contact was generally sharp and the upper contact of the pebbly bed was generally gradational into overlying sandy mudstones.

The occurrence of Facies 12 pebbly mudstones and conglomerates appears restricted to narrow stratigraphic intervals. The pebbly unit commmonly rests on a sharp, possibly erosive contact overlying marine or nonmarine strata, and is always overlain by marine strata. In most cases, there exists a marked facies change across the pebbly unit which appears to mark a significant "break" in the nature of the sedimentation. In the Longview and Sheep River sections, the lithology is similar above and below the pebbly beds (Facies 5) but in both cases the average thickness of the discrete sandstone beds decreases abruptly above the pebbly unit.

In the pebbly mudstones, the pebbles are supported in a sandy mudstone matrix and clasts up to 12 cm in length were observed. Clast supported conglomerates were observed in a few exposures and are composed of chert and quartz pebbles (average 1.0 cm diameter) with minor interstitial sand and mud. At Sheep River, a 60 to 100 cm thick clast supported conglomerate bed is overlain by 10 cm thick matrix supported pebbly mudstone.

In outcrop, the pebbly units appear massive, non imbricated and structureless. However in the Longview and Sheep River exposures, vestiges of a few sharp based thin (less than 2 cm) pebbly sandstone beds were observed approximately 50 to 100 cm above the base of the pebbly unit.

Orientation of the a-b planes of chert pebbles in a matrix supported pebbly mudstone were measured at one interval in each of the Sheep River, Longview, and Maycroft exposures. Similar measurements were made for two different exposures of clast supported conglomerates in the Sheep River section. The orientations of the pebbles were corrected for regional dip and stereonet plots of the poles of the a-b planes of the pebbles were constructed(Figs. 12 to 16). On these plots, a unit containing imbricated pebbles would show a concentration of points clustered around that part of the stereonet where 25 to 30° dips would be plotted (R.G. Walker, pers. comm., 1982). As can be seen on the stereoplots no evidence of an imbrication fabric is apparent in any of the exposures measured. The clustering of points around the centre point of the stereonet plot does however indicate that the majority of a-b planes are approximately flat or within 20° of horizontal. The only stereoplot that shows any preferred direction of dip is for the pebbly mudstone located 140 meters above the base of the Sheep River section (Fig. 13). In this diagram a large number of pebbles preferentially dip to the northwest and to the southeast. Since the two preferred dip directions are opposite to each other this is obviously not an imbrication fabric. It is thus considered that no preferred pebble orientation exists in the pebbly mudstones or conglomerates. There does exist, however, a consistent tendency for the a-b plane of the pebbles to be approximately flat or within 20° of horizontal.

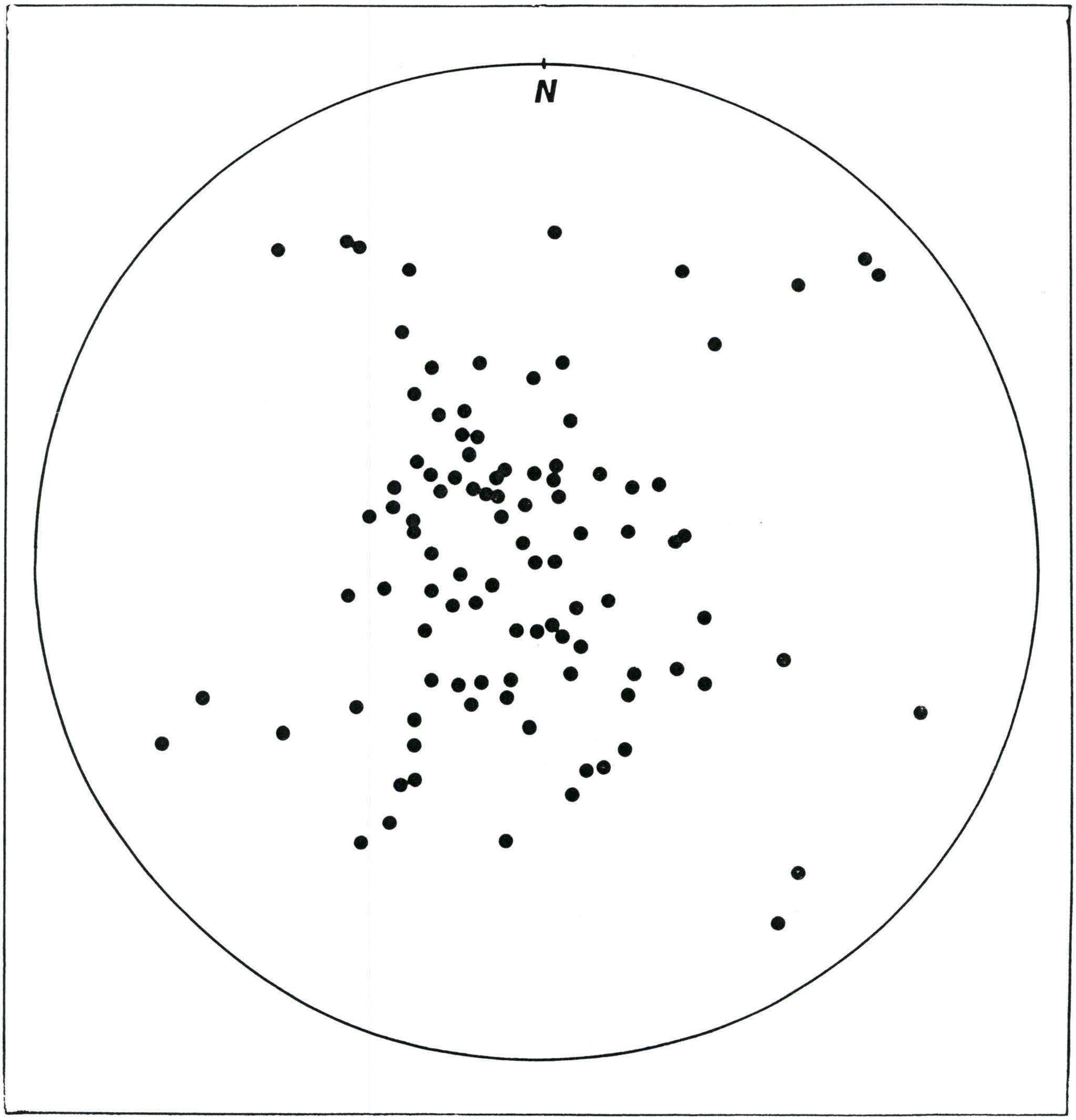


Figure 12 Stereonet plot of poles to the a-b planes of pebbles measured in the pebbly mudstone in the Sheep River section located 130 meters above the base of the section. n = 100; mean dip 081° Az direction.

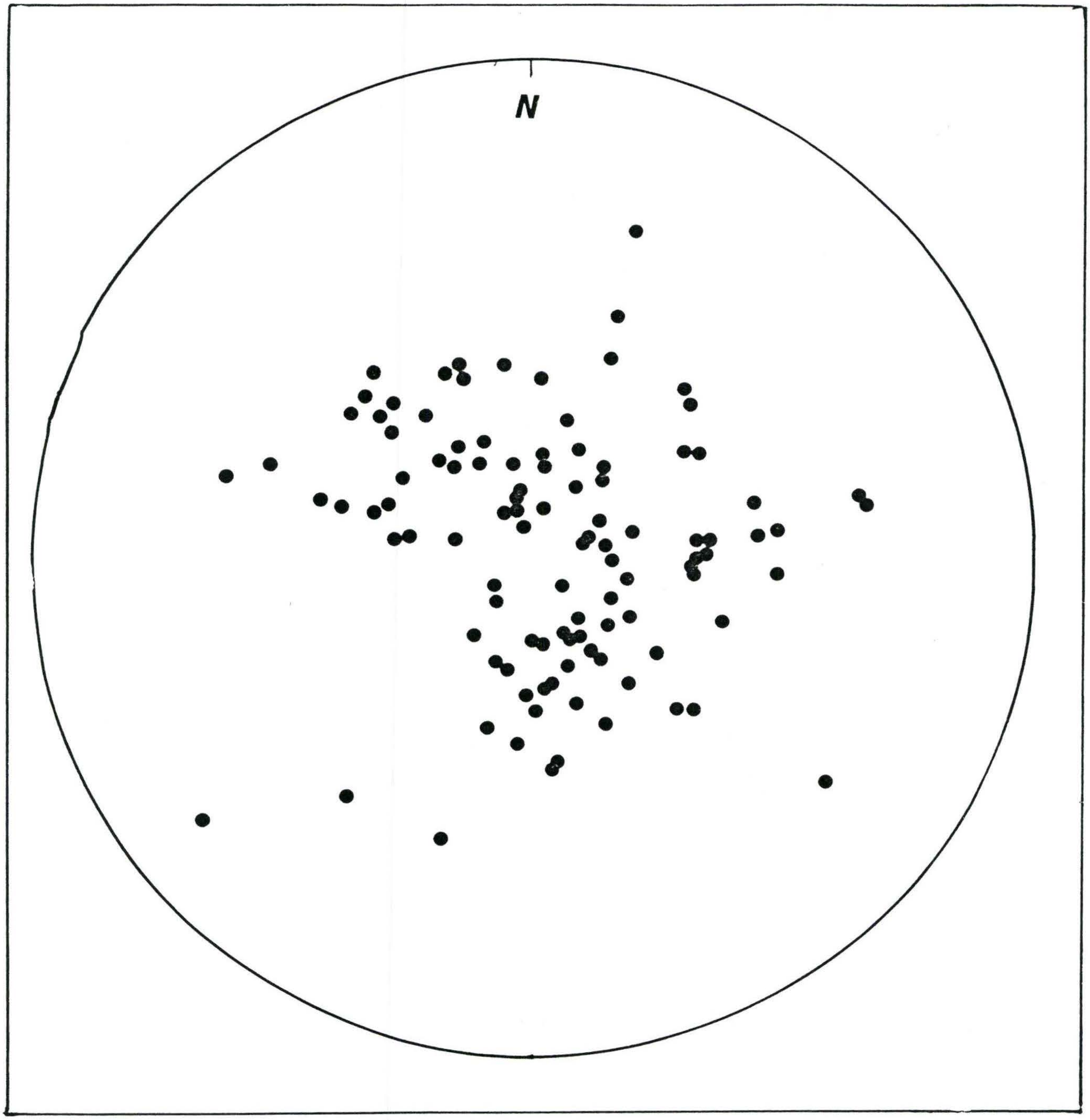


Figure 13 Stereonet plot of poles of the a-b planes of pebbles measured in the pebbly mudstone in the Sheep River section located 140 meters above the base of the section. n = 100; mean dip direction 348° Az.

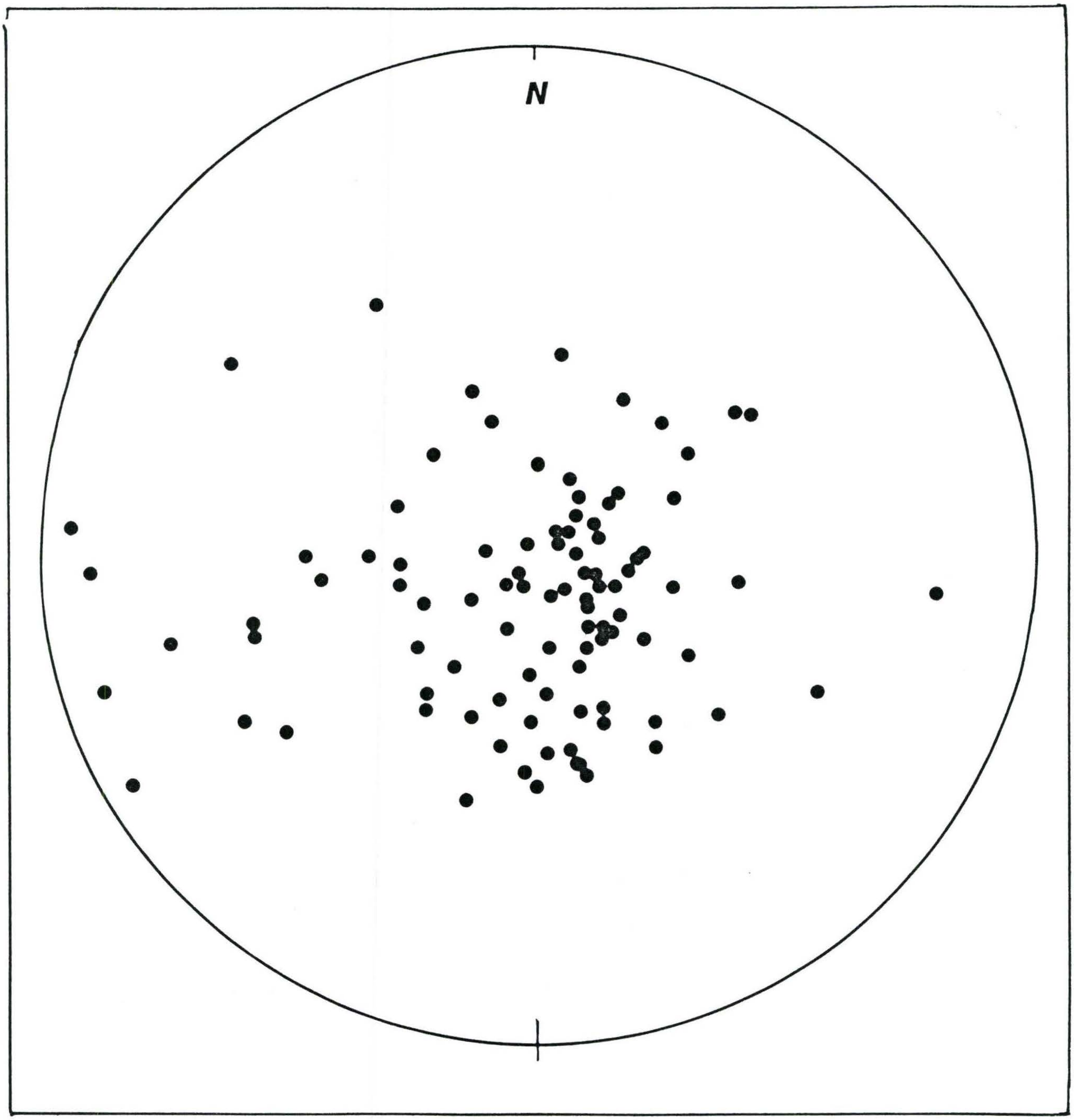


Figure 14 Stereonet plot of poles of the a-b planes of pebbles measured in the conglomerate unit in the Sheep River section located 141 meters above the base of the section. n = 100; mean dip direction 212° Az.

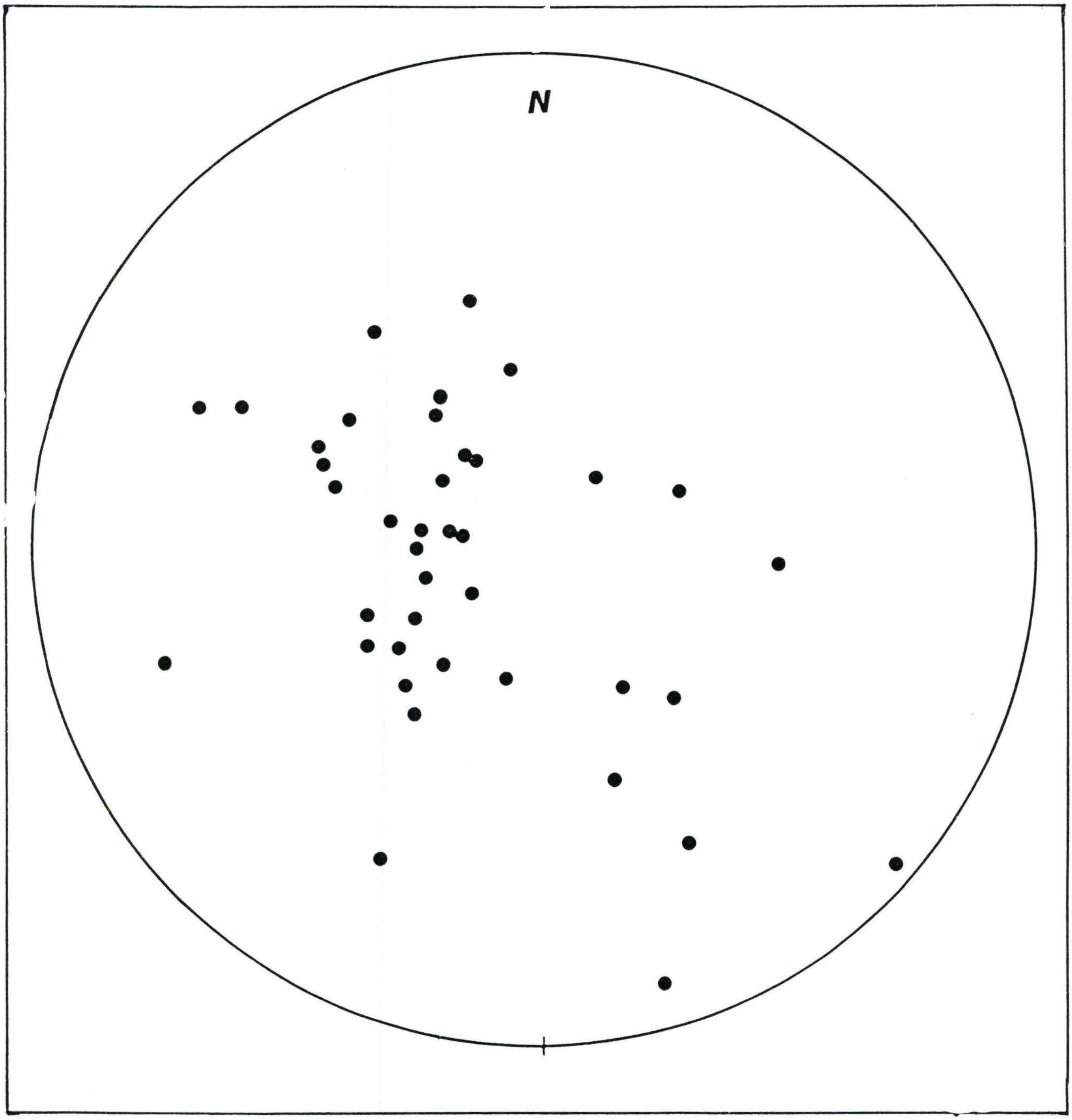


Figure 15 Stereonet plot of poles of the a-b planes of pebbles measured in the pebbly mudstone in the Maycroft section located 221 meters above the base of the section. n = 42; mean dip direction 055° Az.

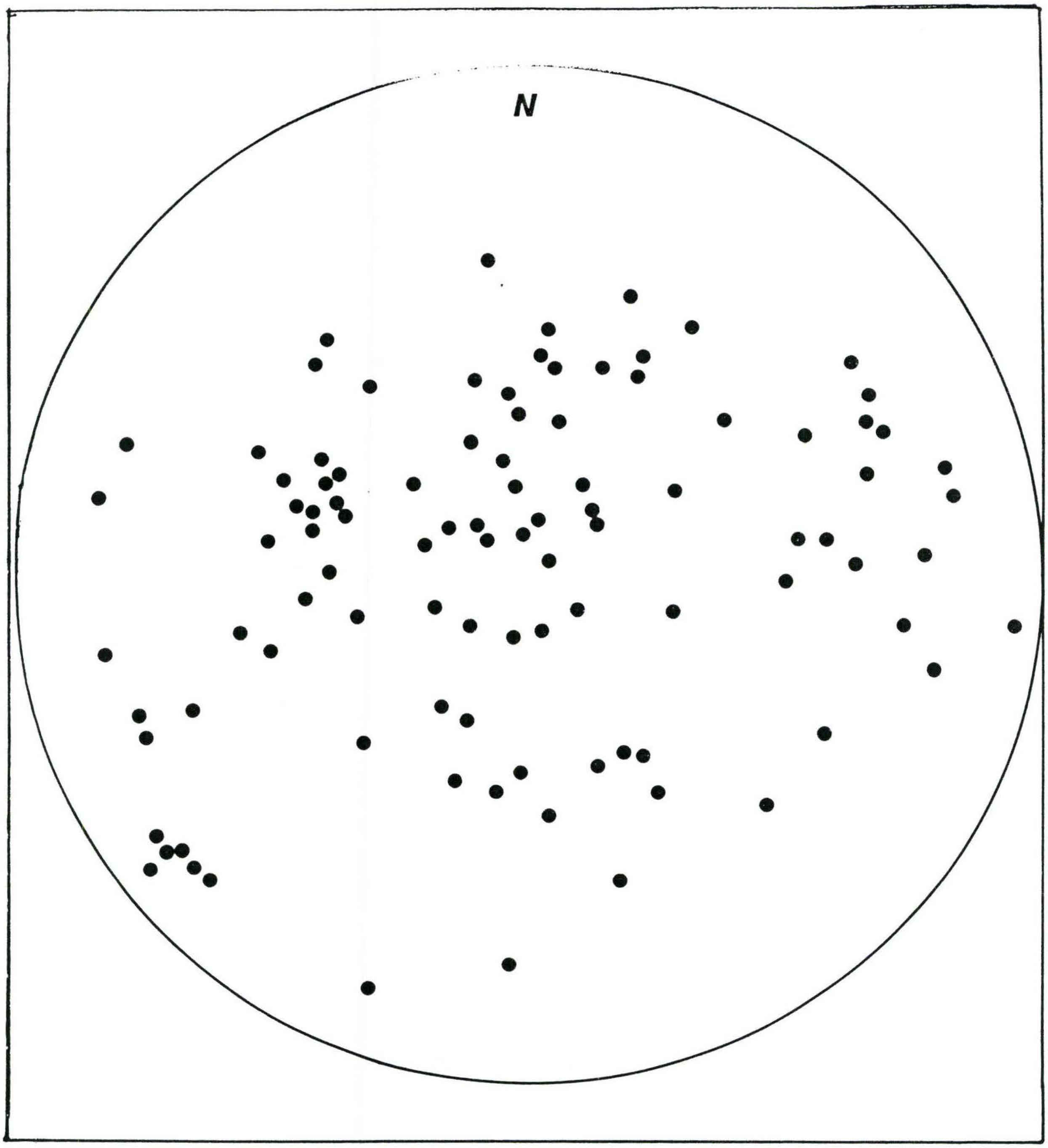


Figure 16 Stereonet plot of poles of the a-b planes of pebbles measured in the pebbly mudstone in the Longview section located 50 meters above the base of the section. n = 100; mean dip direction 099° Az.

6. Facies Sequences

(a) Southern Group (Foldouts F-3, F-8, F-4, F-1, F-5)

The Lundbreck, Maycroft, Oldman River, Trap Creek, and Highwood sections are all located in the southern part of the study area and are characterized by a similar overall sequence of lithofacies. The Coleman and Magnetite Beach exposures are also probably a part of this southern group but there is not enough strata exposed in either section to unequivocally tie down their stratigraphic position. Figure 17 summarizes the stratigraphic and facies relationships observed in the study area.

In general terms, all the sections are dominated by a thick coarsening upward sequence which passes upward from shales and siltstones (Facies 1 to 4) at the base into interbedded sand and shale of Facies 5 and 6 and finally into thick massive weathering sandstones of Facies 7, 8, and 9. This thick sandstone unit is overlain by an alternating succession of rooted carbonaceous mudstones and sandstones (Facies 10) and trough cross bedded fine to medium grained sandstone beds (Facies 11). The succession is in turn overlain by a 11.5 to 34 meter thick unit of bioturbated siltstone and shale (Facies 1 to 4). Generally across a short (1 to 10 meter) stratigraphic interval, this bioturbated mudstone unit passes up into a second sequence of alternating carbonaceous mudstones (Facies 10) and trough cross stratified sandstones (Facies 11).

In the nomenclature used in this study, the weakly bioturbated thinly laminated shales, siltstone, mudstones, and sandstones (Facies 1 to 3) at the base of the section are considered to be part of the Thistle Member. The section of completely bioturbated sandy mudstone (Facies 4) overlying this Thistle Member, where present, is referred to as the Hanson Member. The main coarsening upward sequence and overlying nonmarine strata is referred to as the Chungo Member. The uppermost bioturbated mudstone is considered equivalent to the Nomad Member of the Wapiabi Formation. The overlying nonmarine sequence of Facies 10 and 11 is considered as part of the Belly River Formation.

i Thistle Member

The lowermost part of all sections in the southern group is dominated by mudstone which was interbedded with variable proportions of thin (less than 5 cm) sharp based sandstone and siltstone beds (Facies 1 to 4). Small scale coarsening upward sequences are well developed in most sections in the southern group. In each sequence the proportion and thickness of discrete sandstone beds, and the degree of bioturbation, increases upwards. A typical example of this sequential facies arrangement is shown in

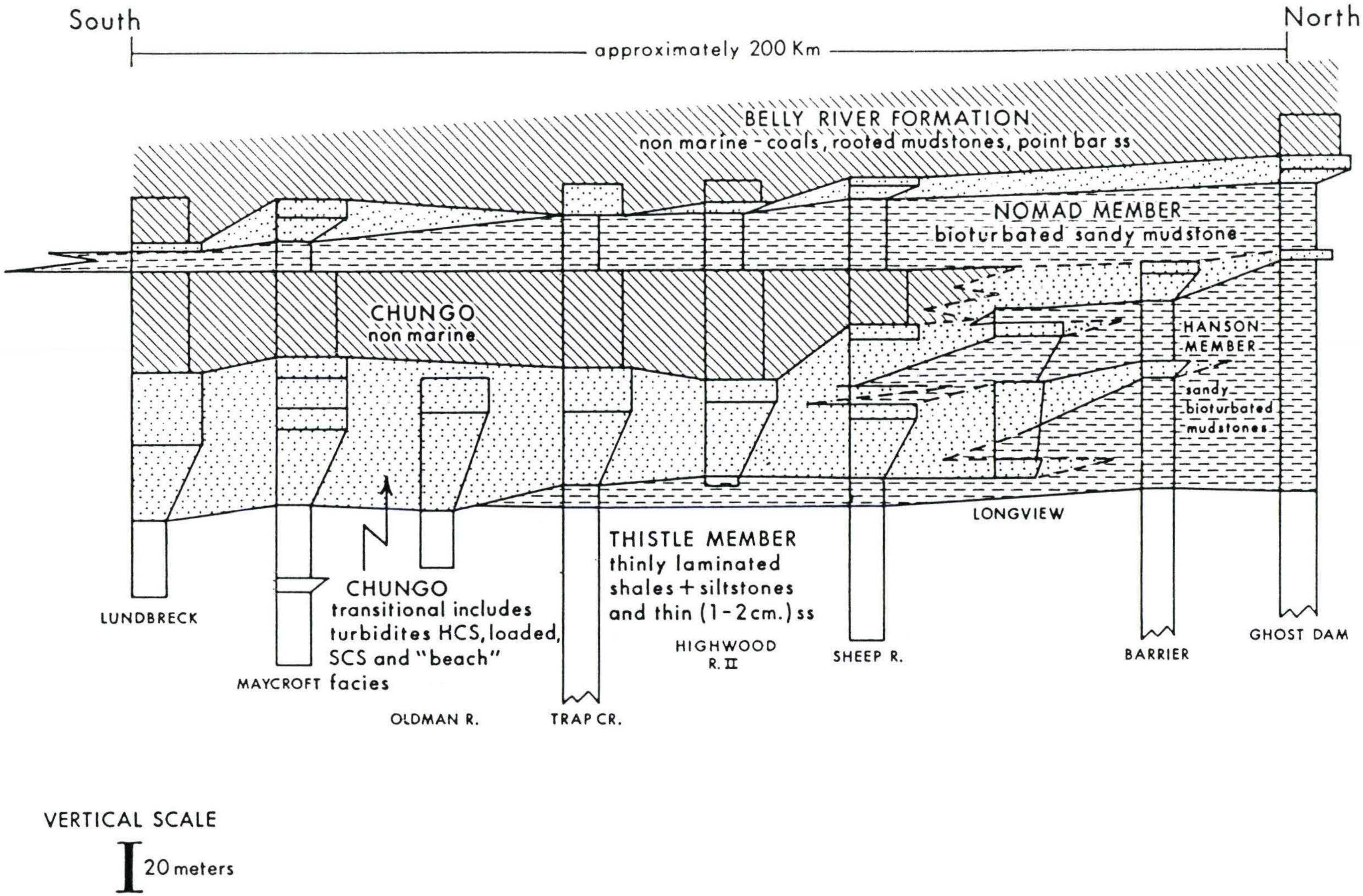


Figure 17 Stratigraphic section and facies relationships, Wapiabi-Belly River Transition, Southwestern Alberta

the Maycroft section across the interval from 36 to 48 meters above the base of the section (Foldout F-8). In this example the vertical facies sequence proceeds in the order 1a-1b-1c-2-3-1a. The overall pattern is not truly cyclic, but rather consists of a series of gradational transitions which results in a progressively higher sand content and increasing bed thickness. The final transition is rather sharp and is commonly marked by a concretionary, slightly phosphatic zone. The thickness of any individual facies unit within each sequence is variable and the thickness of a discrete coarsening upward sequence varies from 10 to 20 meters.

In general there are more cycles developed in the northern part of the study area (Ghost Dam, Barrier Lake sections) and the cycles are not as well developed in the southern part of the study area (Lundbreck, Maycroft and Oldman River sections). Stott (1963) has identified and correlated six "cycles" within the Thistle Member between the Highwood River and the Little Berland River farther north. Figure 18 is a tentative correlation diagram of the coarsening upward sequences across the study area. It is probable that the relatively poor correlations are due to a poor choice of datum and general paucity of data across such a large area. However these poor correlations may also reflect the fact that the processes which generate these coarsening upward sequences are not "basin wide" events.

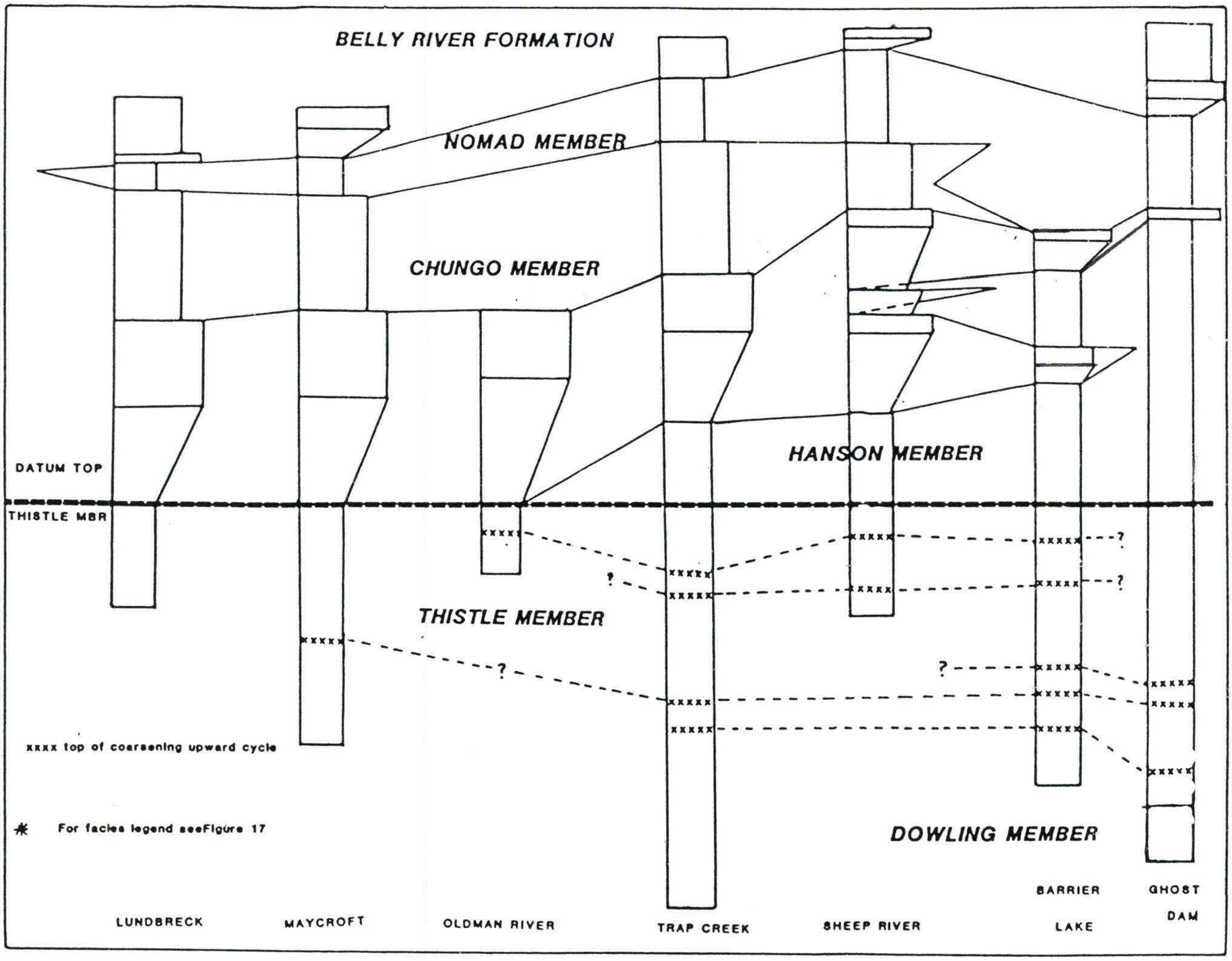


Figure 18 Suggested correlation of tops of thin coarsening upward sequences (CUS) in the Thistle Member of the Wapiabi Formation.

ii Chungo Member

In the southern part of the study area the base of the main coarsening upward sequence is defined at the first occurrence of thicker (greater than 5 cm) sandstone beds in the section. This contact between the underlying mudstone section (Facies 1 to 4) and the overlying sandstone and mudstone section (Facies 5a, 5b, 6) may be either gradational (eg.) Lundbreck, or sharp (eg.) Highwood 2.

As a general rule the mudstones (Facies 1 to 4) are overlain by an interbedded sandstone and mudstone section (Facies 5) which is overlain by a hummocky cross stratified section (Facies 6).

In detail, however, all the sections in the southern group displayed an interbedding of turbidites (Facies 5a, 5b) and hummocky cross stratified (HCS) units (Facies 6). This interbedding necessitated that an arbitrary rule be derived to differentiate these two facies. A minimum of two HCS beds per meter of section was defined as the lower limit of a HCS dominated facies. A sandstone and mudstone section that contained fewer than two HCS beds per meter was included in the turbidite facies. The sandstone to shale ratio and the thickness and proportion of HCS beds was observed to increase upwards in all sections. The total thickness of the continuous "turbidite" Facies (5a, 5b) and HCS Facies (6) varied from a maximum of 61 meters at Lundbreck to a minimum of 32 meters in the Trap Creek section.

In most of the sections in the southern group, the upper contact of the combined turbidite-HCS section was sharp and defined at the first appearance of loaded sandstone beds. However, in the Trap Creek and Highwood sections, thin loaded sandstone beds (Facies 7) may be interbedded with HCS sandstone beds (Facies 6) over a stratigraphic interval of several meters. The total thickness of the loaded section varies from a maximum of 15 meters at Trap Creek to a minimum of 4 meters at Maycroft.

In all the sections of the southern group, the loaded sandstone facies passes upwards into swaley cross stratified (SCS) sandstone of Facies 8. This contact may be very difficult to differentiate because both the loaded and the SCS sandstones form massive resistant exposures and the contact is not well defined. The upper contact of the SCS sandstone varies between different sections. In the Lundbreck section, planar tabular cross bedding and parallel lamination was observed throughout most of the swaley cross stratified section. A thin (4.5 m) fine grained, dense, parallel laminated sandstone (Facies 9) capped the SCS section in this outcrop. In the Highwood 2 and Trap Creek section, the SCS sandstone appears to pass gradationally upwards into trough cross bedded and parallel laminated sandstones of Facies 9. In the Maycroft section the swaley interval is sharply overlain by a medium grained trough cross stratified sandstone that contains abundant clay pebble clasts (Facies 11).

In the Lundbreck, Maycroft, Trap Creek and Highwood 2 sections, the main sandstone of Facies 7, 8, 9, and 10 was overlain by an alternating succession of rooted carbonaceous mudstones and sandstones (Facies 10) and trough cross stratified sandstones (Facies 11). The ratio of Facies 10 to Facies 11 lithologies was variable but averaged approximately 1:1.

iii Nomad Member

In most of the sections in the southern part of the area, the alternating succession of Facies 10 and Facies 11 lithologies is abruptly overlain by a 11.5 to 34 meter thick interval that consists of dark grey bioturbated mudstones and sandstones (Facies 1, 2, 3, or 4). The lower contact of this mudstone is exposed only in the Maycroft and Highwood 2 sections and in both instances, it is marked by a thin (10 to 200 cm) pebbly horizon (Facies 12).

iv Basal Contact, Belly River Formation

In the Maycroft section, a thin (20 m) "coarsening upward sequence" was documented as this lower bioturbated mudstone passed upwards into interbedded mudstones and sandstones (Facies 5, 6) and finally into trough cross stratified sandstone (Facies 11). In the Trap Creek and Lundbreck sections, this bioturbated mudstone unit passes directly into trough cross stratified sandstones (Facies 11). These contacts are poorly exposed, but are apparently abrupt, as they occurred across short (less than 1 meter) stratigraphic intervals. In the Highwood 2 section, the bioturbated mudstones pass upward into interbedded sandstones and mudstones (Facies 5, 6) which are in turn abruptly overlain by a second thick succession of rooted carbonaceous mudstones and sandstones (Facies 10).

(b) Central Group (Foldouts F-11, F-6, F-7)

The Sheep River, Longview, and Bragg Creek sections differ markedly in the degree of exposure and it is thus difficult to discuss them as a group since there is insufficient stratigraphic control to precisely tie down which part of the section is exposed in each outcrop. In general, however, the Chungo Member in the central part of the study area is characterized by a thick sequence of interbedded sandstone and mudstone (Facies 5 and 6). Clean sandstones of the loaded, swaley or trough cross stratified facies comprise a much smaller part of the Chungo Member than they do farther south. Moreover, the nonmarine part of the Chungo Member (Facies 10, 11), if present at all, is much thinner than it was in the southern part of the study area.

Sheep River Section Foldout F-11

i Thistle Member

The Thistle Member in the Sheep River section is characterized by thinly laminated shales, siltstones and sandstones of Facies 1a, 1b, 1c, and 2. These are organized into a series of small scale coarsening upward cycles similar to those described in the Ghost Dam, Barrier Lake, and Trap Creek sections. Two poorly defined cycles (12 and 19 meters thick) were documented in the Thistle Member at Sheep River but no phosphatic material or chert pebbles were observed in the concretionary layers capping these cycles. These cycles correlate fairly well with similar sequences observed in the Trap Creek, Ghost Dam and Barrier Lake sections (Fig. 18).

ii Hanson Member

In the Sheep River section, the Hanson Member consists of a 37 meter thick section of completely bioturbated concretionary sandy mudstone (Facies 4) which gradationally overlies the thinly laminated shales and siltstones of the Thistle Member.

iii Chungo Member

The basal contact of the Chungo Member is gradational as discrete sharp based sandstone beds are interbedded with bioturbated sandy mudstone of the underlying Hanson Member. The total thickness of the Chungo

Member is similar to the total thickness of Chungo strata measured further south. However, the interbedded sandstones and mudstones of Facies 5 and 6 (turbidites, HCS) comprise a much larger proportion of the Chungo Member than they do in the southern parts of the study area.

In the Sheep River section, the Chungo Member appears to consist of two and possibly three coarsening upward sequences. In the lowest coarsening upward sequence approximately 28 meters of interbedded sandstones and mudstones (Facies 5 and 6) are gradationally overlain by 8 meter thick unit of loaded sandstone (Facies 7). This loaded sandstone is, in turn, overlain by another 8 meters of swaley cross stratified sandstone (Facies 8). Parallel lamination was the only primary structure preserved in the interbedded sandstone and mudstone unit (Facies 5 and 6) although HCS beds capped by symmetrical wave ripples were common in the upper parts of the sandstone/mudstone unit. The swaley cross stratified sand which caps this lower coarsening upward sequence is abruptly overlain by a 10 cm thick conglomerate layer which was, in turn, overlain by a 1.2 meter section of bioturbated sandy mudstone which contained a few scattered chert pebbles.

This pebbly mudstone is overlain by a 9 meter thick section of interbedded sandstones and mudstones (Facies 5 and 6) which is capped by a 60 cm thick conglomerate bed which is in turn capped by a 10 cm thick pebbly mudstone.

It is possible that this 10 meter section represents another "coarsening upward" trend similar to that described above. The proportion of discrete sandstone beds and the ratio of HCS/turbidite beds increases upwards and appears to change abruptly across the pebbly unit.

A 23 meter thick section of interbedded sandstones and mudstones (Facies 5 and 6) overlies this pebbly mudstone and forms the lower part of the uppermost coarsening upward sequence in the Chungo Member.

Parallel and ripple lamination is most common in the lower part of the section while HCS and symmetrical wave ripples are more common in the upper parts of the section. A sharp undulating, possibly erosional, surface separates the underlying HCS strata from the overlying medium grained, poorly sorted, trough cross stratified sandstone (Facies 11). The grain size and the scale of cross bedding are both observed to decrease upwards across this thick (7.0 meter) sandstone unit. The top of the sandstone consists of ripple laminated, very fine grained sandstone.

A 29 meter thick covered interval separates this sandstone from an isolated outcrop of bioturbated sandy mudstone which is presumably part of the Nomad Member. If nonmarine Chungo strata (Facies 10, 11) is present in the Sheep River section, it must lie underneath this covered interval and then an upper limit of 29 meters in thickness of nonmarine strata must be invoked. This is approximately half of the thickness of nonmarine Chungo strata described from sections in the southern part of the study area.

iv Nomad Member and transition to Belly River Formation

The Nomad Member is poorly exposed in the Sheep River section. A 25 meter covered interval separates the bioturbated mudstones described above from the beds which mark the transition to Belly River strata. The transition is marked by a sequence of interbedded sandstone and mudstones of Facies 5 which is overlain by a 3.2 meter thick parallel laminated sandstone bed (Facies 9). The strata above this sandstone is poorly exposed but appears to be rooted carbonaceous mudstones and sandstones (Facies 10).

Bragg Creek Section (Chungo Member) Foldout F-6

The Bragg Creek section exposed parts of two coarsening upward sequences and the entire section is interpreted as part of the Chungo Member. Only 5 meters of the lower coarsening upward sequence was exposed. This lower cycle consists of discrete sandstone beds separated by thin sandy mudstones, which gradually amalgamate upwards to form a thick bedded continuous sandstone unit which is capped by a 15 cm thick concretionary surface.

This concretionary zone was overlain by a thin (1.1 meter) section of thinly laminated shale (Facies 1b, 1c) which was, in turn, overlain by 7.4 m thick section of interbedded sandstone and shaley sandstone (Facies 5b, 3). The proportion and thickness of discrete sandstone beds and the proportion of HCS beds increased upwards and the sequence was capped by a 3.2 m thick unit of amalgamated HCS sandstone. This sandstone was sharply overlain by a few meters of bioturbated sandy mudstone (Facies 4) at the top of the outcrop.

<u>Longview Section</u> <u>(Chungo Member)</u> Foldout F-7

The Longview section was dominated by interbedded sandstones and sandy mudstones (Facies 5, 6) and two or possibly three coarsening and thickening upward sequences were documented in the exposure. The entire section is considered as part of the Chungo Member. The lowermost part of the exposure consists of two units of discrete sandstone beds interbedded with sandy mudstone. These sandstone beds are separated by a 3.0 m thick unit of similar lithology that contained abundant chert pebbles.

No obvious change in facies or grain size occurs across the pebbly unit. However, the discrete sandstone beds within the bioturbated mudstone sequence are considerably thicker below the pebbly unit than above the pebbly unit. The significance of an abrupt change in lithology associated with the pebbly or conglomeratic units will be discussed in a later section.

A short (10 m) covered interval separates the exposure discussed above from another sequence of interbedded sandstones and sandy mudstones (Facies 5a, 5b). Several HCS sandstone beds are observed near the top of the exposure which is capped by another pebbly sandstone (Facies 12) layer which is approximately 1.0 m thick.

This pebbly sandstone layer is overlain by a well defined coarsening upward sequence in which the proportion and thickness of discrete sandstone beds and the proportion of HCS sandstone beds, increase upward in the section. This uppermost coarsening upward sequence was overlain by a thick bedded SCS sandstone (Facies 8) approximately 7 m thick which was capped by a third pebbly mudstone layer. A short interval of interbedded mudstone and sandstone overlying the pebbly unit forms the top of the exposure.

(c) Northern Group (Foldouts F-2 AND F-9)

The Ghost Dam and Barrier Lake sections are distinctly different from equivalent sections measured in the southern and central portions of the study area. In general terms, both the Ghost Dam and the Barrier Lake sections are dominated by thinly laminated shale, siltstone, and sandstone (Facies 1 to 4) in the lower part of the section (Dowling and Thistle Members). Completely bioturbated sandy mudstone (Facies 4)(Hanson Member) constitutes the central part of the section. In the Barrier

Lake section, the Chungo Member consists of hummocky, swaley, and trough cross stratified sandstones (Facies 6,7,8) In the Ghost Dam section, the Chungo Member is represented by only a thin bioturbated argillaceous sandstone (Facies 3). The Nomad Member and the transition to the overlying Belly River Formation was poorly exposed at Ghost Dam and not exposed at all in the Barrier Lake section.

i <u>Dowling Member</u>

The lowermost 39 m of the Ghost Dam section is dominated by thinly laminated concretionary shales which contain only small proportions of sharp based sandstone and siltstone laminae (Facies 1a, 1b). The abundance of rusty sideritic concretions is typical of the Dowling Member as defined by Stott (1963). In the Ghost Dam Section, a single coarsening upward sequence was well developed in the Dowling Member and a second coarsening upward cycle appears to span the contact between the Dowling and the Thistle Members. Stott (1963) has recorded the presence of two distinct coarsening upward "cycles" in the Dowling Member and these two coarsening upward sequences described above are probably correlative with his Dowling cycles. However, the correlation diagram for the Thistle Member (Fig. 18) suggests that the coarsening upward sequence of the Dowling Member in the Ghost Dam section is correlative with coarsening upward sequence in the Thistle Member of the

Barrier Lake section.

ii Thistle Member

The lowermost portion of the Barrier Lake section and the lower and middle parts of the Ghost Dam section are characterized by thinly laminated shales, siltstones, and sandstones of the Thistle Member (Facies 1,2). The lower contact with the Dowling Member at Ghost Dam is gradational and marked by a gradual decrease in the number of sideritic concretions in the shale. The upper contact with the Hanson Member is also gradational and marked by a gradual increase in the degree of bioturbation.

In the Barrier Lake section, five distinct coarsening upward sequences were documented in thinly laminated shales, siltstones and sandstones which comprise the Thistle Member. In the Ghost Dam section, three coarsening upward cycles are developed in the lower part of the Thistle Member. The upper Thistle Member at Ghost Dam was characterized by lithologies similar to those in the Barrier Lake section although no consistent vertical facies sequences could be discerned.

iii Hanson Member

The Hanson Member of the Ghost Dam and Barrier Lake sections is characterized by thick rubbly weathering bioturbated sandy mudstone. Locally, in the Barrier Lake section, discrete sandstone beds were recognizable where bioturbation was less intense and Facies 2 and Facies 5 lithologies were thus interbedded in the sandy mudstone. In the Ghost Dam section, local variations in sand content produced more resistant weathering characteristics in some units. However the high degree of bioturbation precluded estimation of the sandstone to shale ratio.

iv Chungo Member

Approximately 34 meters below the top of the Ghost Dam section, two resistant concretionary ridges, cropped out from an otherwise very recessive bioturbated sandy mudstone. The ridges were very sandy and contained traces of phosphatic material and chert pebbles on their upper surface. The mutual proximity of the two ridges suggested that they represented a repetition by small scale reverse faulting. However, when examined in detail, significant differences were observed between the two ridges and this indicated that they may represent two discrete events. Their stratigraphic position (Fig. 17) suggests that they are equivalent to the well developed coarsening upward sandstones of the Chungo exposed in the central and southern parts of the study area.

At Barrier Lake, the Chungo Member is represented by a coarsening upward sequence. In this sequence bioturbated sandy mudstones of the Hanson Member (Facies 4), pass upward into interbedded sandstones and mudstones (Facies 5 and 6) and finally into massive weathering swaley cross stratified sandstones (Facies 8). This overall coarsening upward sequence was capped by a sharp, possibly erosional, surface that was overlain by medium grained, poorly sorted trough cross stratified sandstone (Facies 11).

v Nomad Member and Basal Contact Belly River Formation

The Nomad equivalent of the Ghost Dam section was poorly exposed. It is apparently represented by completely bioturbated sandy mudstones (Facies 4) which pass upward into thinly laminated shale and siltstone (Facies 1b) to interbedded sandstone/shale-siltstone (Facies 5a) and finally into parallel laminated and trough cross bedded sandstone (Facies 9). This sequence was capped by a thick section of poorly exposed rooted carbonaceous mudstones and sandstones (Facies 10) of the Belly River Formation.

The Nomad Member and basal contact of the Belly River Formation were not exposed at Barrier Lake.

7. Markov Chain Analysis of Facies Transition

A Markov process is one in which the probability of occurrence of any particular state is not random, but rather, is related to the nature of the preceeding state or states. A Markov chain analysis is a technique which can be used to determine whether the frequency with which any particular facies transition is observed can be attributed to random processes or whether there exists a preferred vertical succession of the various lithofacies. A summary of the technique is presented in Walker (1979) and the main features will be discussed here.

A tally matrix is first constructed in which the elements F record the number of transitions observed between the various lithofacies. Gradational and sharp boundaries are treated equally and only those contacts directly observed (and not inferred across a covered interval) (Table 1a) are used to construct the matrix.

A second plot, termed the observed upward transition probability matrix, is constructed and a value for each is calculated by the following formula.

$$P_{ij} = \frac{F_{ij}}{SR_i}$$

P_{ij}=observed probability of this facies transition

F_{ij}=observed frequency of this facies transition $i \longrightarrow j$

	1a	1b	1c	2	3	4	5a	5b	6	7	8	9	10	11	12	
1a		15	4	1												20
1b	8		25	4	-	-	5	1								43
1c	5	14		14		1	7									41
2	2	7	6		2	3	3	1								24
3	-	2	1	-		1	1	1	1							7
4	-	1	-	-	2		5	2	2						1	13
5a	1	1	4	3	2	5		4	16	2					2	40
5b	-	1	-	2	1	3	3		6	1					1	18
6	-	-	-	-	-	1	8	5		5	3	2	-	2		26
7	-	-	-	-	-	-	3	-	-		7					10
8										-		6	-	1	2	9
9											1		3	1	-	5
10												-		4	1	5
11													6		1	7
12							1	5	1							7
	6	41	40	24	7	14	35	19	26	8	11	8	9	8	8	275

F_{ij}

Table 1a Tally Matrix of observed transitions

	1a	1b	1	2	3	4	5a	5b	6	7	8	9	10	11	12
1a		.75	.20	.5											
1b	.186		.581	.093	-	-	.116	.023							
1c	.122	.341		.341	-	.024	.171	-	-	-	-	-	-	-	-
2	.083	.292	.25		.083	.125	.125	.042							
3	-	.286	.143	-		.143	.143	.143	.143						
4	-	.077	-	-	.154		.385	.154	.154						.077
5a	.025	.025	.10	.075	.05	.125		.10	.4	.05					.05
5b	-	.056	-	.111	.056	.167	.167		.333	.056					.056
6						.038	.308	.192		.192	.115	.077	-	.077	-
7							.3				.7				
8												.667		.111	.222
9											.2		.6	.2	
10														.8	.2
11													.857		.143
12							.143	.714	.143						

P_{ij}

Table 1b Observed Transition Probability Matrix

SR_i=sum rows, total occurrences of facies i.

A third plot, termed the expected random probability matrix, is constructed with the elements defined by the formula below, assuming that all facies transitions are totally random (Table 1c).

R_{ij}=random probability of a Facies i⟶j transition

$$R_{ij}=\frac{SC_j}{N-SR_i}$$

SC_j=sum columns, number of occurrences of Facies j.

N=total number of occurrences of all facies.

The final step is to compare the observed probabilities with the probabilities expected from a totally random process, by use of the following formula:

$$D(_{ij}) = P(_{ij}) - R(_{ij})$$

D= difference between observed probability and that expected from a random process (Table 1d).

In this last matrix, large positive numbers indicate transitions that occur more frequently than would be expected from a totally random process. From this, a preferred facies relationship diagram as described by Walker (1979) can be constructed (Fig. 19).

From the preferred facies relationship diagram (Fig. 19) it can be seen that a large number of facies transitions occurred but only a few occurred with a significantly higher than random frequency. The data supports a "coarsening or

	1a	1b	1c	2	3	4	5a	5b	6	7	8	9	10	11	12
20		.161	.157	.094	.027	.055	.141	.074	.102	.031	.043	.031	.035	.031	.031
43	.069		.172	.103	.030	.060	.155	.082	.112	.034	.047	.034	.039	.034	.034
41	.068	.175		.102	.030	.060	.154	.081	.111	.034	.047	.034	.038	.034	.034
24	.064	.163	.159		.028	.056	.143	.076	.103	.032	.044	.032	.036	.032	.032
7	.060	.153	.149	.089		.052	.134	.071	.097	.030	.041	.030	.034	.030	.030
13	.061	.156	.153	.092	.027		.137	.073	.099	.031	.042	.031	.034	.031	.031
40	.068	.174	.170	.102	.030	.060		.081	.111	.034	.047	.034	.038	.034	.034
18	.062	.160	.156	.093	.027	.054	.140		.101	.031	.043	.031	.035	.031	.031
26	.064	.165	.161	.096	.028	.056	.145	.076		.032	.044	.032	.036	.032	.032
10	.060	.155	.151	.091	.026	.053	.136	.072	.098		.042	.030	.034	.030	.030
9	.060	.154	.150	.090	.026	.053	.135	.071	.098	.030		.030	.034	.030	.030
5	.059	.152	.148	.089	.026	.052	.133	.070	.096	.030	.041		.033	.030	.030
5	.059	.152	.148	.089	.026	.052	.133	.070	.096	.030	.041	.030		.030	.030
7	.060	.153	.149	.089	.026	.052	.134	.071	.097	.030	.041	.030	.034		.030
7	.060	.153	.149	.089	.026	.052	.134	.071	.097	.030	.041	.030	.034	.030	
275	16	41	40	24	7	14	36	19	26	8	11	8	9	8	8

Table 1c Expected random probability matrix

	1a	1b	1c	2	3	4	5a	5b	6	7	8	9	10	11	12
1a		+ .589	+ .043	+ .046	− .027	− .055	− .141	− .074	− .102	− .031	− .043	− .031	− .035	− .031	− .031
1b	+ .117		+ .409	− .01	− .03	− .06	− .039	.059	− .112	− .034	− .047	− .034	− .039	− .034	− .034
1c	+ .054	+ .166		+ .239	− .30	− .036	+ .017	− .081	− .111	− .034	− .047	− .034	− .038	− .034	− .034
2	+ .19	+ .129	+ .091		+ .055	+ .069	− .018	− .034	− .103	− .032	− .044	− .032	− .036	− .032	− .032
3	+ .060	+ .133	− .006	− .089		+ .09	+ .009	+ .072	+ .046	− .030	− .041	− .030	− .034	− .030	− .030
4	− .061	− .079	− .153	− .082	+ .127		+ .248	+ .081	+ .055	− .031	− .042	− .031	− .034	− .031	− .031
5a	− .043	− .149	− .070	− .027	+ .02	+ .065		+ .019	+ .289	+ .16	− .047	− .034	− .038	− .034	− .034
5b	− .062	− .104	− .156	+ .018	+ .029	+ .113	+ .027		+ .232	+ .025	− .043	− .031	− .035	− .031	− .031
6	− .064	− .165	− .161	− .096	− .028	− .018	+ .163	+ .116		+ .16	+ .071	+ .045	− .036	+ .045	− .032
7	− .060	− .155	− .151	− .091	− .026	− .053	+ .164	− .072	− .098		+ .658	− .030	− .034	− .030	− .030
8	− .060	− .154	− .150	− .090	− .026	− .053	− .135	− .071	− .098	− .030		+ .637	− .034	+ .081	+ .192
9	− .059	− .152	− .148	− .089	− .026	− .052	− .133	− .070	− .096	− .030	+ .159		+ .567	+ .17	− .03
10	−	−	−	−	−	−	−	−	−	−	−	−		+ .77	+ 1.7
11	−	−	−	−	−	−	−	−	−	−	−	−	+ .823		+ .113
12	−	−	−	−	−	−	+ .009	+ .643	+ .046						

Table 1d Matrix of difference between expected and observed probability of facies transitions

thickening upward" model as most facies are overlain by a facies containing thicker sand beds and a higher proportion of discrete sand beds. Within the massive sandstone units, a preferred sequence of loaded to swaley to parallel laminated and trough cross stratified facies is observed to occur with a higher than random frequency. In the nonmarine part of both the Chungo and Belly River units, Facies 10 and 11 were commonly interbedded and their mutual transition was also observed to have a higher than random frequency (Fig. 19).

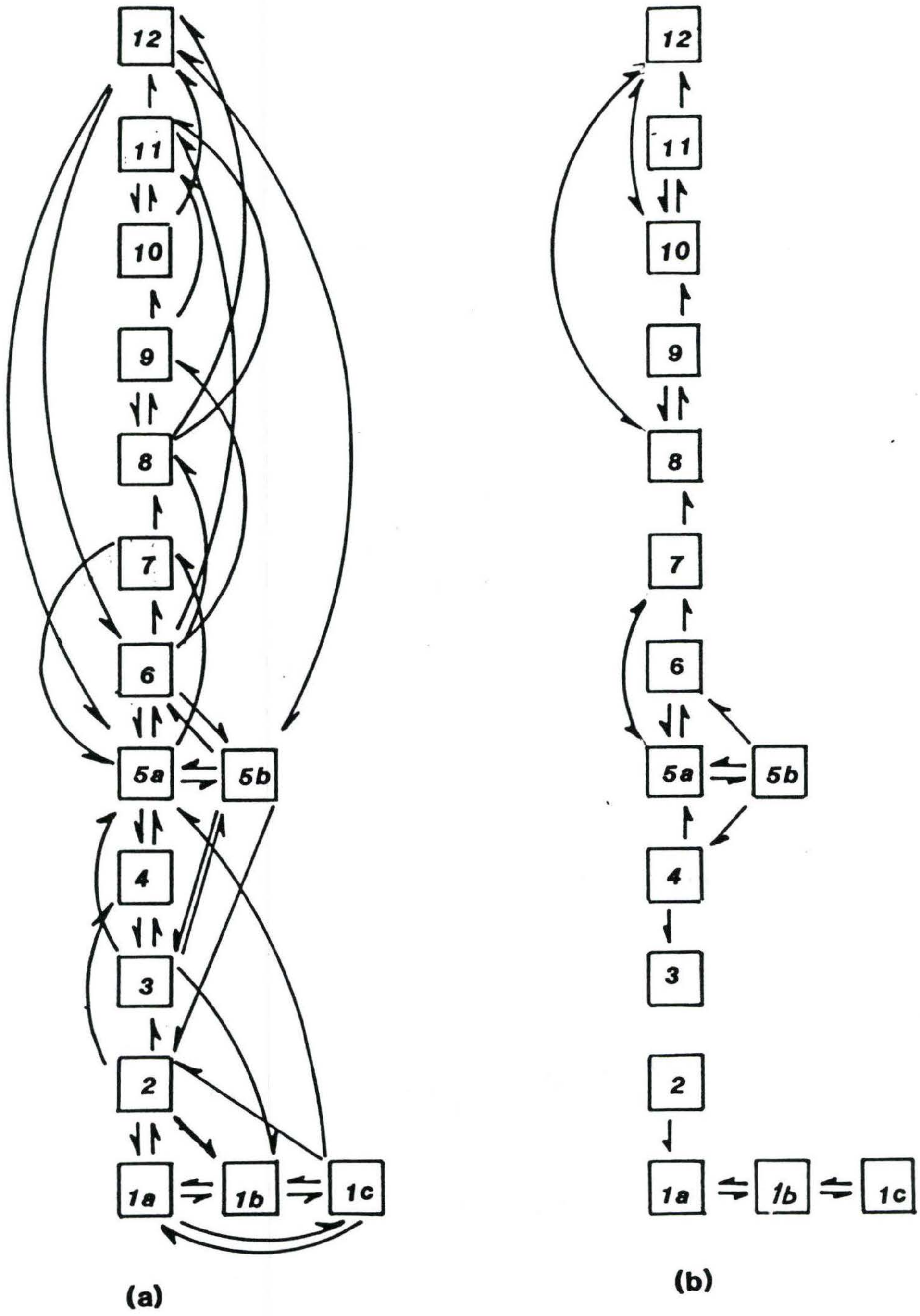


Figure 19 Preferred facies relationships diagrams

A. All facies transitions which were observed to occur with higher than random frequency.

B. Simplified preferred facies relationship diagrams. Only those transitions which were observed to occur with considerably higher than random frequency are plotted (D(ij) greater than .15).

8. Paleocurrent Data

The orientation of directional structures (solemarks, ripple foreset laminations, crestlines of symmetrical wave ripples, and foresets of trough and planar tabular cross stratification) were measured wherever possible in the course of field work. The raw data was corrected for tectonic tilt using a stereonet rotation technique outlined in Potter and Pettijohn (1977).The corrected data is tabulated in Appendix 2. Data from the same stratigraphic unit was generally grouped together and rose diagrams were constructed for each group and plotted on the detailed sections (F-1 to F-12). However, some of the thicker or more complex exposures of a particular member were subdivided into smaller intervals before these calculations were run.

The mean value and dispersion about the mean value for each group was calculated using a programmable HP 33E calculator and a programme published by Lindholm (1979). The essential formulae of this vector summation method are as follows:

$$\tan \bar{\theta} = \frac{\Sigma n \sin\theta}{\Sigma n \cos\theta}$$

$$R = \sqrt{(\Sigma n \sin\theta)^2 + (\Sigma n \cos\theta)^2}$$

$$L = \left(\frac{R}{\Sigma n}\right) \times 100$$

n = observation vector magnitude, all values are assigned a value of 1

θ = azimuthal orientation from 0 to 360° of each directional feature

$\bar{\theta}$ = azimuth of resultant vector

R is the magnitude of the resultant vector and is a measure of dispersion about the mean. L is the magnitude of the resultant vector in percent. L varies from 0% for a completely random distribution, where all vector components will cancel each other out, to 100%, where all observations have exactly the same value. The vector magnitude is therefore a sensitive measure of dispersion that does not imply a normal distribution, as does the use of the standard deviation method (Curray, 1956). Where only a sense of direction is known (ie.) toolmarks, parting lineations, only the data in a range of 0 to 180° is used and each value of theta is doubled before the calculation is made (Lindholm, 1979). The rose diagrams are drafted onto the detailed measured sections and a summary of all paleocurrent data is plotted on Foldout F-13. The paleocurrent data compiled for each stratigraphic unit will be discussed in the next section.

(a) Thistle Member

301 ripple foreset laminations were measured from

the discrete sandstone laminae of the Thistle Member (Appendix 2). Assuming that the turbidite interpretation presented for these sandstone beds is correct then the orientation of the ripples capping the beds should reflect the direction of transport of the turbidity current which deposited the beds. An early study by Pelletier (1965) documented that the current ripples capping sharp based sandstone beds in the lower part of a progradational sequence were oriented offshore. Similar results have been published by Hamblin and Walker (1979) and Leckie and Walker (1982) and these authors have used the orientation of these current ripples to infer direction of paleoslope.

It should be noted that the Thistle Member does contain several thin coarsening upward sequences. However these are not apparently shoreline attached since no associated shoreline facies have been documented in the Thistle interval in the Alberta Basin. For this reason, the associated paleocurrent patterns may not be exactly analogous to those described by Hamblin and Walker (1979) and Leckie and Walker (1982) which are associated with turbidites at the base of a prograding shoreline complex.

If the ripple foreset orientations in the Thistle Member can be considered to be a reliable paleoslope indicators, then a complex basin configuration must be inferred during Thistle time. The rose diagrams patterns differ not only from section to section (Foldout F-12) but also differ vertically within one section (eg.) Barrier Lake section, Foldout F-2. The study area was divided into southern, central, and northern parts and the rose diagrams of ripple foreset orientations for each area are shown in Fig. 20.

Ripple orientations from sections in the southern group (Fig. 20c) indicate that the paleoslope dipped eastward (mean 87°) while the data from the northern part of the study area suggests that the paleoslope was dipping to the south (mean 174°)(Fig. 20a). In the central part of the study area, the orientation of ripples was extremely variable (Fig. 20b, mean 190°). Rupke (1980, p.405) has suggested that such centripetal patterns are common in basin plain turbidite sequences in a marginal or semienclosed sea which received sediment from almost all directions.

In the Barrier Lake section, the paleoslope appears to have changed with time since the mean ripple orientations are different for each successive coarsening upward sequence in the Thistle Member (Foldout F-2). The significance of this variability is unknown. One possible explanation for the vvariability in interpreted paleoslope direction may be related to localized deflection of an eastward dipping regional paleoslope around depositional lobes at the margin of the basin.

(b) Hanson Member

The high degree of bioturbation in the Hanson Member

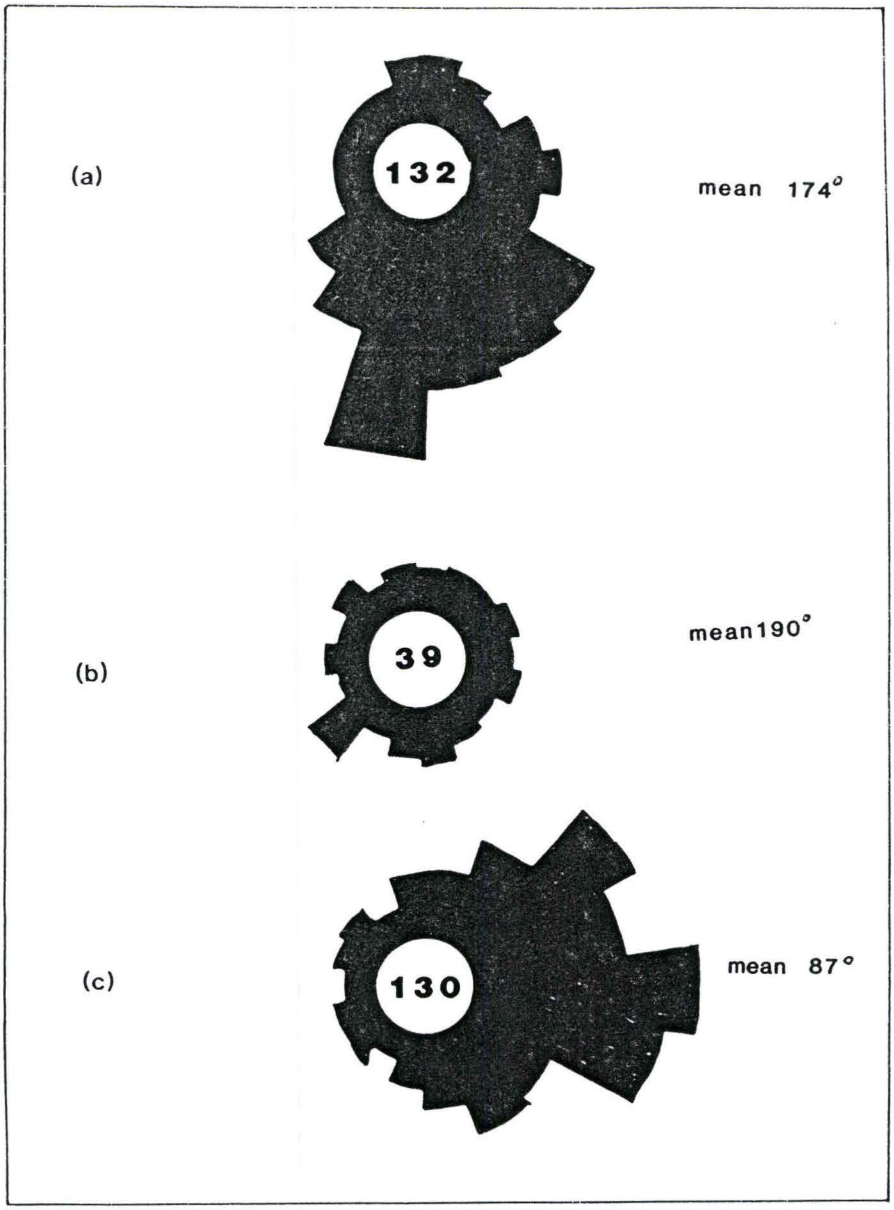


Figure 20 Rose diagrams of ripple foresets from the Thistle Member of the Wapiabi Formation.

a. Northern area
b. Central area
c. Southern area

has completely destroyed any primary sedimentary structures and no paleocurrent data was recorded from this interval.

(c) Chungo Member

168 ripple foreset laminations, 38 solemarks, and 47 symmetrical wave ripples were measured in the interbedded sandstone-mudstone sequences (Facies 1c, 2, 5, 6) in the lower Chungo Member. In addition, 32 trough cross bed foresets were measured from the channel form sandstones (Facies 11) in the upper part of the Chungo Member. In the following discussion the study area is divided into the same southern, central, and northern areas, as discussed previously. No measurable paleocurrent features were observed from the Chungo interval in the northern part of the study area.

In the southern part of the study area, the ripple foresets capping the sharp based sandstone beds (Facies 5a and 5b) at the base of the Chungo section exhibited a well defined northern trend and a mean value of 006 degrees was calculated (Fig. 21a). Since these sharp based beds are interpreted as turbidites, then the mean orientation of the ripples could be used as a paleoslope indicator since the turbidity currents which deposited the beds presumably flowed downslope. The orientation of the solemarks measured at the base of the hummocky (Facies 6) and turbidite (Facies 5) beds was approximately north/south (Fig. 21b) and a mean

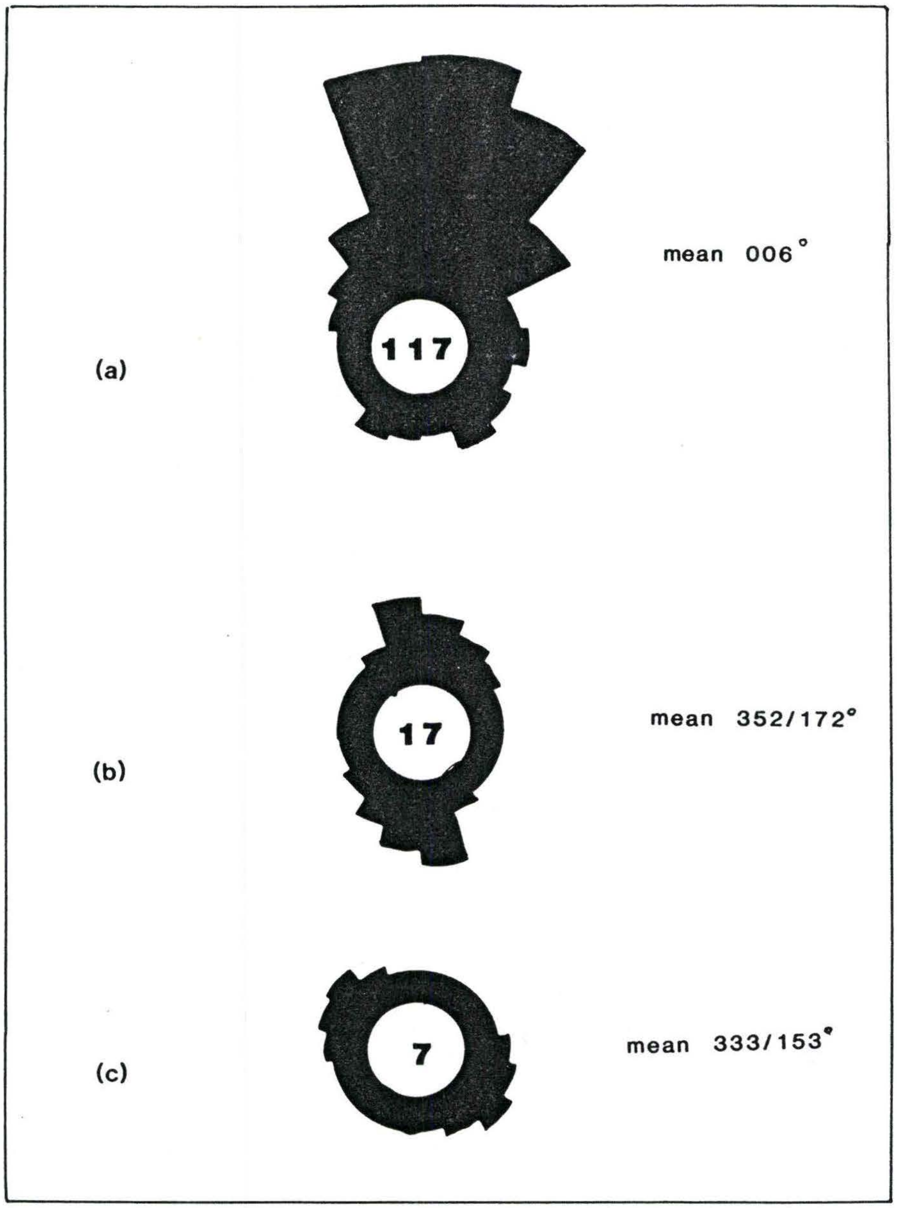


Figure 21 Rose diagrams of paleocurrent features from the Chungo Member in the southern part of the study area.

a. Ripple foreset orientations
b. Solemarks
c. Long axes of symmetrical wave ripples

value of 352/172 degrees was calculated. The solemarks give only the sense of direction since no flutes or absolute directional solemarks were measured. However, the solemarks are found in beds which are capped by ripple foresets which indicate a northerly transport direction. Thus it can be inferred that the currents which formed the solemarks were flowing to the north and not to the south. The orientation of the axes of symmetrical wave ripples exhibits a well defined NW-SE trend (Fig. 21c) and a mean of 333/153 degrees was calculated. Following the reasoning presented by Leckie and Walker (1982), this mean orientation of symmetrical wave ripples can be used as an estimate of the paleoshoreline orientation.

In summary, the paleocurrent data in the Chungo interval in the southern part of the study indicates that the Chungo shoreline was oriented approximately WNW-ESE. The paleoslope dipped to the NNE from this shoreline.

The mean direction of dip for planar tabular foresets in Facies 10 sandstones in the Highwood 2 section was 106 degrees. The mean orientation of the long axes of logs at the base of these sandstones was 122 degrees (Appendix 2). However, these foresets and oriented logs are in sandstones interpreted as nonmarine meandering channel deposits. Since one a few well exposed foresets could be measured, the data base is considered too small to speculate on the mean transport direction for the rivers which deposited the sandstones of Facies 11. It is expected that the river systems feeding a northward prograding WNW-ESE trending shoreline flowed at approximately right angles to this shoreline. However, there is insufficient paleocurrent data in the nonmarine strata to confirm or contradict this assumption.

In the central part of the study area, the rose diagrams of the orientations of ripple foresets in the Chungo Member showed a high dispersion about a calculated mean of 190 degrees (Fig. 22a). The few solemarks present in the hummocky and turbidite facies displayed a NE-SW trend (mean 53/233 degrees) similar to that described in the southern part of the study area (Fig. 22b). The rose diagram of the long axes of symmetrical wave ripples defined a NW-SE trend with a calculated mean of 129/309 degrees (Fig. 22c). These symmetrical wave ripples support the existence of a NNW-ESE trending shoreline similar to that described in the southern part of the study area. The significance of the high variance in the orientation of the ripple foresets in the central part of the study area is unknown. It is considered that the orientation of these ripple foresets neither supports nor contradicts the presence of a WNW-ESE trending shoreline in the central part of the study area during Chungo time.

The existence of a WNW-ESE trending shoreline in southern Alberta during Chungo time, is supported by a study

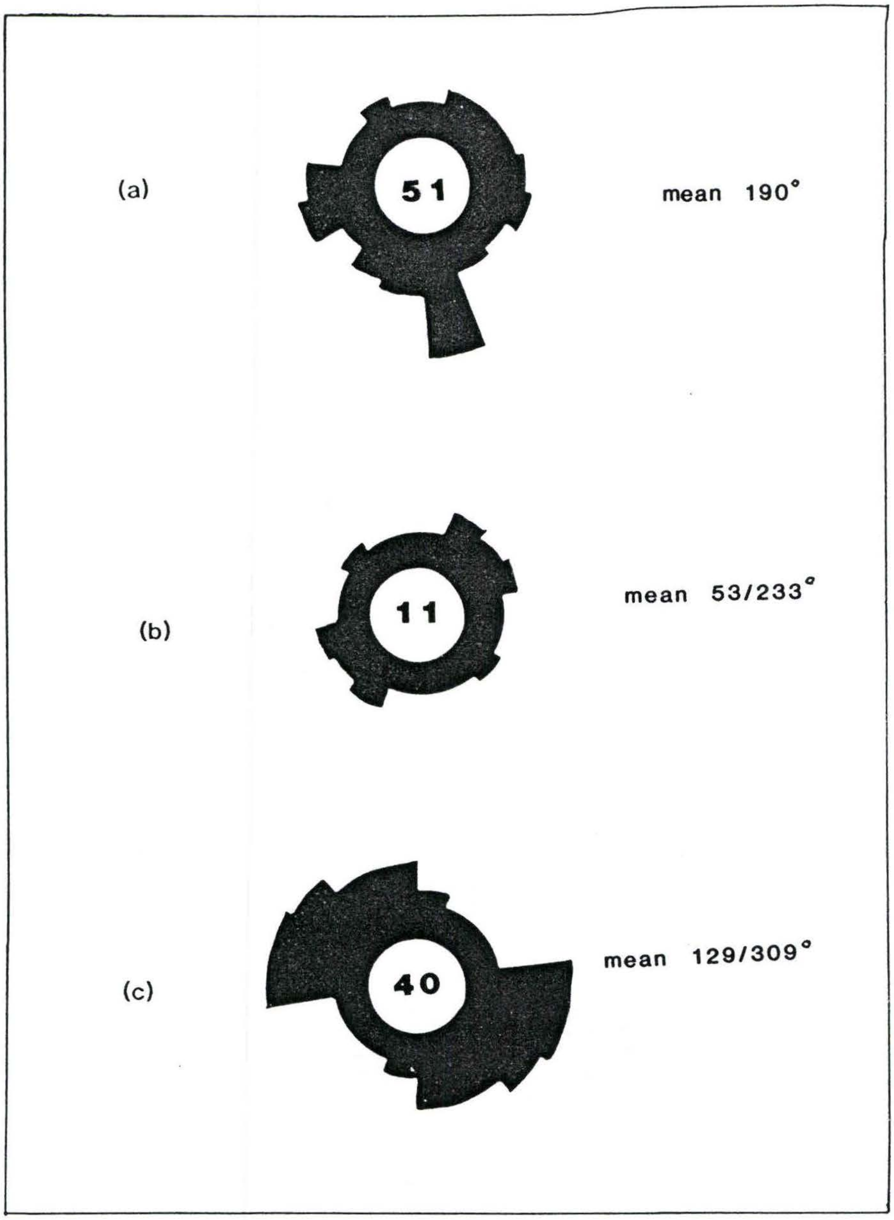


Figure 22 Rose diagram of paleocurrent features from the Chungo Member in the central part of the study area.

a. Ripple foreset orientations
b. Solemarks
c. Long axes of symmetrical wave ripples

of the subsurface equivalent of the Chungo Member (Milk River Sandstone) in the plains east of the study area. Meijer-Drees and Mhyr (1982) reported that the "clean" sandstone in the Milk River Formation pinches out to the northeast. They interpreted that the northward depositional limit of the Milk River Sandstone represents the seaward extent of a NW-SE oriented shoreline system which prograded northward in the shallow marine basin (Fig. 23).

It is interesting to note that the direction of maximum dip of the swaley lamination in the Sheep River and Lundbreck sections is approximately parallel to this postulated shoreline. It is not clear why the lamination at Sheep River dips to the west (mean 252 degrees azimuth) while that at Lundbreck dips to the east (mean 113 degrees azimuth)(Fig. 10).

(d) Nomad Member and Transition to Belly River Formation

No paleocurrent data was measured from the Nomad Member or the overlying beds which are transitional into the Belly River Formation as bioturbation has obscured most primary sedimentary structures. The direction of maximum dip of the beach lamination at the base of the Belly River Formation at Ghost Dam is to the southeast (mean 113 degrees). This suggests that the shoreline was oriented NE-SW and prograded southeastward as Reineck and Singh (1980) have documented that most beach lamination dips offshore.

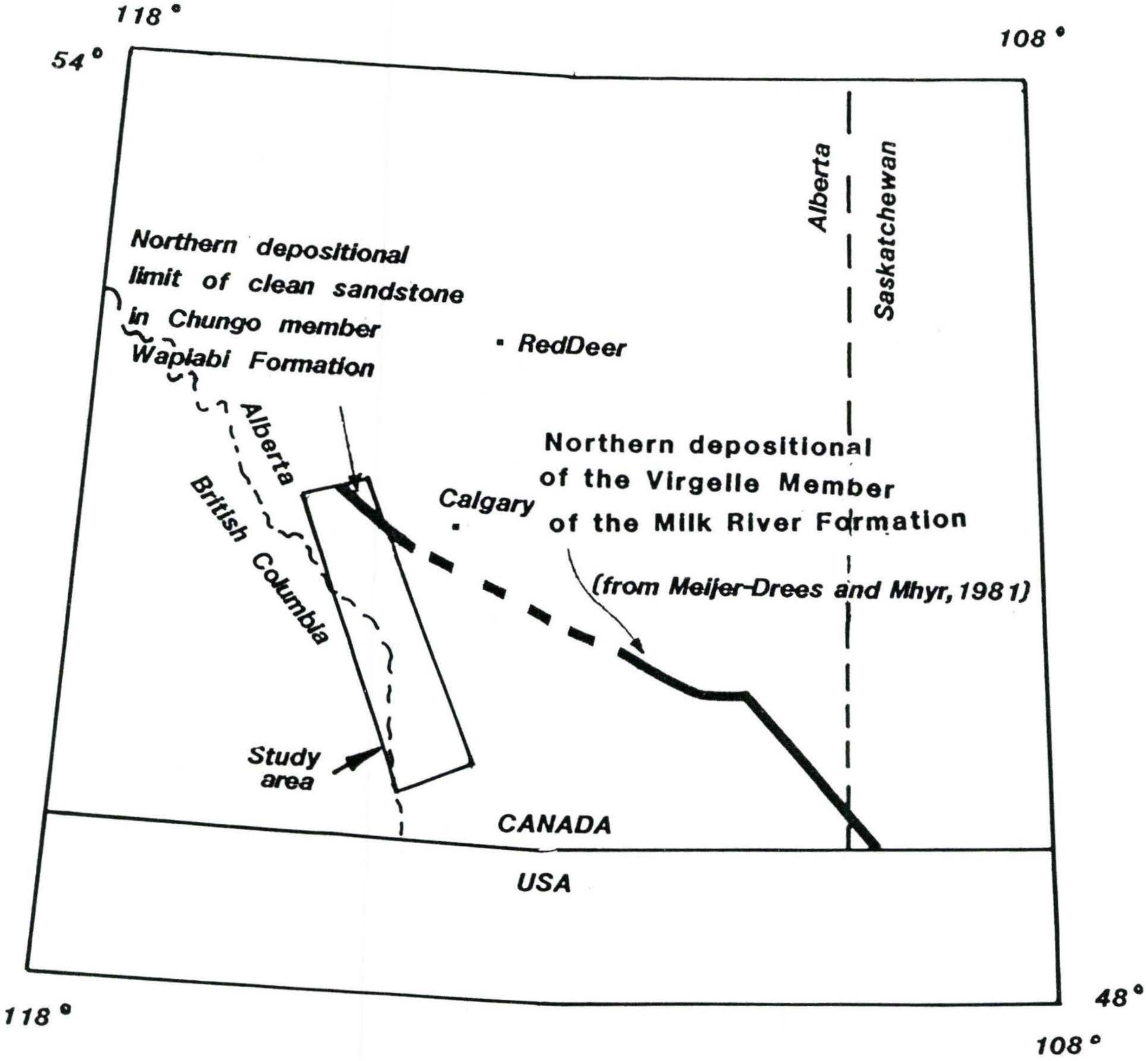


Figure 23 Facies distribution of the Virgelle Member of the Milk River Formation in Southern Alberta (subsurface equivalent of the Chungo Member, Wapiabi Formation)(from Meijer-Drees and Mhyr, 1982).

This configuration is supported by a study by Haywick (1982) who reported that paleocurrent data from the nonmarine strata overlying the beach at Ghost Dam suggested a mean transport direction to the southeast.

9. Petrography

22 thin sections were cut perpendicular to bedding from hand samples from the Trap Creek, Sheep River, Highwood River, Barrier Lake, and Ghost Dam sections. In the Lundbreck, Sheep River, and Highwood River sections, the samples were taken at selected points throughout the stratigraphic sequence. This sampling pattern was employed to determine if any diagenetic or compositional trends existed vertically within the stratigraphic section. All of the thin sections were stained for plagioclase and K-feldspar, using a technique outlined in Appendix 3. All sections were examined under the Luminoscope (cathodoluminescense) as well as under plane light and crossed nicols of a petrographic microscope. Grain size estimates were made by comparison with a Canadian Stratigraphic Service grain size card. A chart published by Folk (1974) was used to estimate the degree of sorting. Estimates of the degree of rounding were made by comparison with a silhouette chart published by Powers (1953). All of the sections were point counted using a 250 point grid, arranged in 5 traverses of 50 points each, oriented normal to bedding.

The petrographic data sheets are included in Appendix 4 and the data is summarized in Table 2. The compositions of the sandstones, as outlined by point counting, are plotted on a QFL diagram (Fig. 24) and on a stratigraphic section (Fig. 25). Some of the salient features of the petrographic study will be discussed here.

(a) Composition

All the samples examined contain significant proportions of quartz, feldspar, and lithic fragments. Where plotted on a QFL diagram, the compositions plot in the fields designated as lithic arkose, feldspathic litharenite, and litharenite, as outlined by Folk (1974, Fig. 24). The lithic component was subdivided into chert, detritial carbonate and other lithic categories where possible. However the grains were generally too fine to subdivide this lithic category with confidence. In many samples, the feldspars are observed in various stages of alteration to clay-carbonate aggregates. In these cases, it is very difficult to differentiate between lithic fragments and altered feldspars. A significant compositional difference is observed between the sandstones of the Belly River Formation and the Chungo Member of the Wapiabi Formation (Figs. 24, 25)(Table 3). The mean proportion of quartz in the Chungo sandstone (36.4%) is distinctly higher than the proportion of quartz in the Belly River sandstones (20.9%).

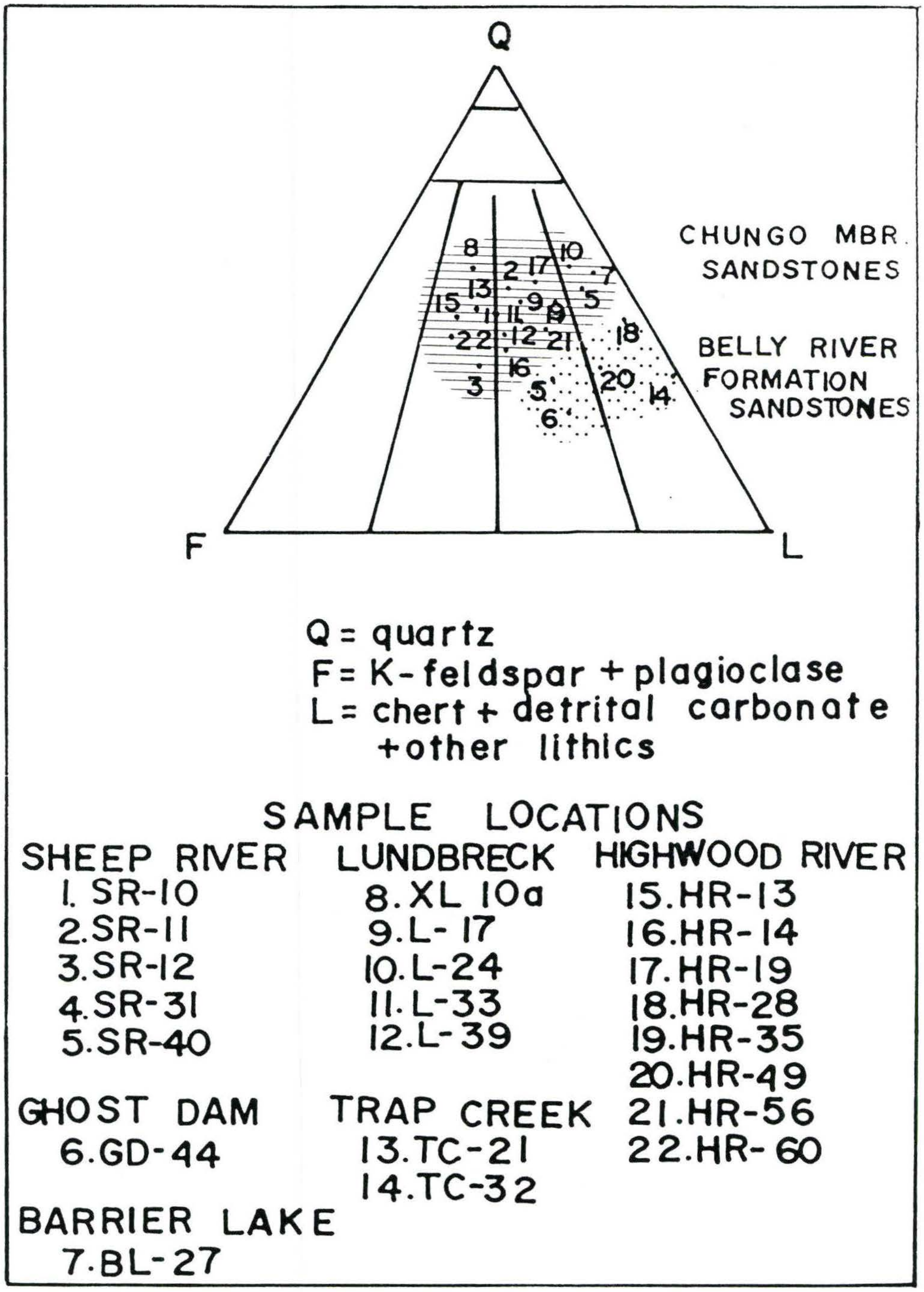


Figure 24 QFL diagram with the composition of the Chungo and Belly River sandstones plotted.

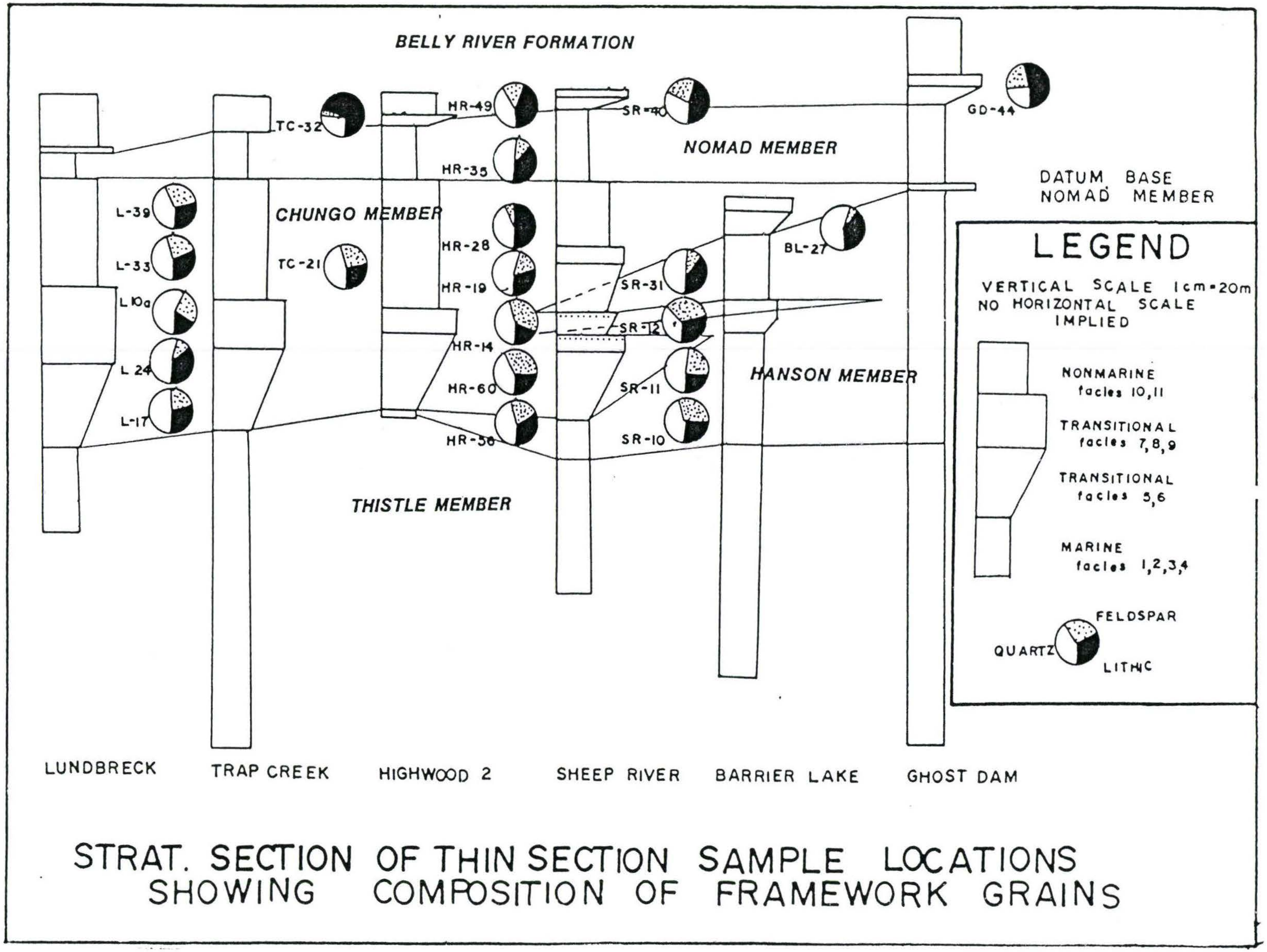
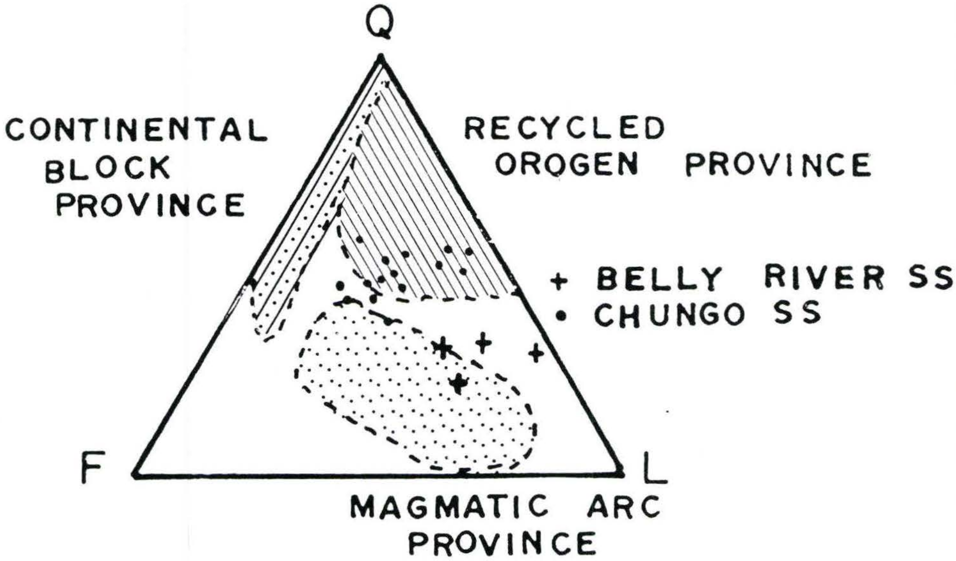


Figure 25 Stratigraphic relationships and framework grain composition of sandstones from the Chungo Member, Wapiabi Formation and from the Belly River Formation in southern Alberta.

Sample #	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix
GD-44	12.8	10.5	2.3.	12.4	0.8	3.4	0.4	13.5	44.0	
SR-40	25.3	16.7	1.9	10.4	0	1.9	1.1	13.0	10.4	8.9
TC-32	20.1	0.6		1.2	1.7	0.6	10.3	42.5	1.7	21.3
HRII-49	25.4	6.8	1.9	24.2	0.4	0.4	1.5	9.8	32.1	
	20.9	8.7	1.5	12.0	0.7	1.6	3.3	19.7	22.0	7.5%
XL10a	28.6	12.8	0.7	4.2		1.8		2.7	48.8	
L-17	44.0	16.3	3.1	7.8	1.2	2.3		16.0	7.8	1.6
L-24	29.2	3.6	0.7	3.6	3.6	3.6		11.7	43.8	
L-33	41.2	16.6	4.0	11.2	2.2	1.1		15.9	7.6	0.4
L-39	36.0	18.8	3.8	7.9	5.1	1.0	0.7	13.0	11.6	1.4
SR-10	37.4	18.7	2.8	3.6	1.6	1.6	2.0	13.5	18.3	
SR-11	42.0	8.5	0	0.7	1.7	3.0	3.8	12.5	16.3	1.04
SR-12	22.4	2.7	0	0.4	2.3	2.3		15.2	35.0	0.4
SR-31	42.5	7.1	0	2.1	1.1	2.9	0.4	30.0	7.1	8.2
HRII-13	39.6	24.5	4.5	1.9	1.1	4.5		9.8	14.0	
HRII-14	24.5	16.4	2.2	2.6	0.70	11.9		5.9	37.5	
HRII-19	35.7	1.3	0.3	3.8	2.9	1.3	0	14.8	20.9	
HRII-28	39.6	3.8		1.5	1.9	1.5		41.9	16.9	3.1
HRII-35	46.3	9.5	1.4	12.4	1.1	5.3		14.8	9.2	
HRII-56	32.8	11.5	1.9	7.6	2.7	5.7		10.7	27.1	
HRII-60	31.7	25.9	3.2	2.9	8.9?	0.7	0.7	13.7	11.2	1.1
TC 21	31	18.6	0.4	3.5	0.8	2.3	0.8	8.5	30.6	3.5
BL 27	51.3	3.4	0.7	15.0		5.2	1.9	15	3.7	3.7
	36.4	12.2	1.65	5.2	2.2	3.2	0.6	14.8	20.4	1.4%

Table 2 Composition of sandstone samples from the Chungo Member Wapiabi Formation and from the Belly River Formation in southern Alberta, determined by petrographic point counting (See Fig. 25 for location of samples).

Figure 26 Composition of Chungo and Belly River sandstones plotted in QFL Diagram proposed by Dickinson and Suczek (1982).



COMPOSITION OF CHUNGO AND BELLY RIVER SANDSTONES PLOTTED ON TECTONIC PROVINCE QFL DIAGRAM PROPOSED BY DICKINSON AND SUSCEK (1982)

The K-feldspar content is slightly higher in the Chungo sandstone (mean 12.2%) than in the Belly River sandstones (mean 8.7%). The plagioclase feldspar content is roughly equivalent in both the Chungo and Belly River sandstones (1.5% versus 1.65% respectively). More significantly, the chert content of the Chungo sandstones (mean 5.2%) is distinctly lower than in the Belly River sandstones (mean 12%). The Belly River sandstone had a slightly higher proportion of other lithics (mean 19.7%) than did the Chungo sandstones (mean 15%). As noted earlier, the "other lithics" component was very difficult to estimate because it was very difficult to differentiate between partially to completely altered feldspar grains and true lithic fragments.

The quartz and chert grains were apparently much more resistant to diagenetic alteration than the feldspar grains. It is considered that the observed differences in the quartz and chert content are much more reliable indices of the compositional differences which exist between the Chungo and Belly River sandstones (Table 3). The composition of the sandstones do not appear to be facies related as samples of rocks from different facies within the same stratigraphic units display similar compositions (Fig. 25).

Table 3 is a summary of petrographic data derived from this study and from previously published studies on the

Source of information (section/Area studied)	Quartz	K feldspar	Plagio.	Chert	Detrital Mica	Detrital Carb.	Opaques	Other Lithics	Sparry Carb.	Matrix
Meyboom (1960) Milk River Formation/South Alberta Plains	60%	< 5% (K feldspar + Plagio.)						total lithics 10%		
Lerbekmo (1963) Belly River Formation, includes Chungo and 1500 feet of overlying Belly River Formation Drywood River, Southern Foothills	50	10	15	10-30	X	minor	minor	total lithics 30%		
Mellon (1961) Chungo equivalent, southern foothills	0-34 16.9%	0-23% 6.6% (K feldspar + Plagio.)		chert and quartzite 0-6.5% 2.1%	0-2.0% .4%	0-28% 15%	0-19% 10.2%	0-26% 3.8%		
McLean (1971) Judith River Fm. (Belly River Eq.) Southern Alberta Plains	15-35%	5-65% (K feldspar + Plagio.) Plag. common & dom. Kspar is common Microcline rare						10-50% lithics		
Ogunyomi and Hills (1977) Foremost Formation (lower Belly River) Southern Plains	32-42%	14-41% (K feldspar + Plagio.)		3-24	minor	minor	X	1-7% volc rock frags.	common	
Hunter (1980) Chungo Member, Highwood River Southern Foothills	39%	8% (K feldspar + Plagio.)		10%	clay & mica 10%	total carbonate 25% (Detrital Carb. to Sparry Carb.)	X	total lithics		
Bullock (1981) Chungo Member, Lundbreck Southern Foothills	40% 34-51%	3-10% 6% (K feldspar + Plagio.)		6-16 11%	clay & mica 13%	total carbonate 7% (Detrital Carb. to Sparry Carb.)		total rock frags.	11%	
Rice & Schurr, (1980) Eagle Sandstone (Chungo Equivalent) Northwest Montana	40-50%	15-30%								10-20%
This study (1982) — Chungo Member	22-51% 36.4%	1.3-25.5% 12.2%	0-4.5% 1.65%	.7-12.4% 5.2%	0-8.9% 2.2%	.7-11.9% 3.2%	.6%	2.7-41.9% 14.8%	3.7-48.8% 20.4%	1.4%
This study (1982) — Belly River Formation	12.8-25.4% 20.9%	.6-16.7% 8.7%	1.9-2.3% 1.5%	1.2-24% 12%	0-1.7% .7%	.4-3.4% 1.6%	.4-10.3% 3.3%	9.8-42.5% 19.7%	1.7-44% 22%	7.5%

Table 3 Comparison of petrographic data derived from various studies of the Belly River-Milk River-Chungo Interval.

same or stratigraphically equivalent strata. It is very difficult to directly compare the data generated by various workers as some have studied just the Chungo Member or equivalent (Meyboom, 1960; Mellon, 1961; Rice and Schurr, 1980; Bullock, 1981) while others have studied just the Belly River or equivalent (McLean, 1971; Ogunyomi and Hills, 1977). The remainder have dealt with undifferentiated Chungo and Belly River sections (Lerbekmo, 1963; Hunter, 1980). Moreover, those studies which dealt with the Belly River strata sampled a much larger proportion of the formation than had been sampled in this thesis.

The quartz content of the Chungo sandstone varies dramatically between the various studies. Meyboom (1960) reported a quartz content of up to 60% in the southern plains. Mellon (1961) reported an average quartz content of only 16.9% in the equivalent strata in the foothills. All other studies of the Chungo sandstone were conducted in the foothills and the quartz contents reported were intermediate between those reported by Meyboom (1960) and Mellon (1961)(Table 3). It appears from this comparison that the compositions of the Chungo sandstone in the southern foothills is indeed different than the composition of the stratigraphically equivalent Milk River of the southern plains.

The reported quartz content of the sandstones of the Belly River Formation and equivalent are also dramatically different between different studies. McLean (1971) reported quartz contents of 15 to 35% in the Belly River(Judith River) section. Ogunyomi and Hills (1977) reported values of 32 to 42% for the same strata in the southern plains. The values reported in this study for the Belly River Formation (mean 20.9%) are most similar to those reported by McLean (1971).

Large differences exist between the reported feldspar content of the Belly River and Chungo sandstones (Table 3). In the Milk River sandstone in the southern plains of Alberta, Meyboom (1960) observed an average combined feldspar content of only 5%. Rice and Schurr (1980) reported feldspar contents of 15 to 30% in the equivalent Eagle sandstone of northwest Montana. The values of most other workers and the values from this study are intermediate between those of Meyboom (1960) and Rice and Schurr (1980). It appears that the feldspar content of the Milk River sandstone in the plains is distinctly higher than the feldspar content in the equivalent Chungo sandstone in the foothills. However, it was noted in the course of this petrographic study that it was very difficult to differentiate between quartz and clear potassic feldspar grains unless very careful staining techniques were employed (Appendix 3). It is possible that the high quartz content and low feldspar content reported by Meyboom (1960) relative to all other published data, may possibly be due to technical problems in sample preparation and subsequent misidentificaion of minerals. This point is significant because it could resolve an apparently unexplained large compositional difference between Chungo sandstones of the foothills and the equivalent Milk River sandstone of the plains.

It is very difficult to compare the proportion of the remaining framework components between the various studies in Table 3 because different workers have grouped the lithic component, the chert component and the detrital carbonate grains differently. In general, the combined chert and lithic component is fairly high (greater than 20%) in both the Chungo and the Belly River intervals. In general the Belly River sandstones are observed to have a distinctly higher combined lithic-chert component. This observation is consistent with the data presented in this thesis (Table 3).

(b) Grain Size

All of the samples studied consisted of very fine to fine grained sandstone. Medium grained to granule sized material was observed as a minor component in three samples. Within the main Chungo coarsening upward sequence, the sands below the HCS section were generally too fine grained to work with petrographically. The vertical change in grain size across the coarsening upward trend was actually very subtle and the coarsest material in the sequence, excluding clay pebble intraclasts, consisted of fine grained sandstone with a minor medium grained component. Granule sized material was observed in the lag of a nonmarine channel sandstone (Facies 11, sample HR-28) in the Highwood River section. However, this was a unique exposure and most of the sandstones of this facies consist of fine grained sand only with varying proportions of clay pebble intraclasts.

(c) Sorting

Most of the samples examined appear to be moderately to well sorted and the degree of sorting does not generally appear to be affected by the facies which was sampled. An exception to this perhaps is found in the sandstones of Facies 11 where varying proportions of clay intraclasts give the rock a poorly sorted texture. A low matrix content is suggested but this may be difficult to determine as the ubiquitous "cruddy" clay carbonate cement is petrographically similar to the matrix. The sandstones from the Belly River Formation appear to have a higher matrix content but it is very difficult to distinguish between compacted lithic fragments and true matrix.

(d) Angularity

All of the samples examined were dominated by angular to subangular grains. Rounded to subround grains were noticeably rare in the samples studied. Where viewed under cathodeluminescence, it appears that many of the grains are heavily corroded where in contact with the carbonate cement. It appears thus, that at least some of the angular texture may be attributed to diagenetic processes. No quartz overgrowths were observed in any of the grains.

(e) Diagenesis

All 22 thin sections were examined with the petrographic microscope and the Luminoscope, for the purposes of determining the paragenetic sequence and nature of the diagenetic processes. In the Luminoscope, the thin sections were studied without cover slips. Best fluorescence was observed at voltages of 8 to 10 KV and currents of 0.4 to 0.6 milliamperes.

Under plane light and crossed nicols, most of the samples appeared to have a high matrix and/or lithic content and variable amounts of carbonate cement (Plates 7a,b,c,d). It was generally difficult to differentiate between matrix, squashed lithic grains, and clay cement. The Luminoscope proved to be very useful in distinguishing clay cement from lithic grains or matrix. The cement typically displayed a "smooth" blue fluorescence which had pore filling habit (Plate 8D). This cement contrasted with the matrix and lithic fragments which had a very irregular mottled texture

Plate 7

A. Sample SR-10, Chungo Member, loaded facies. Plane light. Scale bar 0.5 mm in length. Point counted 37.4% quartz, 18.7% K-feldspar, 3.6% chert.

B. Sample SR-10, as above. Crossed nicols. Note the irregular grain-cement contacts.

C. Sample SR-40, Belly River Formation. Plane light. Note the lower quartz content and higher proportion of chert as compared to SR-10. Same scale as A,B.

D. Sample SR-40, as above. Crossed nicols. Note difficulties in differentiating grain-cement boundaries, particularly where the grains are altered feldspars or lithic fragments. Same scale as A,B.

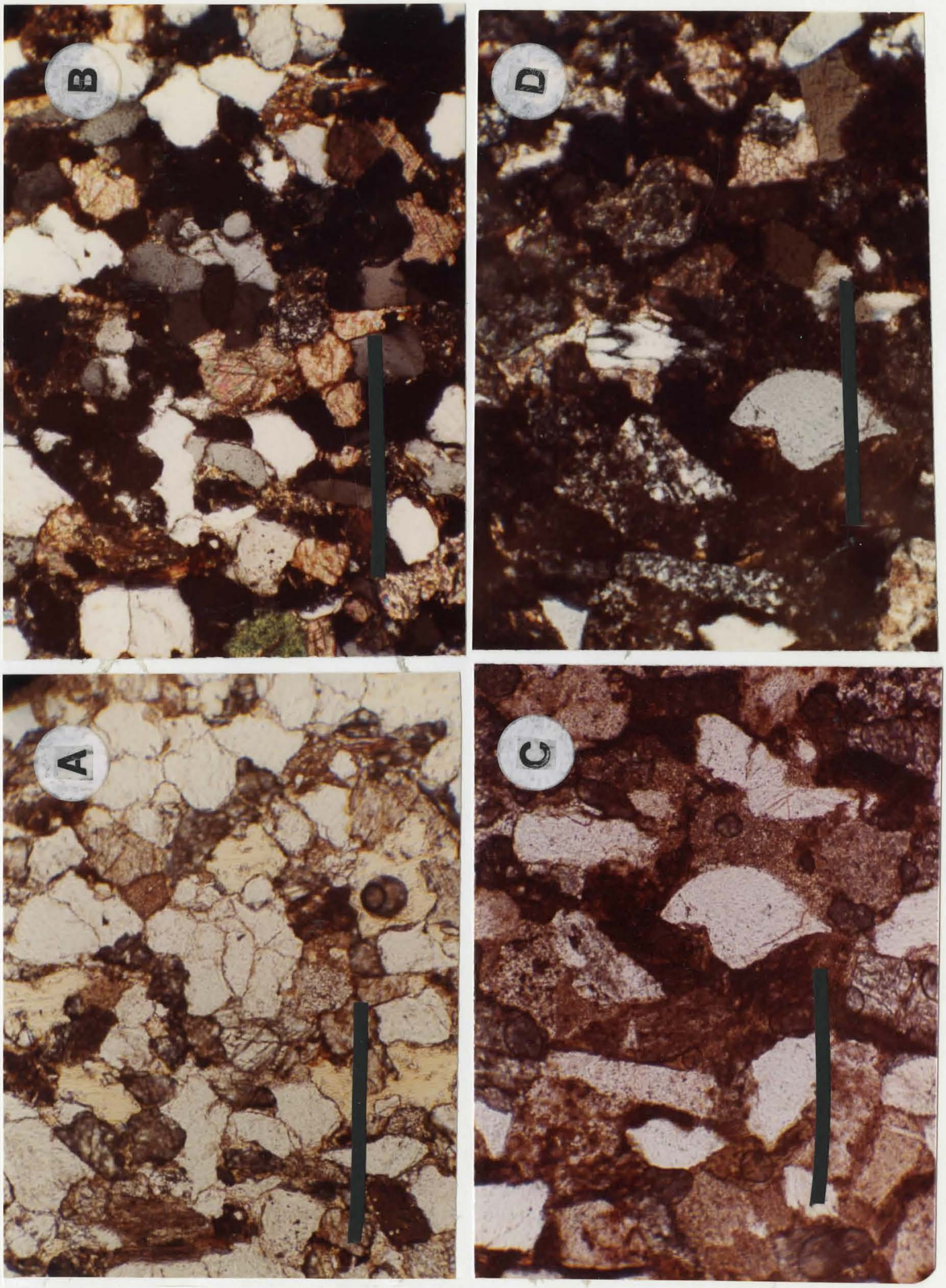

B
D
A
C

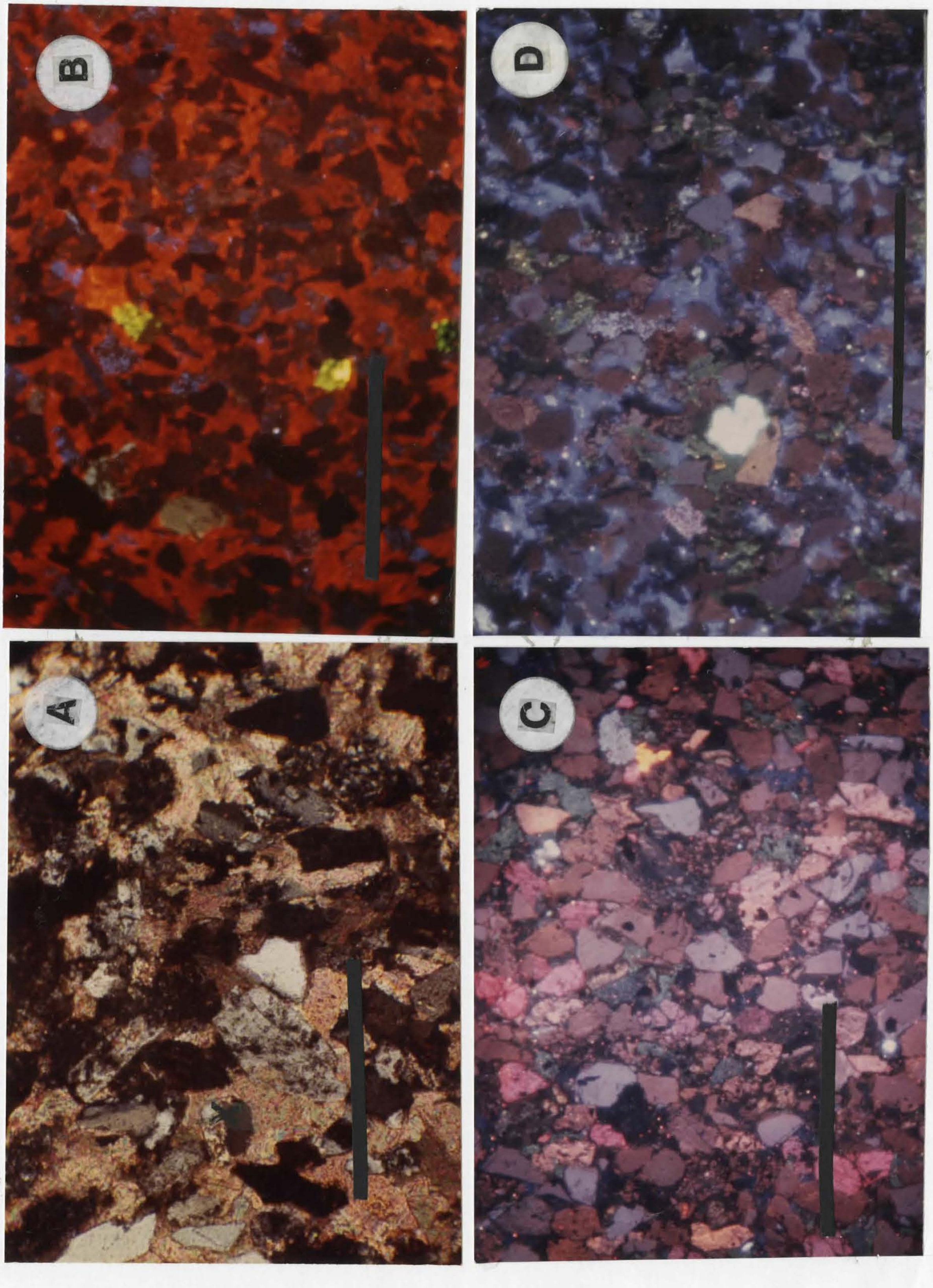
Plate 8

A. Sample GD-44, Belly River Formation. Crossed nicols. Note the aggressive carbonate cement phase. In some parts of the slides, marked X, the grains appear to be floating or supported in carbonate cement. Scale bar 0.5 mm.

B. Sample GD-44, Belly River Formation, Ghost Dam section. CL photo. Scale bar 1 mm. Note ubiquitous red fluorescing carbonate cement and angular nature of grains. Note also the low content of quartz (blue fluorescing) in Belly River strata.

C. Sample TC-32, Belly River Formation, Trap Creek section. Scale bar 1 mm. Note the irregular "rough" textured matrix which binds the grains, in contrast to even textured and fluorescing cement in the Plate 9A and 9B. Note also very angular nature of grains.

D. Sample HR-28, Chungo Member, Highwood River section. CL photo. Scale bar 1 mm. Note two distinct stages of cementation. Early ubiquitous light blue fluorescing probably chlorite. Note angular texture to grains and absence of deformed grains (no significant compaction before cementation). Note also later green fluorescing carbonate cement which has replaced a few discrete grains and filling in remaining porosity. Cement composition determined by conventional petrographic methods.


B
D
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C

and were only very weakly fluorescing (Plate 8C).

Two different ages of cement were recognized in the samples. The earliest cement is a dark, high relief, "cruddy" almost isotropic material with an even blue fluorescence. This cement occurs as a pore filling cement (Plate 8D) and as a replacement of discrete grains.

This cement has the petrographic characteristics of chlorite, a mineral which was previously identified by X-ray diffraction methods in samples from this formation (Lerbekmo, 1963). The distribution and habit of this chlorite cement is very erratic and locally variable. For example, samples SR-11 and SR-12 were collected from the same outcrop and the same facies, yet the proportion and distribution of chlorite is very different in the two samples (See Appendix 4, Table 2 for description). In general, samples containing a high proportion of chlorite as discrete grains generally have an abnormally low feldspar content. This suggests that feldspar is being replaced by chlorite.

A later carbonate cement characterized by bright orange to red fluorescence postdated the early chlorite cement. This later carbonate occurs as a porefilling cement and as replacement of discrete grains (Plate 8B). Sparry carbonate cement is very prevalent and in some samples, comprises up to 50% of the total slide (eg. XL10a). In other samples the carbonate is conspicuously absent. This is particularly true where the porosity of the sandstone was low, either due to having a high matrix content (eg. TC 32, Plate 8C) or due to having been completely filled by the earlier chlorite cement (eg. SR-10, Plate 7A, B). In some samples, wisps and inclusions of chlorite cement are surrounded by carbonate, suggesting that the chlorite cement has been partially to completely replaced by carbonate.

It appears that the solutions depositing the carbonate were very aggressive. Many of the lithic fragments are also partially to completely replaced by carbonate and some quartz grain margins, where in contact with carbonate cement, appear to be heavily corroded (Plate 8A).

In a few samples, (eg. HR-28) traces of a green fluorescing pore filling carbonate cement are present and it appears that this event has postdated the red fluorescing carbonate cement (Plate 8D).

It is difficult to ascertain the timing of the extensive cementation. Under plane light and crossed nicols, what appears to be abundant squashed lithic fragments are common (Plate 7C,D). However, when observed with the Luminoscope, it is clear that most of the grains are not deformed by compaction (Plate 8B) and presumably the cement was deposited before significant burial and compaction occurred.

10. Microfossil Content of the Upper Wapiabi Formation

Previous studies by Wall (1967) have documented that the various members of the Wapiabi Formation could be differentiated on the basis of distinctive microfaunal assemblages. Figure 8 outlines the correlations between Stott's (1963) nomenclature scheme and the microfaunal assemblage associated with each stratigraphic unit.

In the course of field work, large (2 to 3 kg) samples of shale or mudstone were taken at 10 to 30 m intervals across the section. Where marked facies changes occurred, the samples were spaced more closely. This technique was used to determine whether the change in lithology was accompanied by a change in the microfossil content. In the laboratory, samples from the Lundbreck, Trap Creek, and Ghost Dam sections were processed. Since these sections collectively encompassed the greatest stratigraphic interval, they should thus document any progressive change in microfossil content. The samples were processed using a technique outlined in Appendix 5 and the microfossils were picked from each processed sample using a needle and a binocular microscope.

In most of the samples, no microfossils were recovered at all. In those samples that did contain recoverable microfossils, the recoveries were mediocre to very poor. Figure 27 outlines the location of samples which did yield microfossils. The identification of the microfossils was conducted by Dr. John Wall and his report on the samples is included in Appendix 5.

The microfauna was analyzed in this study primarily to aid in correlation across areas where marked facies changes occurred and where time equivalence of the various lithostratigraphic units was poorly understood. In addition, any information or constraints on the environmental conditions (water depth, salinity, turbidity, etc.) that could be derived from the microfaunal assemblages were used to develop the overall depositional model for the Upper Wapiabi Formation. This thesis is concerned only with the Dowling, Thistle, Hanson, Chungo, and Nomad Members of the Wapiabi Formation. Thus only those assemblages associated with these stratigraphic units will be discussed (Fig. 8).

The Brachythere bullopora assemblage (number six) is associated with the Upper Dowling and Lower Thistle Members in the study area. Wall (1967) has noted that this assemblage crosses both lithostratigraphic and megafaunal (ammonite) zone boundaries and has indicated that it is probably not a reliable time marker. The association of agglutinated and calcareous foraminifera is thought to represent deposition in cool to temperate, slightly turbid

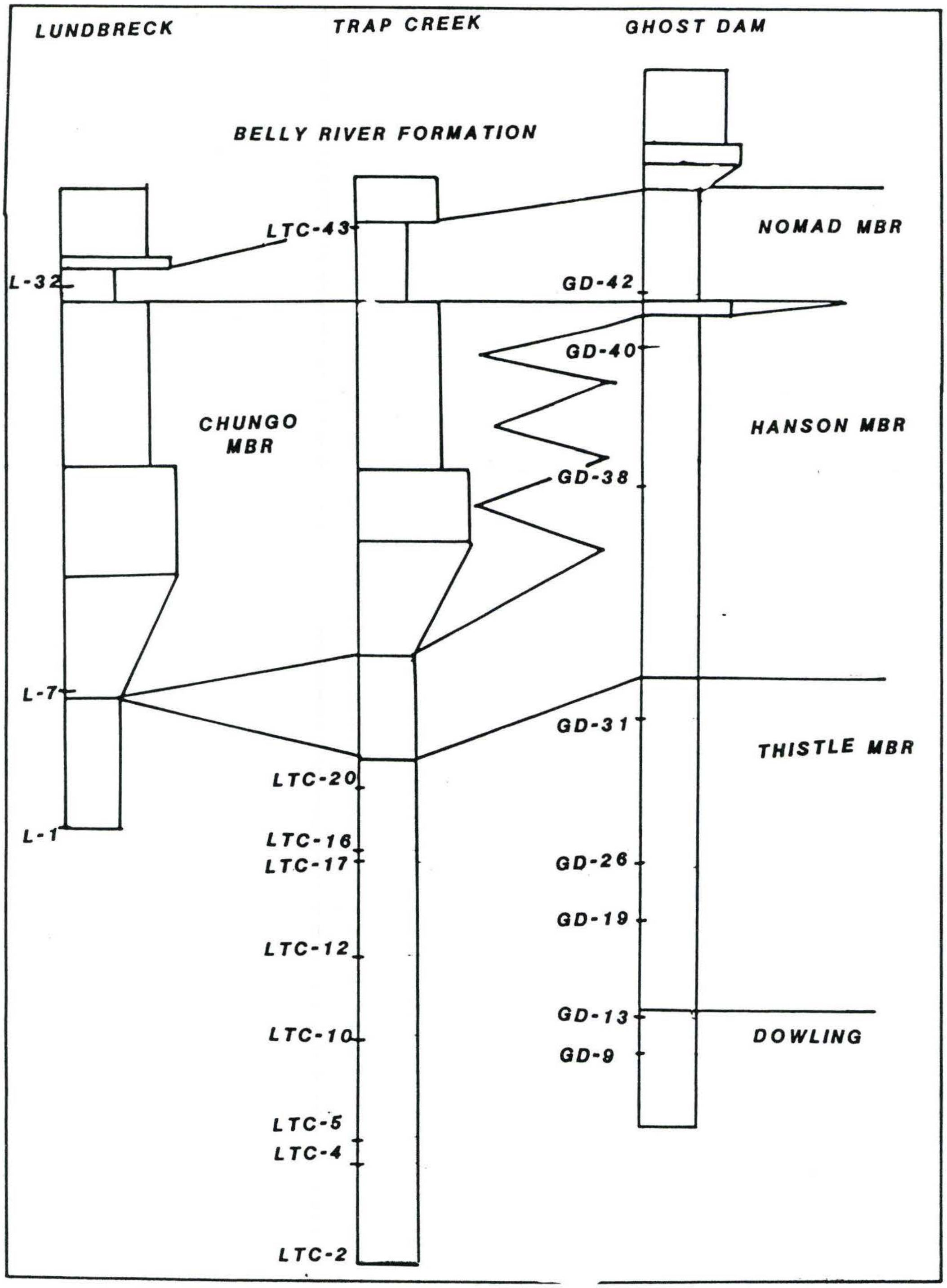


Figure 27 Location of microfaunal samples taken from mudstones of the Wapiabi and Belly River Formations.

seawater of normal salinity in middle neritic depths (Wall, 1967).

The overlying Anonomalinoides henbesti assemblage (number seven) is associated with the Upper Thistle Member of the Wapiabi Formation in the study area. The assemblage contains a mixed agglutinated and calcareous fauna. The dominance of calcareous fauna suggests a deepening of the Cretaceous sea, relative to the underlying Brachythere bullopora assemblage.

The Upper Pelagic assemblage (number eight) is associated with the Hanson Member of the Wapiabi Formation in the southern foothills. However, it occurs progressively lower in the lithostratigraphic section as one proceeds from north to south. Wall (1967) has noted that since this assemblage transgresses megafaunal (ammonite) zones, its reliability as a time datum is also questionable. However, if the assemblage does prove to be a time marker, then the fact that it occurs at progressively lower stratigraphic intervals to the north would indicate that the Thistle, Hanson, and Dowling Members are markedly diachronous. Each individual member would become progressively younger to the north. The predominance of calcareous fauna in this assemblage suggests greater water depths, presumably more distal from a clastic source than the underlying assemblage seven (Wall, 1967).

Wall's (1967) Trochammina ribstonensis (number nine) is not developed in the southern foothills. Its absence is probably related to the withdrawal of the Cretaceous Seaway from southern Alberta, due to the northward progradation of the Chungo shoreline at that time. The dominance of agglutinated over pelagic forams in this biostratigraphic unit suggests that the shales and mudstones were deposited at shallower depths and in more turbid water than the underlying Upper Pelagic assemblage.

The Lenticulina assemblage (number ten) which Wall (1967) has defined is associated with the Nomad Member of the Wapiabi Formation. The predominance of calcareous benthonic foraminifera documents a return of deeper marine conditions to southern Alberta, following the overall shoaling associated with the underlying Chungo Member. The microfossil content suggests that the Nomad mudstones were deposited under middle neritic conditions.

In the samples analyzed in this study, the microfossil recoveries were generally very poor. Moreover, the species which were identified were mostly long ranging and unsuitable for dating or detailed correlations. Wall (1982; see Appendix 5) has indicated that in the Ghost Dam section the sample GD-13 contains fauna typical of the Upper Thistle Member while the samples GD-38 and GD-40 do contain microfossils typical of the Hanson Member. Beyond these statements, the microfossil recoveries are insufficient to aid in correlations. It is significant however, that the microfossils assemblages do not contradict any of the correlations established in Fig. 17.

Wall (1982; see Appendix 5) has interpreted that all the microfossils collected in this study were probably deposited in the inner shelf zone at water depths of 50 to 75 meters. The presence of calcareous forams at the base of the Trap Creek section may suggest deeper water than equivalent Thistle strata in the other sections. However, the apparent absence of calcareous fauna in the other sections may be due to post depositional processes such as diagenetic leaching (Wall, 1982). Thus, this inference of relative water depth may be incorrect.

The association of marine forams and in situ megaspores at the base of the Chungo sandstone at Lundbreck is indicative of a marginal marine setting (Wall, 1982; see Appendix 5). This observation is supportive of the shoreline interpretation proposed in this study.

The presence of marine microfossils in the Nomad Member at Trap Creek indicates that the transgressing Nomad sea progressed at least as far south as the Trap Creek area. This is supported by data presented by Bullock (1980) who reported presence of marine microfossils at the Nomad interval in the Lundbreck section. This suggests that the transgressing Nomad Sea extended southward beyond the southern limits of the study area.

11. Facies Interpretation

This section will attempt to interpret the environmental processes and conditions that existed during deposition of the various lithofacies. A discussion of the lithofacies sequences and their paleoenvironmental interpretations will be discussed in a subsequent section.

(a) Facies 1a, 1b, 1c Interpretation

Shale, silt, and thin (less than 5cm) sand beds.

These three facies are similar in that they all consist of thinly laminated shale with varying proportions of interbedded sharp based siltstone and sandstone beds. These facies are generally intimately associated in the field and their mutual contacts are generally gradational. It is thus interpreted that they are formed from similar processes which varied in intensity and which resulted in deposition of different proportions of sandstone, siltstone, and shale in the section.

The abundance of marine trace fauna, body fossils, and marine microfauna all indicate that normal marine salinity conditions existed at the time of deposition. Rhizocorallium is interpreted as post depositional, deposit feeding crustacean traces in a shallow shelf setting (Seilacher, 1967). Gyrochorte is generally considered as a shallow shelf gastropod crawling trace although Hallam (1970) has documented Gyrochorte in nonmarine, brackish and deep marine settings and has suggested that it would be made by gastropods, tunneling amphipods, or burrowing worms.

The thinly laminated shale is interpreted to have been deposited from suspension in a low energy marine setting. The thin silt and sand laminae record the periodic introduction of coarser sediments into the low energy environment. This phenomenon could be attributed to several processes.

Johnson (1980, p.252) has suggested that similar beds represent deposition of sediment from suspension that has been entrained by storms. Hamblin (1978) has documented similar discrete siltstone and sandstone laminae in the Jurassic-Cretaceous Fernie Kootenay Formation in southern Alberta. He concluded that they were deposited by waning density currents generated by storm surge activity on the adjacent shoreline.

Stow and Shanmugan (1980) have studied recent and ancient examples of fine grained turbidites which have a similar scale to those described in Facies 1 and 2. They have interpreted that the structures represent deposition from different stages of a large muddy turbidity flow, associated with different parts of a "deep water" slope, base of slope and basin plain environment. Although the "deep water" thin turbidites documented by Stow and Shanmugan (1980) are not exact analogs for Facies 1a, 1b, and 1c, it is important to recognize that very thick, muddy slow moving (10 to 15 cm per second) turbidity flows with relatively low concentrations of suspended sediment could generate structures similar to those observed in Facies 1a, 1b, and 1c.

Another possible explanation for the presence of thin interbedded sandstones and mudstones in a shelf setting has been proposed by Nelson (1982). Box cores taken from recent shelf sediments up to 100 km offshore in the northern Bering Sea were reported to contain sharp based sand beds. These sand beds varied from 1 to 20 cm in thickness and contained parallel and ripple foreset lamination. Nelson (1982) reported that bottom current velocities capable of moving sand sized material were attained during the early and final stages of a storm. In the early stages, the bottom current was variable in direction and essentially wind driven. However, in the later stages of the storm, the bottom currents were directed offshore (downslope). These currents were considered as waning storm surge ebb currents produced by relaxing of storm surge setup (Nelson, 1982). Nelson's (1982) study also demonstrated that the thickness of the sandstone beds decreased farther offshore. Sand beds of the scale observed in Facies 1 (1 to 5 cm) were commonly found 60 to 75 km offshore from the present shoreline (Nelson, 1982).

It is also possible that some of the thinner laminae were deposited by eolian processes. Sand or silt could have been removed from the exposed sandy shorelines and transported out to the shelf. Although it is doubtful that eolian processes were responsible for moving significant volumes of clastic material to the shelf, it is possible that some of the thinner laminae were deposited by this process.

The commonly observed transition from thinly laminated to moderately bioturbated shales and siltstones may reflect either changes in the rate of sedimentation and/or bioturbation. It may also reflect vertical and lateral changes in the pycnocline (a layer of water across which the oxygen content decreases rapidly with depth). It has been demonstrated by Byers (1977) that the change in pycnocline may be related to a change in sealevel or a change in mixing depth. Bozanich (1979) has explained that successions of alternating bioturbated and non bioturbated sediments in the Permian Basin are due to storm activity periodically mixing oxygenated surface water with stagnant basin water. Another mechanism involves periodic mixing of oxygenated water from the basin or from the outer shelf, with stagnant water from locally reducing basins, a process that could be initiated by tide or storm activity (Bozanich, 1979).

The significance of the small scale coarsening upward sequences capped by concretionary phosphatic, pebbly beds remains unclear. These cycles may represent the basinal equivalent of a regressive cycle which is terminated by an abrupt transgressive event. The concretionary slightly phosphatic pebbly horizons are generally tightly cemented and contain variable proportions of glauconite and pyrite. They are very similar to "submarine hardgrounds" reported in many carbonate sequences (Wilson, 1975). In the carbonate sequences, the hardground surfaces generally mark a transgressive event. The rate of sediment accumulation was sufficiently slow to allow for extensive boring and concentration of the glauconite, pyrite, phosphate, shark's teeth and shell hash. In the clastic sequences described in this thesis, these hardground surfaces probably developed offshore during a transgressive event during a time when most of the fine muds were trapped in the estuaries and lower reaches of the coastal river systems.

(b) Facies 2 Interpretation

Facies 2 is characterized by an interbedded sequence of sharp based thin (1 to 5 cm) sandstone beds which are interbedded with variable proportions of siltstone and only minor proportions of shale. It is suggested that the sand beds represent periodic incursions of coarser sediment into a shelf setting where silt sized material normally accumulated. The sand could have been transported by either density currents or storm surge ebb currents as outlined for Facies 1. The noted absence of shale laminae may suggest Facies 2 represents a slightly higher energy environment than was proposed for Facies 1. The fact that Facies 2 is commonly found stratigraphically above Facies 1a, 1b, and 1c in the coarsening upward sequences may support the earlier suggestion that these are actually shoaling upward sequences. At shallower depths, the bottom sediments would be more frequently disturbed by large storm waves. This would create a higher energy environment that would more likely winnow the finer clay sized fraction from the bottom sediment.

The ubiquitous burrowing documented in Facies 2 attests to the fact that the bottom was well oxygenated at all times and thus conducive to development of a benthic infauna. The widespread bioturbation may also indicate a very slow sedimentation rate where biogenic processes dominated over physical processes.

Similar interbedded sandstone-siltstone lithologies were documented in recent cores in the Gulf of Gaeta in the transition zone between the shoreface and shelf mud environment in water depths of 10 to 20 m (Reineck and Singh, 1980). However, their descriptions suggest that the modern sediments are more highly bioturbated than were the exposures of Facies 2.

Similar lithologies were also observed in the delta front environment of the recent Mississippi delta (Coleman, 1975); and in the lower portions of the lower delta front facies of the Upper Cretaceous Blackhawk Formation at Book Cliffs, Utah (Balsley, 1980).

(c) Facies 3 Interpretation

The extensive bioturbation has destroyed almost all primary sedimentary structures in Facies 3 sandstones. This indicates that the bottom sediments were well oxygenated and that biologic reworking was dominant over reworking by inorganic physical processes. The bioturbated sandstone may contain vestiges of sharp based sandstone beds and is commonly interbedded with sandstone/mudstone sequences of Facies 2 and 5. Both these facts suggest that the sand in Facies 3 sandstone was introduced into the shallow marine setting by either density or storm surge ebb currents. However subsequent intense bioturbation had destroyed most primary sedimentary structures in the Facies 3 sandstones.

(d) Facies 4 Interpretation

The presence of marine trace and body fossils indicates that this facies accumulated under normal marine salinity conditions. The absence of primary inorganic sedimentary structures makes further interpretation difficult. The fact that Facies 4 mudstones are locally interbedded with Facies 2, 3, and 5 suggests that Facies 4 was deposited by similar processes. However more intense bioturbation, possibly related to slower rates of deposition, has completely destroyed any primary sedimentary structures. The correlation diagram (Fig. 17) demonstrates that the thick exposures of Facies 4 that were reported in the Ghost Dam and Barrier Lake sections (Hanson Member) are stratigraphically equivalent to, and probably the offshore or basinal equivalent of, the "clean" sandstones of Facies 5, 6, 7, 8, and 9.

(e) Facies 5 Interpretation

Facies 5 is characterized by a sequence of thick (5 to 30 cm) sharp based sandstone beds, exhibiting parallel and ripple foreset laminations, which are interbedded with bioturbated mudstones. The diverse marine fauna and abundance of bioturbation is supportive of fully marine conditions. Weimer and Hoyt (1964) have suggested that presence of *Ophiomorpha* is evidence of a sandy beach environment. However Frey *et al*. (1978) have documented *C. major* burrows in lagoons, bays, estuaries, offshore shoals, and deep water fan settings and have indicated that *Ophiomorpha* type burrows are not diagnostic of any particular environment.

The succession of discrete sharp based sandstones and mudstones apparently records the periodic incursion of coarser sediment into a low energy shelf setting in which clays and silts accumulated under normal energy (fairweather) conditions. The high degree of bioturbation reported in the mudstones between the discrete sandstone beds probably resulted from slow rate of accumulation under conditions conducive to growth of benthic fauna. The discrete beds of Facies 5 are generally thicker than those of Facies 1, 2, or 3. Similar transitions have been interpreted by Hamblin and Walker (1979) to indicate that the source of the sediment was closer and was probably related to progradation of an adjacent shoreline towards the site of deposition. Two possible mechanisms are proposed to explain the sandstone/mudstone interbedding.

Hayes (1967) studied the effects of Hurricane Carla on the shelf offshore from Padre Island, Texas. He reported that sand removed from the beachface was transported seaward via a storm generated density current. This current deposited a single sand bed up to 9 cm thick in water depths up to at least 36 m and across areas of at least 675 square km.

Hamblin and Walker (1979) have interpreted similar lithologies in the Jurassic Fernie to Kootenay transition as storm generated density current deposits. Moreover, they have used solemarks and the orientation of ripple foreset laminations to infer slope direction. Similar interpretations have been made for the Lundbreck and Highwood 2 sections which were previously studied by Bullock (1981) and Hunter (1980) respectively.

An alternative method for explaining an interbedded sequence of sandstone and mudstone in a shelf setting is presented by Nelson (1982) and this process is discussed in the interpretation of Facies 1. Nelson (1982) has studied recent box cores in the Bering Sea and has noted the presence of sharp based sandstone up to 20 cm thick. These beds contained structures analogous to those observed in Facies 5 and were common across large areas of the shelf up to 100 km offshore and in water depths of up to 20 m. Nelson (1982) has interpreted the sand beds as deposits of a waning storm surge ebb current. He has also indicated that wave driven bottom currents were also capable of moving significant quantities of silt and sand sized material. There is insufficient data available at present, to evaluate the process presented by Nelson (1982) as an alternative to a density current model. It is presented as an alternative explanation for the presence of sharp based sandstone beds located several tens of kilometers offshore in a shelf setting.

The presence of vertical escape burrows in the discrete beds suggests that the unit was deposited in a relatively short time span. The parallel and ripple lamination is analogous to the TB, TC, TBC lamination of classic turbidites which are unquestionably regarded as density current deposits. For this reason, the density current model is strongly favoured here. The process initiating the density current remains unclear. The association of the "turbidite" facies with hummocky cross stratified sandstone, which is interpreted as a storm deposit, suggests that the density current was initiated by a storm related process such as a shoreline storm wave surge.

(f) Facies 6 Interpretation

The alternating succession of discrete sharp based hummocky cross stratified sandstones and bioturbated mudstones recorded periodic incursions of coarser sediment into a quiet marine environment into which silts and clays normally accumulated.

The process which forms HCS has not been duplicated in wavetank experiments but this is probably due to the problems in constructing models of a proper scale. More importantly, HCS has not yet been identified in the modern setting although this may be due to problems in identifying the structure in small box cores. Howard and Reineck (1981) have described laminated sands that are "probably hummocky bedded" in water depths of 9.3 to 18.7 m on the high energy California shelf but they were not very explicit in their descriptions.

The HCS structure has been interpreted by Harms *et al.* (1975) to result from the interaction of storm surge with the sandy substrate. At peak velocities, large volumes of sand are entrained in the water column. This sand is subsequently deposited rapidly as the velocity of the surge diminishes. As the sand rapidly dropped out of suspension, swell waves moulded the bottom topography into a series of hummocks and swales. This process generated a series of low angle truncations and the familiar HCS structure.

Dott and Bourgeois (1982) have pointed out the presence of pebbles and large shells along the lower scoured base of many HCS beds. They have suggested that flow velocities of several hundred centimeters per second may be responsible for the initial scouring event. The same workers have noted the abundance of parting lineation along bedding planes and cited this as evidence that tractive forces had a significant influence in the formation of the HCS structure. The individual laminae within each hummocky bed is thought to have been deposited by a single wave or wave train (Dott and Bourgeois, 1982). More significantly, Dott and Bourgeois (1982) have suggested that the HCS bedform may represent a transitional bedform between linear oscillatory ripples and a truly flat bed.

An important consideration regarding the origin of HCS sandstone beds is that it is consistently found in the same relative stratigraphic position. Invariably HCS sandstones are found above the shelf type bioturbated mudstones and sandstones, and below trough cross bedded and planar laminated sandstones interpreted as beach deposits. The first occurrence of HCS in a shoaling upward sequence apparently records the "storm wave base" or maximum depth at which storm waves begin to interact with the bottom sediments. Hamblin and Walker (1979) estimate that HCS is probably formed at depths of 15 to 20 m. Dott and Bourgeois (1982) suggest that the structure may be formed at depths of 2 to 80 m. However, the preservation potential for structures formed at the shallower depths is very low as the HCS bedform would probably be reworked by subsequent fair weather processes.

The interbedding of HCS and parallel laminated "turbidite" beds (Facies 5a, 5b) probably records the different depths at which storms of varying intensity would interact with the bottom. The "turbidite" beds are considered to be the down slope equivalent of the HCS beds. The turbidite beds were probably deposited by density currents generated by wave surge that formed the HCS upslope.

A study of the Jurassic Fernie-Kootenay transition by Hamblin and Walker (1979) has documented that solemarks on both the HCS and "turbidite" facies are oriented down a paleoslope which was determined by several independent means. They suggested that the HCS represents either reworking of an initial density current deposit or that the directional aspects of the storm generated current which formed the HCS were influenced by slope.

A recent publication by Duke (in preparation) has studied the temporal and spatial distribution of various rock formations which are reported to contain HCS. He has documented that over half of the 100 or so reported occurrences have a paleogeographical and paleolatitudinal location that would have been traversed by hurricanes. He cites this data as evidence that, in many cases, the structure is largely generated by hurricane activity.

(g) <u>Facies 7 Interpretation</u>

The soft sediment deformation structures described in Facies 7 have been interpreted by Lerand and Oliver (1975) and Nelson and Glaister (1975) as slump deposits and by Hunter (1980) and Bullock (1981) as load structures.

By definition, slump structures result from lateral downslope translation of a coherent mass of sediment (Helwig, 1970). Load structures are considered to be "in situ" soft sediment deformation features. Although the processes are markedly different, the end product of both processes may be similar and thus the deformational mechanism may be difficult to distinguish in poor exposures.

Slumps are typically 1 to 9 meters thick and are commonly restricted to an interval contained by undeformed strata. The slump structures have a basal decollement surface, and a non periodic wavelength (Helwig, 1970). The orientation of slump fold axes have been used to estimate paleoslope (Woodcock, 1979). Slumps develop when the coherence and frictional shear strength of the sediment mass is exceeded by the shear stress exerted by the tangential component of gravity. The sediment mass fails along discrete shear planes (Kuenen, 1952).

Load structures are basically a response to gravitational instabilities caused by deposition of dense sediment over lighter sediment. When the gravitational force exceeds the shear strength of both beds, loading can occur. The density differences may result from compositional differences, (eg.) sand loading into mud. In addition, loading may result from more consolidated sediment loading into less consolidated sediment of similar texture and composition, but with different packing, and water content. Load structures are commonly confined to a single sedimentation unit and contacts are typically sharp (Lowe, 1978). The flowage of sand is related to a loss of strength associated with liquefaction, fluidization or hydroplastic behaviour. The flowage may be triggered by earthquakes, storm surges, or by the rapid dumping of a thick layer of dense sediment onto underlying water saturated sediment.

The underlying sediment could expel pore water which would migrate upwards and possibly liquify the overlying sand, resulting in the loading.

No consistent trend was observed in the orientation of fold axes in the deformed horizons, (Fig. 9). However there was obviously insufficient data (5 measurements) to evaluate this technique and to help distinguish between a slump and a load mechanism. Lowe (1978) has indicated that the symmetry of the axial planes of the folds may be used to differentiate load features from slump folds. Load features would have vertical axial planes while slump folds would have inclined axial surfaces. However, the orientation of the axial planes of the fold structures was not measured in the course of field work and thus it is impossible to evaluate the structures in this study using this technique.

The retention of deformed laminae within the deformed beds suggests that hydroplastic behaviour was more important than a liquifaction or a fluidized flow process (Lowe, 1978). The truncation of the deformed laminae by a sharp planar to wave rippled upper surface contact indicates that some process, planed off the top of the deformed bed before subsequent sediments were deposited. This process may have been a wave surge.

I favour an autoloading mechanism for most of the structures observed in Facies 7. In this mechanism, storm generated density currents would rapidly deposit thick sands layers (0.3 to 2.0 m thick) onto the sands of the shallow shelf. The overlying sand possibly being more densely packed, would have a higher density and would force water out of the underlying sediments. This water would be expelled upward into the overlying sand, promoting loss of shear strength and subsequently, deformation and loading. Some of the deformed units at Sheep River may have a slump origin as the lower contact is curviplanar and concave upwards and, possibly represents a basal decollement surface.

Lowe (1978) has reported that load structures are formed by a very rapid, almost instantaneous increase in the rate of sedimentation (dumping). Coleman (1975) considered that slumping as observed off the Mississippi delta, was initiated by rapid sedimentation and subsequent failure down steep slopes. Thus, regardless whether the deformation structures have a slump or load origin, their presence appears to indicate that rapid sedimentation rates were common during deposition of the lower part of the Chungo sequence.

(h) Facies 8 Interpretation

Swaley cross stratification was first formally defined by Leckie and Walker (1982) and was interpreted as a storm generated structure that was formed above fair weather wave base. They suggest that the storms may not have been of sufficient magnitude to generate significant density currents and HCS structures in the deeper water. However, it appears that the storms were frequent enough and strong enough to remove most of the record of fairweather processes. Leckie and Walker (1982) also reported that the swaley cross stratified facies is very typically found between a HCS facies and a beach facies sandstone in regressive sequences. They cited this as evidence for a shallow nearshore interpretation.

In this study, most of the swaley cross stratification sections were underlain by a loaded sandstone facies. This transition was observed to occur with a much higher than random frequency (Table 1). The swaley cross stratified facies was, in turn, almost always overlain by parallel laminated and trough cross stratified sandstone which was interpreted as a nearshore to beach deposit. Thus it appears that the swaley cross stratified sandstone was deposited in a nearshore to possibly inner shelf environment.

It is difficult to interpret the nature of the processes which generate the swaley cross stratification. The presence of large, deformed shale rip up clasts (up to 40 cm in length) in the sandstone appear to record periodic high energy conditions. The abundance of coarse detrital mica suggests that selective winnowing of the hydraulically finer sediment was not significant.

The nature of the depositional mechanism remains unclear, mainly because the structure has not been recognized in recent environments. However, this problem, as with HCS, may be due to difficulties in observing a broad shallow structure in box cores. The prevalence of lamination which blankets and parallels the underlying swaley topography may indicate very rapid deposition of sand from suspension in highly agitated waters above a sandy substrate. The most likely cause of agitation of the waters is storms.

It should be noted that the rose diagrams of direction of maximum dip of the laminae, after correction for tectonic dip, reveal a westerly dip at Sheep River and a well defined easterly dip at Lundbreck (Fig. 10). If the Chungo shoreline did in fact trend WNW-ESE as has been proposed earlier, then it is interesting that the maximum dip of the swaley lamination is approximately parallel to this shoreline.

(i) Facies 9 Interpretation

The association of trough cross stratification and parallel lamination has been documented in the foreshore and shoreface of many recent beaches (Reineck and Singh, 1980). The fact that Facies 9 sandstone marks the interpreted contact between marine and nonmarine strata supports a foreshore to shoreface interpretation.

It was demonstrated by Clifton (1969) that the parallel lamination can result from wave backwash in the foreshore on high and low energy beaches. Trough cross stratification could be generated by the migration of megaripples in small rip current channels and between longshore bars (Reineck and Singh, 1980). Clifton et al. (1971) have documented a laterally extensive outer rough zone in a high energy nearshore environment (water depths of 2 to 4 meters) which is dominated by landward oriented lunate megaripples. The migration of these megaripples would presumably generate trough cross stratification analogous to that observed in the Facies 9 sandstones.

The weakly bipolar trough cross strata observed at Highwood 2 section may indicate a weak tidal influence on nearshore sedimentation. Similar, but not identical, bidirectional cross stratification has been reported in recent tidal inlet associated sands (Hubbard and Barwis, 1976) and in ancient sediments (Carter, 1978). The observed NE-SW directional trend could reflect landward and seaward directed currents associated with a NW-SE trending shoreline. In general, however there is probably insufficient data to evaluate this. The maximum dip of the parallel lamination in the exposure of Facies 9 at Ghost Dam was oriented to the SE. This could indicate a SE dipping beachslope, but again, the data base for this interpretation is very limited.

The heavy mineral accumulations which cap the Magnetite Beach exposure are very similar to recent deposits along the foreshore of Sapelo Island, Georgia. Woolsely et al. (1975) reported that storm wave erosion of dunes and beach ridges generated lenticular heavy mineral accumulations when waning storm conditions were coincident with high tide. When peak storm conditions were coincident with high tide, maximum erosion of the dune systems occurred but no heavy mineral accumulations were developed. Wind deflation of the foreshore also generated heavy mineral accumulations but these were generated less than 1 centimeter thick. Although this model was developed in a transgressive setting, Woolsely et al. (1975) stressed that minor transgressive events related to small changes in sea level or change in sediment supply, could generate similar accumulations in an overall regressive setting.

It has been suggested by Balsley (1980) that the absence of landward dipping planar tabular cross stratified sandstone in foreshore and shoreface sandstones indicates that the shoreface surface was topographically simple. The shoreface was probably devoid of ridge and runnel or nearshore bar systems which would generate angle of repose foresets as they migrated landward and welded onto the beach face.

The abundance of detrital mica in Facies 9 sandstone appears to contradict a foreshore or shoreface interpretation. Since the mica flakes are hydraulically equivalent to very fine sand, they are generally winnowed out of the nearshore environment and deposited further seaward (Doyle et al., 1968; Adegoke and Stanley, 1972). The high mica content in the Trap Creek section has been cited by Nelson and Glaister (1975) as evidence of deposition in a delta front and distributary mouth bar environment. In this environment winnowing would be less pronounced than on the foreshore of a beach. I suggest that the abundance of mica may reflect very rapid sedimentation rates which resulted in insufficient time for extended winnowing of the mica fraction. In addition, a very high mica content in the sediment source may permit extensive winnowing to occur while retaining a significant mica content in the final deposit.

(j) Facies 10 Interpretation

The abundance of root traces and carbonaceous detritus, the presence of mud cracks and thin coal seams, and the absence of marine trace fauna, all attest to the fact that Facies 10 is nonmarine. This is supported by the fact that in most exposures studied, Facies 10 sediments overlie a thick sandstone which is interpreted as a regressive shoreline deposit. The interbedding of Facies 10 with Facies 11 lithologies, which are interpreted as a point bar deposits of a meandering river system, suggests that Facies 10 was deposited as overbank sediments in a floodplain setting. The interbedding of mudstones and discrete sandstones records periodic incursions of coarser sediment into the floodbasin, probably as crevasse splays or as natural levee aggradation. The exposures of Facies 10 were generally poor and no attempt was made to differentiate these overbank sediments into various subfacies. The carbonaceous black mudstone which directly overlies the massive "beach" sandstone at Trap Creek is distinctive from the other exposures of Facies 10. The dark color, the presence of pyrite, and lack of signs of exposure suggest that it was deposited in a deep lagoon or backswamp where reducing conditions prevailed and coarse clastic input was negligible over a considerable period of time.

(k) Facies 11 Interpretation

Since exposures of Facies 11 sandstones are observed in two distinct stratigraphic contexts, this facies will be interpreted in two separate settings.

The discrete units of trough cross stratified sandstones which are interbedded with nonmarine, carbonaceous rooted mudstones are interpreted as point bar deposits in a high sinuosity, single channel (meandering) river system. The sedimentary structures and textures observed are analagous to those described in recent point bars (Bernard and Majors, 1963) and to those described in ancient deposits which were interpreted as meandering river point bar deposits (Allen, 1965b). No lateral accretion surfaces (epsilon cross stratification) were observed but this may reflect, in part, the poor exposures of Facies 11 in the study area.

Paleohydraulic estimates were determined using the various formulae cited in Ethridge and Schumm (1978)(Table 4). However, these values should be considered as only very crude estimates. Most of their formulae are based on width and depth estimates derived from dimensions of the epsilon cross stratification, a structure which was not observed in any of the sections. In this study, the depth of the channel is estimated to be equal to the thickness of the coarse member (Allen, 1965b). The width is not measured but rather is determined from a width-depth relationship proposed by Leeder (1973). In order to use the formula proposed by Leeder (1973) it must be assumed that the channel were highly sinuous.There is insufficient lateral control to confirm if this is strictly true.

The estimated average mean annual discharge (Table 4) for the rivers which deposited the sandstone of Facies 11 is approximately 2 to 5 orders of magnitude smaller than the discharge of the Mississippi (17,300 cubic meters per second) and approximately 1 order of magnitude smaller than the discharge of the lower Wabash River in Illinois

Table 4: Channel Parameters Estimated for Facies 11 Sandstones

PARAMETER	AVERAGE	MAXIMUM	MINIMUM
D=Depth of channel	5m	8m	3m
W=6.8D bankfull width (from Leeder 1973) for highly sinuous streams, P>1.7	81m	167m	37m
F=W/D width depth ratio (from Schumm 1972)	16.2	20.9	12.3
P=3.5F sinuosity (from Schumm 1963)	1.65	1.54	1.77
Qm mean annual discharge (from Schumm, 1972) in cfs, converted to $m^3 sec^{-1}$	1860 cfs ($55\ m^3 sec^{-1}$)	8114 cfs ($229\ m^3 sec^{-1}$)	375cfs ($11\ m^3 sec^{-1}$)

Note all calculations performed above were made in Imperial units and converted to metric units.

(Jackson, 1975).

A different interpretation is proposed for the exposure of Facies 11 sandstone which caps the upper coarsening upward sequence in the Chungo Member at Sheep River and for the exposure in the Trap Creek section where Facies 11 sandstone rests directly on bioturbated marine mudstones. In both instances the exposure of Facies 11 sandstone is interpreted to mark the transition from marine to nonmarine conditions. Thus, the sandstone presumably marks the passage of some type of shoreline.

The sharp basal contact appears to mark a sudden change in energy conditions in a shallow marine setting. One possible interpretation would involve shifting of a distributary channel within a marginal marine, possibly deltaic setting. Reading (1980) has reported that coarsening upward sequences generated by the progradation of either a river or tide dominated delta may be truncated in their upper portions by fluvial or tidal channel sandstone sequences. Similar sequences have been reported in the Niger delta where fluvial, wave, and tidal activity is important (Allen, 1965a).

Similar coarsening upward sequences truncated by a sharp erosive contact, and overlain by a lag, have been observed by Kumar and Sanders (1974) in recent tidal inlets. These inlets have migrated along shore, cutting down into shoreface sediments below a barrier island system.

An ancient analog to this has been observed in the Carboniferous strata of Kentucky by Horne and Ferm (1976).

Finally, a recent study by Hunter et al. (1979) documented that the progradation of a barred shoreline similar to that exposed off the Oregon coast would result in shoreface sediments being overlain by a laterally extensive erosion surface, which may or may not generate a lag deposit. This erosion surface would be overlain by trough cross bedded and planar laminated sands of the nearshore system.

In general, there is insufficient exposure in the sections studied to conclusively determine the depositional environment of the sandstones of Facies 11 which cap a coarsening upward sequence. The features observed could be produced by distributary channel shifting in a tide or river dominated delta system, by migration of tidal inlets along a barrier island trend, or by the progradation of a barred mainland beach.

(1) Facies 12 Interpretation

Pebbly mudstones and conglomerates appear to record an abrupt break in the sedimentation record in most exposures. In the Maycroft and Highwood 2 sections, the pebbly units define the contact between underlying nonmarine strata and the overlying marine strata. In most of the other exposures, the pebbly units separate a lower "shallower" marine sequence from an overlying, relatively deeper marine facies. Thus the pebbly units appear to mark an abrupt deepening or transgressive event.

The general absence of a primary fabric in the pebbly mudstones indicates that either the process depositing the unit left no fabric or that any original fabric was destroyed by bioturbation or reworking. Pemberton (pers. comm.) has considered it unlikely that burrowing organisms would be capable of moving the coarse (up to 12 cm) pebble and cobble sized fraction of the pebbly mudstones. Thus it appears that the absence of sedimentary fabric is related to the primary depositional process.

The presence of pebbles floating in a sandy muddy matrix and absence of oriented or imbricated clasts is typical of debris flow deposits (Harms _et al._, 1975). Debris flow deposits typically contain variable proportions of sand and pebble or cobble sized material that are floating in a mud supported matrix.

The point at which movement is initiated is related to the slope and the thickness, density and matrix strength of the sediment-water mass. Movement begins when the shear stress at the base of the flow exceeds the strength of the sediment-water mass. Subaqueous debris flows have been documented (Harms _et al._, 1975) although Blatt _et al._ (1980) have noted that in subaqueous system, the moving mass commonly incorporates additional water. As additional water is introduced into the flow, the strength of the sediment-water mass decreases and this increases mobility to the point where a turbidity current may be initiated. The main problem with invoking a debris flow mechanism is that the slopes in the nearshore to mid shelf setting are probably too low to initiate sediment gravity flows of this type. Most documented submarine debris flows deposits are associated with submarine fan sequences. These submarine fans were deposited at the base of the continental slope where much higher slopes would be present than in a shallow shelf setting.

A second explanation for the presence of the pebbly mudstones is that they represent a transgressive lag deposit. Swift et al. (1971) have interpreted thin pebbly mudstones and conglomerates on the shelf of the Eastern United States as a lag deposit. These lag deposits remained after the transgressing sea had winnowed and removed the remainder of the beach and shore face sediment by a process termed shoreface retreat. Swift (pers. comm. 1982) has argued that up to 10 m of section can be removed by this process. The problem with this theory is that there exists a marked, almost complete absence of coarse clastic material in the nearshore and nonmarine section that was being transgressed. Thus even winnowing thick sections of these sediments could not concentrate significant accumulations of pebbly sized material.

A third possible mechanism for explaining the presence of isolated pebbles floating in a mud matrix was forwarded by Crowell (1957). He suggested that the pebbles and sand sized material were rapidly transported and deposited onto a wet mud substrate. This resulted in the foundering of pebbles into the underlying unconsolidated mud. This is a possible explanation for some of the the pebbly mudstones but does not appear to account for the source of the pebbles or the reason why the pebbly units are restricted to narrow, apparently transgressive depositional intervals.

A fourth mechanism capable of leaving non oriented pebbles floating in a muddy matrix has been proposed by McLean and Wall (1982). They consider that the pebbles were connected to seaweed roots which were subsequently transported offshore. I don't consider this a likely explanation for the thicker pebbly units, or for the sharp based pebbly beds. However some of the isolated pebbles (dropstones?) found in burrowed offshore sediments could have been transported by this process.

12. Interpretation of Facies Sequences

> "Only the ontological method can save us from stratigraphy and only the laws of correlation of facies are in a position to broaden our knowledge. Every facies is related to other contemporaneous facies and when we want to interpret a fossil deposit, we must compare it with the sediments it is connected with at the present time. Only those facies and facies areas can be superimposed primarily which can be observed together at the present time."
>
> Johannes Walther, 1894
> (from Middleton, 1973)

The above statements represent some of the earliest ideas which emphasized the importance of recognizing facies sequences in the interpretation of a stratigraphic section. The purpose of this chapter is to discuss the facies sequences observed in the various sections, in order to better understand the nature of the depositional basin. On the basis of facies sequences, the study area was subdivided into three parts. Each of these parts will be interpreted separately in the following section.

(a) Southern Group

In a broad sense, the sections in the southern part of the study area are characterized by two distinct depositional sequences, each of which marks a transition from marine to nonmarine sedimentation.

i Chungo Regression

In the lower depositional sequence, the marine Thistle Member is overlain by a thick regressive coarsening upward unit which is capped by a thick (to maximum of 34 meters) sandstone of the loaded, swaley, parallel laminated and trough cross stratified facies.

The interbedded sandstones and mudstones at the base of this coarsening upward sequence is dominated by turbidites and hummocky cross-stratified sandstone beds. Both these features are interpreted as storm-generated features. The exact mechanism responsible for initiation of the density current which deposited the turbidites remains unclear. It is possible that the severe wave action associated with a major storm could induce anomalously high bottom pressures at the sediment water interface. Coleman (1975) has documented that slumping and liquifaction of an unconsolidated sediment-water mass can be initiated by this process on the delta-front region of the Mississippi delta where the slopes are less than 0.4 degrees. Middleton and Southard (1980) have noted that a debris flow could evolve into turbulent density flow if additional water is incorporated into the moving sediment-water mass, and if the slope and thickness of the flow are large enough to allow the flow to accelerate to the point where it could become turbulent. It should be pointed out that Middleton and

Southard (1980) indicate that relatively steep slopes (greater than 2.8°) are required to accelerate both subaqueous and subaerial debris flows to the point where they become turbulent. It is unlikely that slopes of this magnitude would be encountered in either a deltaic or a shelf enviornment. Coleman (1975) has reported that maximum depositional slopes in a deltaic environment rarely exceed 0.5 to 0.75° while slopes on the shelf range from .003 to 0.48°. The exact mechanism responsible for initiation of the density currents which deposited the turbidites remains unclear. It is probably related to some type of storm initiated instantaneous failure or slumping of an unconsolidated sediment-liquid mass in a nearshore setting.

Once the fully turbulent density current has been established, it is likely that the current could transport sand sized material down very gentle shelf gradients across large areas of the shelf.

The top of the main Chungo sandstone is commonly rooted and it is overlain by a thick section of nonmarine coastal plain sandstones and mudstones. The sandstone obviously marks the progradation of some type of shoreline. The fact that the sequence is similar in all the exposures studied suggests that the massive sandstone has a laterally extensive sheet-like geometry.

Elliot (1980) has reported that sheet sandstones with sedimentary structures similar to those described in this unit might have been deposited by the progradation of either a wave-dominated delta, a barrier island shoreline, or a mainland beach. Elliot (1980) stressed that distinction between these shoreline morphologies should be based on regional considerations such as the presence or absence of associated deltaic distributary channels.

If the poorly sorted, pebbly, trough cross stratified sandstones which cap the main Chungo sand at Highwood River and Maycroft are interpreted as distributary channel-fill deposits, then a wave dominated deltaic environment is favoured. I think this is a poor criterion to distinguish deltaic from nondeltaic settings. Coleman (1975) has noted that distributary channels comprise only a very small proportion of the areal extent of a wave dominated delta. Thus channel fill deposits would comprise only a very small proportion of the resulting delta deposit. Balsley (1980) has also noted that distributary channel fill deposits are rare in a wave dominated delta complex and that their presence or absence does not serve to differentiate between a deltaic or nondeltaic setting.

A major problem encountered when attempting to distinguish between a wave dominated deltaic deposit and a regressive shoreline deposit is defining what exactly is meant by each of these terms. By the definition used in this thesis in a wave dominated deltaic setting the bulk of sediment is derived from a single river system and the sediment accumulation should have a lobate or arcuate geometry centered on the mouth of the river. A recent example of this would be the Sao Franscisco delta as described by Coleman (1975). A mainland shoreline deposit would be fed by a series of smaller river systems or by longshore drift. The morphology of the sand body would thus conform to the shape of the coastline. In this study there is insufficient lateral control to determine the shape of the sandstone body or the distribution and number of rivers which fed the shoreline system. I consider that the Chungo Sandstone could have been deposited by either a wave dominated delta or a regressive sandy shoreline.

Reineck and Singh (1980) have suggested that a regressive barrier island deposit can be distinguished from regressive mainland attached beach deposit by examining the facies sequence which overlies the beach sand. On a prograding barrier island coast the coastal sand is overlain successively by tidal flat and lagoonal deposits, coaly marsh deposits and alluvium. On a prograding mainland beach coast, the tidal flat and lagoonal deposits are missing and the coastal sand is overlain directly by coaly marsh deposits and alluvium.

In most exposures of the southern group studied, there is no evidence of lagoonal or coaly marsh deposits above the beach facies sandstone. It appears that the beach was mainland attached. The carbonaceous shale unit overlying the beach sands (Facies 9) at Trap Creek suggests that lagoonal conditions may have existed locally along the shoreline. I think that the argument presented by Reineck and Singh (1980) is overly simplistic. There is little published data which documents whether or not the back barrier lagoon will be translated seaward as the barrier island progrades seaward or even whether a barrier island-lagoon morphology will be present in a strictly regressive setting.

It is difficult to find an exact modern analog for the Chungo system. Most recent regressive shoreline deposits are less than 10 to 15 meters thick while the Chungo sand sheet varies from 24 to 34 meters in thickness (D. Swift, pers. comm. 1982). A few anomalously thick sections could be due to vertical aggradation of a shoreline complex, resulting from temporary balance in the rate of subsidence and sedimentation. The thick sandstone could also be interpreted as distributary mouth bar or channel fill deposits. However, the fact that all of the complete coarsening sequences are capped by a thick sandstone suggests that the great thickness is a regional feature of the regressive unit. Moreover, similar thicknesses have been reported by wave and storm dominated regressive units in the Jurassic and Cretaceous of the Western Interior (Hamblin and Walker, 1979; Rice, 1980; Leckie and Walker, 1982). I think that the addition of a thick swaley cross stratified sandstone section underlying the beach facies sandstone is responsible for the large thickness of the regressive sand sheet. The presence of the SCS Facies is probably related to the much deeper wave base in a storm dominated environment.

The angular to subangular nature of the detrital grains and the generally high content of detrital mica and unstable lithic fragments is also atypical of beach and shoreline sediments. As indicated earlier, some of the angularity may be ascribed to corrosive diagenetic processes. However, even in slides where this process is not pronounced, the grains are still quite angular. Similar angular textures have been reported from the shoreface and foreshore sediments of other storm dominated regressive units (Hamblin and Walker, 1979). It is possible that the relatively angular textures may be a diagnostic feature of a storm influenced environment. Swash and backwash processes are important only in the uppermost part of the regressive deposit. The bulk of sand would spend little time in the swash zone but would instead be transported offshore, possibly below fair weather wave base. In this zone, transport of grains is intermittent and rounding processes are not pronounced. The thick section of nonmarine point bar and overbank deposits which cap the regressive sand unit was probably deposited in a low lying coastal plain similar to the coastal plain adjacent to the lower reaches of the recent Mississippi River.

ii Nomad-Belly River Transition

The nonmarine strata at the top of the Chungo Member is abruptly terminated by a thin pebbly mudstone unit which appears to mark a transgressive event and a return to marine conditions. It has been reported by Asquith (1974) and Ryer (1977) that transgressive shifts of shoreline are typically non depositional within Mesozoic strata of the Western Interior and this seems to be the case for the Nomad transgression as well. The Nomad Member appears to thin to the south and only a very thin bioturbated mudstone containing marine microfauna is present near the southern limit of the study area. The upper boundary of the Nomad Member is quite abrupt and the return to nonmarine conditions occurs over a very narrow stratigraphic interval. The high variability in the nature of the facies sequences which mark this transition is typical of both river and tide dominated delta deposits (Reading, 1980). In most exposures, a poorly sorted trough cross stratified fining upward pebbly sandstone body marks this transition. These features are similar to active channel fill sequences which are formed by the lateral accretion of the margin of a sinuous distributary channel in tidally influenced deltas such as the Burdekin (Coleman, 1975). Baganz *et al*. (1975) have demonstrated that active channel fill deposits would not be common in the lower delta plain of river dominated deltas such as the Mississippi. In these deltas, the distributaries are straight and channel switching is generally accomplished by abrupt cutoff and switching, rather than by gradual migration of the channel margins. Moreover, the trough cross bedded sandstone unit, is thinner by an order of magnitude, than distributary channels of the river dominated Mississippi delta. However, these sandstone units are similar in thickness to active channel fill deposits described from the tidally influenced deltas such as the Burdekin (Coleman, 1975). One might have expected to find flaser bedding or herring bone cross stratification in a tidally influenced delta. However the apparent absence of these features may reflect the poor exposures of the strata which exposes Nomad to Belly River transition. I think that there is basically insufficient data to tie down more precisely the nature of the conditions which existed during deposition of strata transitional between the Nomad member and Belly River Formation. It is important to note that this regression differs markedly in several aspects from the earlier Chungo regression. The Chungo regressive sequence is much thicker, it contains much more evidence of storm influence (hummocky and swaley cross stratified units), and generally exhibits a much more consistent facies sequence than does the Nomad Belly River regression.

(b) Central Group

The Thistle and Nomad Members in the central part of the study area are similar to equivalent units described in the other sections. However both the Hanson and the Chungo Members differ considerably in either lithology or thickness from equivalent strata in the northern and southern parts of the study area. The Thistle Member has a similar lithology to Thistle strata in the other sections. However the paleocurrent patterns recorded were generally much less consistent than those observed in sections to the north and south. In general, I assumed that the orientation of ripple foresets on the thin turbidites is related, as least in part, to slope orientation. This high variability in foreset orientations may be indicating that during Thistle time, the paleoslope in the central part of the study area was sufficiently low that it had little influence on controlling the direction of turbidite flows. Reading (1980) has suggested that turbidite sections exhibiting a high variation in paleocurrent trends have been documented in the flat featureless axial or central portions of a sedimentary basin. Using this argument, I would suggest that the Thistle strata of the Sheep River section was deposited in a more central or axial part of the Wapiabi Basin, relative to the Thistle strata in the Trap Creek, Maycroft, and Ghost Dam sections.

In the central part of the study area, the Hanson Member was only exposed in the Sheep River section and its lithology was similar to that exposed elsewhere in the study area. The thickness of the Hanson Member at Sheep River is intermediate between the complete absence of Hanson strata in the south and the thick units reported in Ghost Dam and Barrier Lake. In the facies correlation diagram (Fig. 17) it can be seen that the Hanson Member is stratigraphically equivalent to, and presumably the basinal equivalent of, the clean well bedded sandstone of the Chungo Member in the south.

The lithology of the Chungo Member is very dissimilar to equivalent strata exposed in the northern and southern parts of the study area. Generally speaking, the Chungo Member is represented by a thick sequence of transitional marine strata of the turbidite, hummocky and swaley facies. If nonmarine strata is present (but unexposed) at the top of the Chungo Member, it is much thinner than the nonmarine interval exposed in the Chungo Member farther south. When examined in detail, it is obvious that these transitional marine strata are organized into at least two and possibly three discrete coarsening upward sequences. Each sequence is abruptly terminated by a pebbly mudstone or conglomerate unit. The pebbly unit is generally overlain by "deeper" strata of bioturbated mudstone that gradationally develop into another coarsening upward sequence above. The coarsening upward trends are interpreted as shoaling upward trends. If the presence of pebbly mudstone and the termination of a coarsening upward sequence is interpreted as a transgressive event, then a complex sedimentological history is required to explain the strata in the central part of the study area.In the south, a single regressive episode is reported for the Chungo Member. In the central part of the study area at least two and possibly three regressive-transgressive episodes must have occurred. Only the uppermost cycle may have resulted in emergence with subsequent deposition of nonmarine strata. It appears that the northward advance of the Chungo shoreline was halted before it had reached the central part of the study area. This would explain the apparent absence in the nonmarine Chungo strata in the central and northern parts of the study area. The anomalously thick exposures of nearshore to shallow shelf facies sandstones (turbidites, HCS, SCS Facies) in the Sheep River and Longview sections indicate that the section did not shoal to the point of emergence. Instead the section appears to have accreted vertically with the shoreline remaining some distance to the south. The coarsening upward sequences recorded in the Sheep River section were presumably associated with minor progradational shifts of shoreline.

The Nomad Member is only poorly exposed in the Sheep River section but unfortunately, its lower contact with the underlying Chungo Member is obscured by overburden. The base of the Nomad Member marks the beginning of a major transgression which resulted in a southward shift of the shoreline of at least 150 km. The transition of the Nomad to the overlying nonmarine Belly River Formation is only exposed in the Sheep River section. A thin (5 meter) coarsening upward sequence is capped by a thin parallel laminated "beach" type sandstone similar to that reported in the Ghost Dam section. No lagoonal type sediments were observed above this beach, suggesting it was mainland attached (Reineck and Singh, 1980). However this section was poorly exposed and there is insufficient data available to interpret this sequence with any degree of confidence.

(c) Northern Group

In the Ghost Dam and Barrier Lake exposures, the Thistle Member is similar to exposures of the Thistle Member in the south. However the Hanson and Chungo Members differ markedly from equivalent strata in the south. The thick unit of bioturbated sandy mudstone which characterizes the Hanson Member in the northern part of the study area appears to be stratigraphically equivalent to, and presumably the offshore equivalent of, the Chungo Member to the south (Fig. 17). The high degree of bioturbation indicates that organic burrowing processes were dominant over wind, wave or current activity. Moreover the basin floor was sufficiently well oxygenated to permit the infauna to proliferate. At Ghost Dam the thin Chungo Member is also heavily bioturbated but it contains a much higher sand content and lower mud content than the underlying Hanson Member. The lower mud content may reflect more agitated bottom conditions, possibly due to shoaling. This shoaling would result from "shallowing" of the basin associated with the advance of the Chungo shoreline from the south. Since no physical sedimentary structures are found in the Chungo Member at Ghost Dam, the basin obviously did not shoal to the point where physical processes had dominated over organic burrowing processes. In the Barrier Lake section, the Chungo Member is characterized by clean well bedded sandstones and it is obvious that physical processes are dominant over organic processes. There is really insufficient exposure to precisely tie down the depositional environment which the clean trough cross stratified sandstones were deposited in.

The exposure is similar to an outcrop of Chungo sandstone which has been interpreted as a shoaling offshore bar sequence or a barrier beach deposit (Lerand, in press)

The Nomad Member is lithologically similar to the equivalent unit exposed farther south and apparently marks an abrupt deepening of the water column. The abrupt decrease in sand content, relative to the underlying Chungo, probably reflects the increased distance to the shoreline source as the Nomad transgression presumably caused the

Chungo shoreline to retreat from 100 to 200 km to the south. The transition from the Nomad to the overlying Belly River Formation is only exposed in the Ghost Dam section and it is marked by a thin beach deposit sandstone separating the marine and nonmarine strata. There is no evidence of lagoonal or tidal flat sediments overlying the beach sandstone and this beach was probably mainland attached although there is insufficient exposure to test this hypothesis. The fact that the beach facies rests directly on top of a very thin HCS section suggests that the marine basin that the shoreline prograded into was very shallow and that the progradational event was very rapid. A similar very thin marine to nonmarine transition was observed in all sections which exposed the Nomad-Belly River contact. This point seems to indicate that the Nomad basin was not nearly as deep as was the basin which the Chungo shoreline prograded into.

13. Source Area and Dispersal Patterns

Sandstone compositions are influenced by the nature of the source terrain, the nature of the sedimentary processes which link the source to the basin, and by the nature of the processes that exist within the depositional basin. Dickinson and Suczek (1982) subdivided a series of compositional ternary diagrams into fields which they felt were representative of tectonic environment. They included foreland basins in their recycled orogen category. They reported that sandstones from this setting are typically marked by a moderately high quartz content, a strikingly low feldspar content, and of a high content of recycled sedimentary detritus. The compositions of the Chungo and Belly River sandstones are plotted on their QFL diagram in Fig. 26.

(a) Chungo Member

The high feldspar content observed in the Chungo Member is atypical of foreland basin sediments. Foreland basins receive most sediment from thrust faulted highlands which generally contain little feldspar. In addition the craton derived component is generally quite mature and contains little feldspar. In addition to acting as a source, the thrust faulted highland also acts as a shield preventing the basin from receiving igneous detritus from the magmatic arc. Where feldspathic suites exist within a foreland basin, Dickinson and Suczek (1982) had observed that they are generally associated with uplifted plutonic basement rocks adjacent to the sedimentary basin. The absence of microcline and feldspars with perthititic textures in the Chungo sandstone suggests, but does not dictate, however, that a plutonic source was not responsible for the high feldspar content. Lerbekmo (1963) considered that the detrital feldspar had volcanic affinities and may have been derived from the Elkhorn Volcanic Group of Montana. However, Lerbekmo (1963) has also indicated that the relatively coarse texture of some of the interbedded bentonites required that the source was much closer to the depositional basin. Lerbekmo (1963) postulated that the volcanogenic detritus had have been derived from volcanic vents now buried under the thrust belt of southwestern Alberta. McLean (1971) felt that both the Chungo and the Belly River (Judith River) Formation sandstone represented a mixture of volcaniclastic detritus from the Elkhorn Mountains and recycled sedimentary detritus from the rising Cordillera. Field and petrographic studies of the Elkhorn area located approximately 300 km south of the study area have demonstrated that in excess of 11000 feet (3300 meters) of explosive volcaniclastic material was deposited during Santonian to Campanian time. The bulk of this volcanic material consisted of welded rhyolitic tuff with a high content of quartz and potassic feldspar phenocrysts (Smedes, 1966). Erosion and significant reworking of source rocks of this composition, with an added input of sedimentary detritus from the rising mountains to the west, could generate a sediment with composition similar to that of Chungo Member. This theory is supported by recently published regional facies maps for the Eagle Sandstone (Chungo equivalent) in northern Montana. These facies maps suggest that the source of the sediment lay in the approximate position of the Elkhorn volcanic field (Gautier and Rice, 1981; Meijer Drees and Mhyr, 1982)(Fig. 28).

(b) Belly River Formation

The relatively low feldspar content and high lithic content of the Belly River sandstone, compared with the adjacent Chungo sandstone, is problematical. The petrography appears to indicate a rather rapid change in the proportion of sedimentary and volcanic detritus being fed into the depositional basin. It is unlikely that depositional processes were significantly different since similar facies were sampled in both stratigraphic units. The higher proportion of unstable lithic fragments in the Belly River sediments may suggest that weathering was less

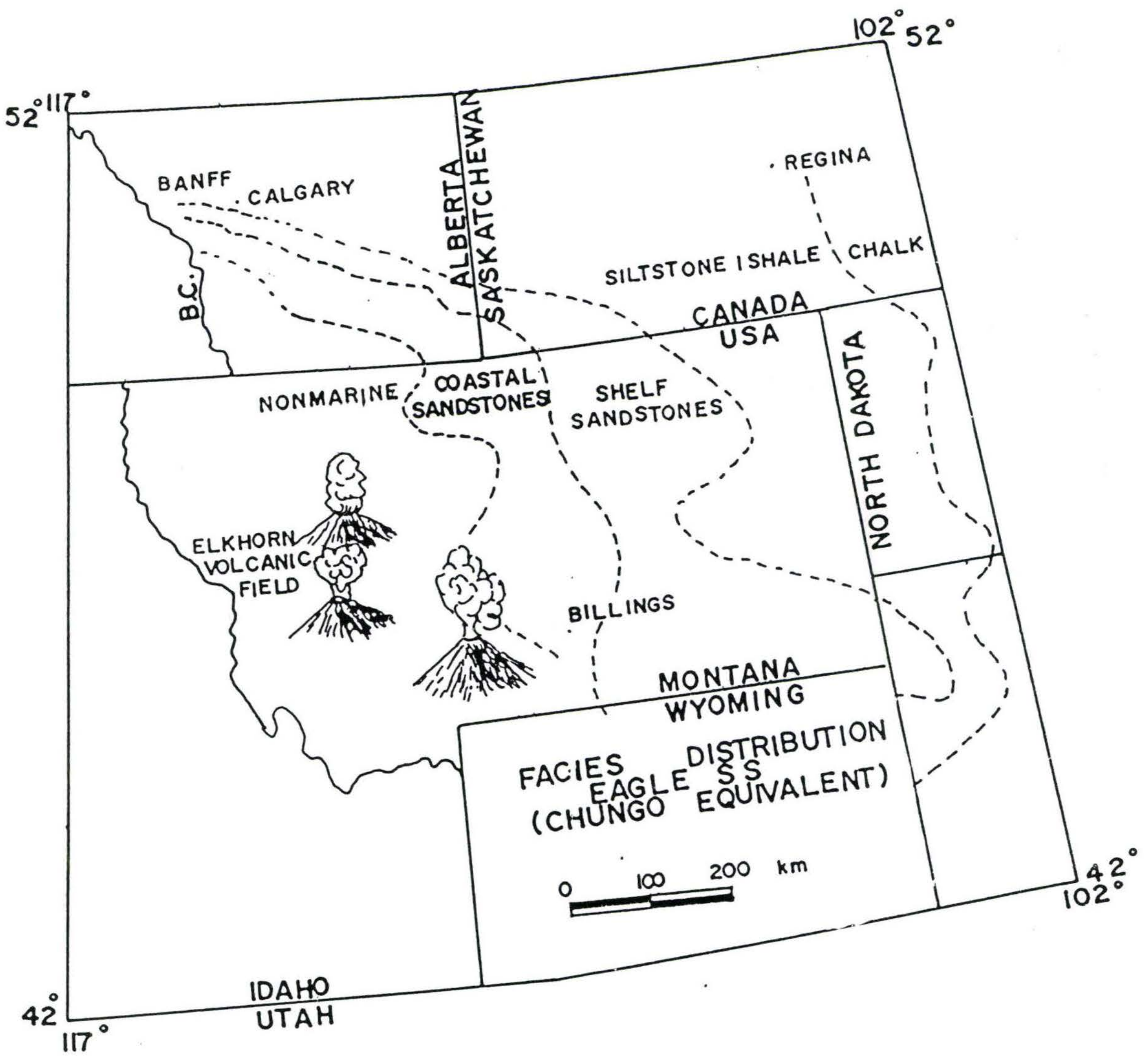


Figure 28 Facies distribution of the Chungo Sandstone (Eagle-Milk River equivalent (from Gautier and Rice, 1981)).

intense or perhaps the distance of transport from source to basin was shorter. However it is unlikely that this alone was responsible for the compositional differences observed. Data published by Lerbekmo (1963) suggests that not only the proportion but also the composition of the feldspar and lithic component differs between the Chungo and the Belly River Sandstone units. McLean (1971) recognized a similar compositional difference between the stratigraphically equivalent units of the plains (Eagle and Judith River Formations). He (McLean, 1971) suggested that the same source terrain shed sediment of a different composition as different structural units were progressively exposed. While this is a possible explanation, other data exists which suggests that a change in source to basin configuration did occur between Chungo and Belly River time.

A heavy mineral study by Rahmani and Lerbekmo (1975) has indicated that during Belly River time, the source terrain lay to the northwest, not to the southwest, as proposed in this study for the Chungo. They proposed that the rising Omineca geanticline of the Cordillera was a likely source for Belly River sediments and that the rivers which drained this highland flowed southeasterly, obliquely away from the mountain front (Fig. 29). This model is supported by the consistent paleocurrent data in the nonmarine, basal Belly River strata at Ghost Dam which also indicated a net southeasterly flow (Haywick, 1982).

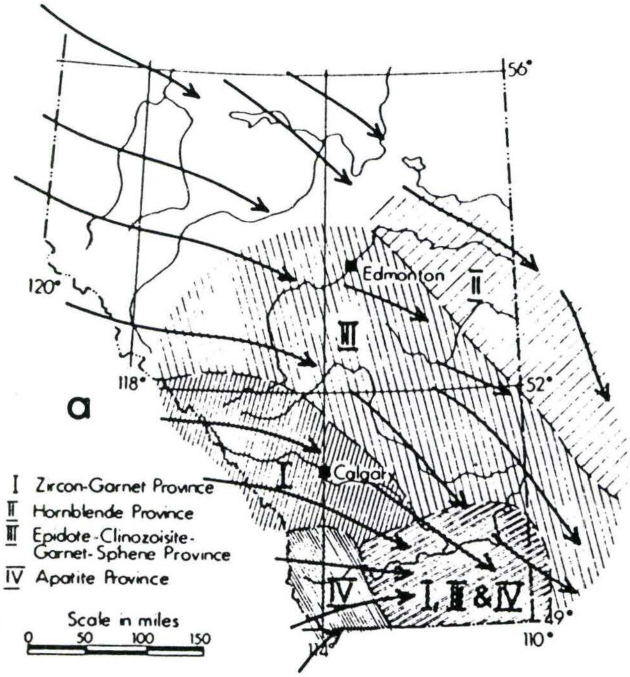


Figure 29
Heavy Mineral provinces and dispersal patterns, Belly River time.

from Rahmani and Lerbekmo 1975

In summary, the above petrographic and heavy mineral data suggests that the difference in composition between the two units may be related to a changing source terrain. During the main Chungo regression, the bulk of sediment was derived fom a volcanic source to the southwest. During the Belly River time, the sediment was probably derived from the Omineca geanticline of the Cordilleran, to the west and to the northwest.

14. Discussion of Diagenesis

There is insufficient data in this thesis to precisely ascertain the nature of the diagenetic processes which affected the mudstones and sandstones of the Wapiabi and Belly River Formations in southern Alberta. However, this discussion will compare the textural and compositional characteristics of both the mudstones and sandstones presented in this study, with the data and interpretations of more sophisticated diagenetic studies. This could at least place some broad constraints on the nature of the diagenetic processes.

(a) Diagenesis of Mudstones of the Dowling, Thistle, Hanson, and Nomad Members

Several papers have recently emerged which have studied the textures and mineral assemblages in recent muds and ancient mudstone sequences. These studies were directed at understanding the diagenetic processes which accompany burial and compaction. Berner (1981) recognized four geochemical environments which can be differentiated on the basis of diagenetic mineral assemblages in the mudstone and in the associated concretions. Berner (1981) has also demonstrated that the mineral assemblages observed in the mudstones are related to such factors as the initial organic content of the sediment, the rate of sedimentation and to the availability of dissolved oxygen and sulphate both in the basin and below the sediment/water interface. Maynard (1982) supplemented Berner's scheme, with stable isotope data and the bioturbation attributes of the sediment, to develop a more complicated geochemical environment classification scheme. Although the mudstones examined in this thesis were not studied in sufficient detail to precisely understand their diagenetic history, some broad generalizations can be made.

The abundance of siderite concretions in both the Hanson and Dowling Members of the Wapiabi Formation is very similar to Berner's anoxic, non sulfidic environment. Within this environment, reducable organic material is still present in the mud after all the dissolved oxygen in the pore water has been consumed by aerobic microorganisms in the oxic zone. In modern sediments, the oxic zone rarely extends more than a few millimeters below the sediment water interface and almost never beyond 1 meter in depth (Berner, 1981). The anoxic non sulfidic environment is also characterized by low concentrations of dissolved sulphate. Most of the sulphate was probably removed by sulphate reducing bacteria at shallow depths just below the oxic zone. Since the dissolved oxygen and sulphate concentrations are very low, the proliferation of aerobic and sulphate reducing bacteria which break down the organic material at shallower depths is inhibited. In their place, bacteria capable of reducing nitrates and previously formed or detrital Fe and Mn oxides are responsible for breaking down the organic material. These bacteria produce reduced species of Fe and Mn and large quantities of methane (CH_4) and carbon dioxide (CO_2)(Maynard, 1982).

(b) Diagenesis of Chungo and Belly River Sandstones

Although the main thrust of this study was not to outline the diagenetic history of the sandstones, some broad generalizations about the mineral assemblages and textural relationships can be made.

A detailed petrographic and x-ray diffraction study of the diagenetic to very low rank metamorphic mineral assemblages equivalent Upper Cretaceous sandstones was published in northwestern Montana by Hoffman and Hower (1979). They reported that the diagenetic mineral assemblages were very variable and related to both framework composition and depth of burial. It is interesting to note that the diagenetic assemblage of their volcanic derived sandstones was dominated by layer silicates (zeolites, chlorite, kaolinite) and that the carbonate component was generally less than 5%. By contrast, the stratigraphically equivalent Chungo and Belly River sandstones studied in this thesis are dominated by the carbonate component phase (up to 50% modal count). The chlorite or phyllosilicate phase is distinctly subordinate, and in some cases, completely absent. Hoffman and Hower (1979) have proposed that in volcaniclastic sandstones, it is the partial pressure of CO_2 which controlled the mineralogic distribution of calcium. Surdam and Boles (1979) have supported this and indicated that the partial pressure of CO_2 or HCO_3^- species, is, in turn related to the distribution and decomposition of organic matter in the sediment. If the amount of organic matter is the limiting factor, then sandstones with low organic content will not be subjected to carbonatization reactions. In these cases, the zeolite/phyllosilicates cements as outlined by Hoffman and Hower (1979) may be favoured. On the other hand where the sandstones and associated mudstones have a high initial organic content which is subsequently been reduced by anaerobic bacteria, large volumes of CO_2 and methane can be generated (Maynard, 1982).

Since the concentration of dissolved oxygen and reduced sulphides is very low, the formation of Fe-oxides or Fe-sulphides is inhibited. As the bacterial activity progressively decomposed more and more of the organic material, the concentration of both Fe^{2+} and dissolved CO_2 increased to the point where both siderite ($FeCO_3$) and vivianite ($Fe(PO_4)8H_2O$) became stable and precipitated out.

The fact that several concretions had an ammonite fossil core suggests that the local concentration of organic material was responsible for localizing the precipitating mineral phase in the form of a nodule or concretion.

Gautier (1982) studied concretions in the Upper Cretaceous Gammon Shale in Montana and Wyoming. He has indicated that not only the initial organic content but also the rate of sedimentation could influence the presence or absence of diagenetically formed concretions in marine mudstones. Using stable isotopes and textural characteristics of the shale, Gautier (1982) was able to demonstrate concretions could develop at depths of less than 10 m in areas of rapid sediment accumulation. Concretions could form at depths greater than 200 m in areas where sediment accumulation was very slow.

The absence of siderite concretions in the Thistle Member of the Wapiabi Formation may reflect either a lower initial organic content of the mudstones or a lower sedimentation rate for the shale-siltstone sequence. If the sedimentation rate was very slow, most of the organic material would be decomposed by aerobic bacteria before it was buried beneath the oxic zone. Thus, by the time that the sediment was buried to a depth where sulphate or nitrate producing bacteria could take over all the active organic matter would be already broken down and this aspect of the early diagenetic process would cease (Gautier, 1982).

If large volumes of this microbiologically produced carbon dioxide or bicarbonate can migrate into juxtaposed and interbedded sandstones, then carbonatization processes can be very extensive (Surdam and Boles, 1979). Since most of the organic material in the mudstones would be broken down by bacteria very soon after burial, one would expect that the expulsion of the carbon dioxide or dissolved bicarbonate from the pore water of the mudstones would occur very early. This should thus initiate a very early carbonate cementation event in the sandstones. However, the petrographic data from the Belly River and Chungo sandstones suggests that the carbonate cement was not an early phase, but rather, it postdated an earlier pore filling chlorite cement. Thus, if a high partial pressure of CO_2 was required for the formation of the ubiquitous carbonate cement, then the source of the CO_2 was probably not the early diagenetic decomposition of organic matter but rather an unknown later diagenetic source.

15. Conclusions

Detailed stratigraphic and facies mapping has greatly increased the understanding of the depositional processes and paleogeography which existed during Upper Cretaceous time in southwestern Alberta.

The Thistle Member of the Wapiabi Formation was the lowermost unit studied and it was lithologically similar in all parts of the study area. It typically consists of thinly laminated shale with siltstone and thin sharp based (less than 5 cm) sandstone beds which were presumably introduced into a shallow shelf setting by turbidity currents. Assuming that the direction of the turbidity currents was controlled, or at least, influenced by slope, a complex paleogeography must be inferred during deposition of the Thistle Member. In the southern part of the study area consistent north and northeast flowing turbidity currents are indicated. In the northern part of the study area, most turbidity currents had flowed to the south and southwest.

The Hanson Member of the Wapiabi Formation consists of a monotonous sequence of concretionary, highly bio-turbated sandy mudstone. This unit is completely absent in the southern part of the study area but forms very thick units in the northern part of the study area. It is stratigraphically equivalent to the Chungo Member and apparently represents an offshore or basinal equivalent of the Chungo sandstones. The lack of preserved primary sedimentary structures precludes a detailed sedimentological interpretation. However the high degree of bioturbation suggests that the floor of the marine basin was well oxygenated at all times.

The Chungo Member is a regressive sandstone unit which is found near the top of the Wapiabi Formation. It is observed to undergo dramatic facies changes across the study area. In the southern part of the study area, the Chungo Member is represented by a single thick regressive coarsening upward sequence which becomes emergent and is overlain by approximately 60 meters of nonmarine strata. In the lower part of the section, the sequence is dominated by sandstones of the turbidite and HCS and SCS facies, all of which are believed to record significant storm influence in a shallow marine setting. The upper part of the coarsening upward sequence is dominated by trough and planar cross stratification and parallel and low angle convergent lamination. These structures are believed to record fair weather processes in a nearshore to foreshore "beach" setting. The fact that all sections display a similar sequence of lithofacies suggests that this main regressive Chungo sandstone has a sheet like geometry and was probably deposited by a prograding shoreline or wave dominated delta. There is little evidence of a lagoonal facies capping the main regressive sand and the sandy shoreline was probably mainland attached. This would be analogous to the recent sandy wave dominated Sao Francisco delta of Brazil.

Paleocurrent data indicates that the Chungo-Milk River shoreline complex prograded from south to north not from west to east as has been proposed by previous workers. The nonmarine section in the upper Chungo was dominated by thin, high sinuosity river point bar sandstones and carbonaceous sandstones and mudstones which were probably deposited as overbank material in a low lying coastal plain setting.

In the central part of the study area, the Chungo Member is dominated by a thick section of interbedded sandstones and mudstones of the turbidite, HCS, and SCS Facies. These facies are organized into two and possibly three regressive coarsening upward sequences, each of which is terminated by a thin transgressive conglomerate or pebbly mudstone. Nonmarine strata was not documented in the Chungo Member in the central part of the study area. This suggests that the section did not shoal to the point of emergence as it did further to the south. Presumably the advance of the shoreline was halted, either by partial cut off of sediment supply or change in the rate of sedimentation and subsidence. During the late Chungo time, the shoreline was therefore approximately stationary and the entire shelf and nearshore sequence accreted vertically. This resulted in sections of nearshore and shallow marine sediments which were much thicker than would be expected in a simple regressive situation.

To the north in the Ghost Dam section, the Chungo interval has undergone another major facies change to be replaced by bioturbated sandy mudstones of the Hanson Member. In the extreme northwest (Barrier Lake section) the Chungo interval is represented by clean sandstones of the HCS, SCS, and pebbly trough cross stratified facies. This is the only part of the study area where an east west facies change is observed. The WNW-ESE trending shoreline described in the Chungo further south probably started to swing NNW in this part of the study area, generating an apparent east west facies change within Chungo interval at this point.

The Nomad Member is a thin unit of bioturbated mudstone which forms the uppermost unit of the Wapiabi Formation. It separates the underlying Chungo strata from the overlying strata of the Belly River Formation. The base of the Nomad is commonly marked by a thin pebbly mudstone. This pebbly unit apparently records a transgressive event and a major shift of the Cretaceous shoreline approximately 150 km to the south. The transition from the marine Nomad Member to the overlying nonmarine Belly River Formation is very abrupt and very dissimilar to the Chungo regressive sequence. In the southern part of the study area this transition is typically marked by a thin fining upwards sandstone unit. This sandstone was probably deposited in the lower reaches of a tidally influenced deltaic system such as the recent Burdekin River delta. In the northern part of the study area, the Nomad to Belly River transition is commonly marked by a thin parallel laminated and trough cross stratified "beach type" sandstone.

The petrographic composition of the Chungo and Belly River sandstones plot on a QFL diagram in fields designated as lithic arkose, feldspathic litharenite, and litharenite. The Chungo sandstones have a distinctly higher K feldspar and quartz content. This suggests that extensive volcanic fields of Campanian age in northwestern Montana contributed significant amounts of detritus into the basin. The fact that the distribution of the Chungo sandstone (Eagle equivalent) is broadly centered on the Elkhorn volcanic field supports the fact that it contributed a large proportion of the detritus to the Chungo-Eagle regressive shoreline.

The Belly River sandstones have a lower quartz content and a much higher chert and other lithic fragment content. This indicates that the bulk of detritus was derived from erosion of uplifted Paleozoic carbonates which were exposed in the rising Cordillera to the west.

List of References

Adegoke, O.S., and Stanley, D.J. 1972, Mica and shells as indicators of energy levels and depositional regime on the Nigerian shelf. Marine Geology V.6 p. 61-66

Allen, J.R.L.A., 1965a, Coastal geomorphology of eastern Nigeria, beach ridge barrier islands and vegetated tidal flats. Geologie en Mijnbouw V.44 p. 1-21

-------------, 1965b, The sedimentology and paleogeography of the Lower Old Red Sandstone of Anglesley, North Wales. Yorks. Geol. Soc. Proc. V.35 p. 139-185

Asquith, D.O., 1974, Sedimentary models, cycles and deltas. Upper Cretaceous, Wyoming. Am. Assoc. Petroleum Geologists Bull., V.54 p. 1184-1224

Balsley, J.K., 1980, Cretaceous wave dominated delta systems, Book Cliffs East central Utah Field guide, Amoco Production Company, Denver, Colorado.

Baganz, B.P., Horne, J.C., Ferm, J.C., 1975, Carboniferous and recent Mississippi lower delta plains. Gulf Coast. Assoc. Trans. V.25 p. 183-191

Belyea, H.R., and Labreque, J.E., 1972, Devonian stratigraphy and facies of the southern Canadian Rocky Mountains and adjacent plains. 24th Int. Geol. Congress, Montreal, Guidebook C-18

Bernard, H.A., and Majors, C.F. Jr., 1963, Recent meander belt deposits of the Brazos River: an alluvial "sand" model. Am. Assoc. Petroleum Geologists Bull. V.47 p 350-

Berner, R.A., 1981, A new geochemical classification for sedimentary environments. Jour. Sed. Petrology V.51 No. 2 p. 359-365

Blatt, H., Middleton, G.V., and Murray, R.C., 1980, The Origin of Sedimentary Rocks, 2nd Edition, Prentice Hall, New York

Bozanich, R.G., 1979, The Bell Canyon and Cherry Canyon formations, eastern Delaware Basin, Texas. in N.M. Sullivan, ed., Soc. Econ. Paleontologists Mineralogists Spec. Pub. 79-18 p. 121-141

Bullock, A., 1981, Sedimentation of the Wapiabi-Belly River transition (Upper Cretaceous) at Lundbreck Falls, Alberta. unpublished BSc thesis, McMaster University, Hamilton, Ontario

Byers, C.W., 1977, Biofacies patterns in euxinic basins: a general model. in Cook, H.E., and Enos, P., eds. Deep water carbonate environments, Soc. Econ. Paleontologists Mineralogists Spec. Pub. 25 p. 5-17

Cairnes, D.D., 1905, The Foothills of the Rocky Mountains south of the mainline of the Canadian Pacific Railway. Geol. Surv. Canada Summary Rept. 1905

Campbell, F.A., and Lerbekmo, J.F., 1963, Mineralogic and chemical variations between Upper Cretaceous continental Belly River shales and marine Wapiabi shales in western Canada. Sedimentology, V. 2 p. 215-226

Carter, C.H., 1978, A regressive barrier and barrier protected deposit Late Tertiary Cohansey Sand. Jour. Sed. Petrology V. 48 p. 933-950

Clifton, H.E., 1969, Beach lamination, nature and origin. Marine Geology, V. 7 p. 553-559

------------, Hunter, R.E., and Phillips, R.L., 1971, Depositional processes and structures in a non barred high energy nearshore environment. Jour. Sed. Petrology V. 41 p. 651-670

Coleman, J.M., 1975, Deltas, processes of deposition and models for exploration. Continuing Education Pub. Comp., Champaign, Illinois, 107p.

Crockford, M.B.B., 1949, Oldman and Foremost Formations of southern Alberta. Am. Assoc. Petroleum Geologists Bull. V. 33, No. 3, p.500-510

Crowell, J.C., 1957, Origin of pebbly mudstone. Geol. Soc. America Bull. V. 18 p.993-1000

Curray, J.R., 1956, The analysis of two dimensional orientation data. Am. Assoc. Petroleum Geologists Bull. V. 40 p. 2440-2456

Dahlstrom, C.D.A., 1970, Structural geology of the eastern margin of the Canadian Rockies. Can. Soc. Petroleum Geologists Bull. V. 18, No. 3, p. 332-406

Dawson, G.M., 1883, Report on the region in the vicinity of the Bow and Belly Rivers, N.W.T., Geol. Surv. Canada Rept. Prog. 1880-1882

------------ 1884, Report on the region in the vicinity of the Bow and Belly Rivers, N.W.T., Geol. Surv. Canada Rept. Prog. 1882-1884

de Raaf, J.F.M., Reading, H.G., and Walker, R.G., 1965, Cyclic sedimentation in the Lower Westphalian of north Devon, England. Sedimentology, V. 4, p. 1-52

Dickinson, W.R., and Suczek, C.A., 1982, Plate tectonics and sandstone compositions. Am. Assoc. Petroleum Geologists Bull. V.63, p. 2164-2182

Dott, R.H., and Bourgeois, J., 1982, Hummocky cross stratification, significance of its variable bedding sequences. Geol. Soc. America Bull. V.93 p.663-680

Dowling, D.B., 1915, Water supply, southeastern Alberta. Geol. Surv. Canada Summ. Rept. 1915, p. 102-110

Eisbacher, G.H., 1977, Mesozoic-Tertiary basin models for the Canadian Cordillera and their geologic constraints. Canadian Jour. Earth Sci., V. 14, p. 2414-2421

--------------, Carrigy, M.A., and Campbell, R.B., 1974, Paleodrainage pattern and late orogenic basins of the Canadian Cordillera in, Dickinson, W.R., ed., Tectonics and Sedimentation, Soc. Econ. Paleontologists Mineralogists, Spec. Pub. 22, p. 143-166

Elliot, T., 1980, Clastic Shorelines in Reading, H.G. (1980)(ed.), Sedimentary Environments and Facies, First Edition, Elsevier, New York

Etheridge, F.G., and Schumm, S.A., 1978, Reconstructing paleochannel morphologic and flow characteristics. in Miall, A.D., ed., Fluvial Sedimentology. Can. Soc. Petroleum Geologists, Mem. 5, p. 703-722

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

Frey, R.W., Howard, J.D., and Pryor, J., 1978, Ophiomorpha Paleogeography, Paleoclimatology, Paleoecology. V. 23, p. 199

Gautier, D.L., 1982, Siderite concretions, indications of early diagenesis in the Gammon Shale, Cretaceous. Jour. Sed. Petrology. V. 52, No. 3, p. 859-871

-----------, and Rice, D.D., 1981, Comparison of conventional and low permeability reservoirs of shallow gas in the Northern Great Plains, reprint of talk presented at the Society of Petroleum Engineers, May 29, 1981, Denver, Colorado

Hallam, A., 1970, Gyrochorte and other trace fossils in the Forest Marble of Dorset, England, in Crimes, T.P., and Harper, J.C., eds., Trace Fossils, Seel House Press, Liverpool

Hamblin, A.P., 1978, Sedimentology of a prograding shallow marine slope and shelf sequence, Upper Jurassic Fernie-Kootenay transition, southern Front Ranges. M.Sc. thesis, McMaster University, Hamilton, Canada

-------------, and Walker, R.G., 1979, Storm dominated shallow marine deposits; the Fernie-Kootenay transition, southern Rocky Mountains. Canadian Jour. Earth Sci., V. 16, p. 1673-1690

Harms, J.C., Southard, J.B., Spearing, D.R. and Walker, R.G., 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences. Soc. Econ. Paleontologists Mineralogists Short Course Lecture Notes No. 2, 161p.

Hayes, M.O., 1967, Hurricanes as geologic agents, case studies of hurricanes Carla 1961 and Cindy 1963, Univ. Texas Austin Bureau Econ. Geol. Report No. 61

Haywick, D.W., 1982, Sedimentology of the Wapiabi-Belly River transition and the Belly River Formation, Upper Cretaceous Ghost Dam, Alberta. unpublished B.Sc. thesis, McMaster University, Hamilton, Canada

Helwig, J., 1970, Slump folds and early structures. Jour. Geol., V. 78, p. 172-187

Herr, R.L., 1965, Upper Cretaceous Alberta group in the subsurface of the Waterton gas field. Geol. Surv. Canada Paper 65-37

Hoffman, J., and Hower, J., 1979, Clay mineral assemblages as low grade geothermometers, thrust faulted belt of northwest Montana. in, Scholle, P.A., and Schluger, P.R., eds., Aspects of Diagenesis. Soc. Econ. Paleontologists Mineralogists Spec. Pub. 26, p. 55-

79

Horne, J.C., and Ferm, J.C., 1976, Carboniferous depositional environments in the Pocahontas Basin, Eastern Kentucky and southwest Virginia. Field guidebook, Department of Geology, University of South Carolina

Howard, J.D. and Reineck, H.E., 1981, Depositional facies in a high energy beach to offshore sequences, comparison with a low energy sequence. Am. Assoc. Petroleum Geologists, V. 65, No. 5, p. 807-831

Hubbard, D.K., and Barwis, J.H., 1976, Discussion of tidal inlet sand bodies: examples from South Carolina coast. in, Hayes, M.O., and Kana, T.W., eds. Terrigenous Clast Depositional Environments. Am. Assoc. Petroleum Geologists Field Course, University South Carolina, Tech. Rept. No. 11-CRD, p. 11-28 to 11-142

Hume, G.S., 1930, The Highwood-Jumping Pound Anticline. Geol. Surv. Canada Summ. Rept. 1930B

Hunter, D.F., 1980, Changing depositional environments in the Wapiabi-Belly River transition near Longview, Alberta. unpublished B.Sc. thesis, McMaster University, Hamilton, Canada

Hunter, R.E., Clifton, H.E., and Phillips, R.L., 1979, Depositional processes and sedimentary structures in a barred nearshore system, Southern Oregon coast. Jour. Sed. Petrology, V. 49, No. 3, p. 711-726

Irwin, J.S., 1931, Stratigraphic correlation and nomenclature in the plains of southern Alberta. Am. Assoc. Petroleum Geologists Bull. V. 15, p. 1129-1139

Jackson, R.G., 1975, Velocity bedform texture patterns of meander bends in the Lower Wabash River of Illinois and Indiana. Bull. Geol. Soc. America V. 86, p. 1511-1522

Johnson, H.D., 1980, Shallow Siliclastic Seas IN Reading, H.G., 1980)(Ed.) Sedimentary Environments and Facies, Elsevier, New York

Jones, P.B. and Workum, R.H., 1978, Geological guide to the Central Foothills and Rocky Mountains of Alberta. Canadian Soc. Petrol. Geol. Guidebook

Kumar, N., and Sanders, J.E., 1974, Inlet sequence: a vertical succession of sedimentary structures created by lateral migration of a tidal inlet. Sedimentology, V. 21, p. 491-532

Kuenen, P.H., 1952, Estimated size of the Grandbanks turbidity current. Am. Jour. Science. V. 250, p. 874-884

Leckie, D.A., and Walker, R.G., 1982, Storm and tide dominated shorelines in Cretaceous Moosebar-Lower Gates interval: outcrop equivalents of Deep Basin gas trap in Western Canada. Am. Assoc. Petroleum Geologists Bull., V. 66, No. 2, p. 138-157

Leeder, M.R., 1973, Fluviatile fining upwards cycles and the magnitude of paleochannels. Geol. Mag., V. 110, p. 265-276

Lerand, M.M. and Oliver, T., 1975, Stratigraphy and sedimentology in the Lundbreck section, in, Shawa, M.S., ed., Guidebook to selected sedimentary environments in southwestern Alberta, Canada. Can. Soc. Petroleum Geologists Field Conference

Lerbekmo, J.F., 1961, Stratigraphic relationship between the Milk River Formation of southern Alberta and the Belly River Formation of the southern Foothills of Alberta. Jour. Alberta Soc. Petroleum Geologists, V. 9, p. 273-276

--------------, 1963, Petrology of the Belly River Formation, southern Alberta foothills. Sedimentology, V. 2, p. 54-86

Lindholm, R.C., 1979, The use of programmable calculators in sedimentology. Jour. Sed. Petrology, V. , p.

Lowe, D.R., 1978, Water escape structures in coarse grained sediments. Sedimentology, V. 22, p. 157-204

Malloch, C.S., 1911, Bighorn coal basin. Geol. Surv. Canada Mem. 9E

Maynard, J.B, 1982, Extension of Berners "New geochemical classification for sedimentary environments" to ancient sediments. Jour. Sed. Petrology, V. 52, No. 4, p. 1325-1331

McLean, J.R., 1971, Stratigraphy of the Upper Cretaceous Judith River Formation in the Canadian Great Plains. Saskatchewan Research Council. Geology Division Report, Report 11, 96p.

------------, 1977, Lithostratigraphic nomenclature of the Upper Cretaceous Judith River Formation in southern Alberta, philosophy and practise. Can. Soc. Petroleum Geologists Bull. V. 25, No. 6, p. 1105-1114

------------ and Wall, J., 1982, The Early Cretaceous Moosebar Sea in Alberta. Can. Soc of Petroleum Geologists Bull. V. 29, No. 3, p. 334-377

Meijer Drees, N.C., and Mhyr, D.W., 1982, The Upper Cretaceous Milk River and Lea Park Formations in southern Alberta. Can. Soc. Petroleum Geologists Bull. V. 29, No. 1, p. 42-74

Mellon, G.B., 1961, Sedimentary magnetite deposits of the Crowsnest Pass region of southwestern Alberta. Res. Council of Alberta, Mem. No. 2

Meyboom, P., 1960, Geology and groundwater resources of the Milk River sandstone in southern Alberta. Res. Council of Alberta, Memoir 2

Middleton, G.V., 1973, Johannes Walthers law of the correlation of facies. Geol. Soc. America Bull. V. 84, p. 979-988

-------------- and Southard, J.B., 1977, Mechanics of Sediment Movement Short Course #3. Soc. Econ. Paleontologists and Mineralogists Eastern Section

Nelson, C.H., 1982, Modern shallow water graded sand layers from storm surges, Bering Shelf, a mimic of Bouma sequences and turbidite systems. Jour. Sed. Petroloy, V. 52, No. 2, p. 537-545

Nelson, H.W. and Glaister, R.P., 1975, Trap Creek basal Belly River section or deltaic progradational sequence, in, Shawa, M.S., ed., Guidebook to selected sedimentary environments in, Shawa, M.S., ed., Guidebook to selected sedimentary environments in southwestern Alberta, Canada

Norris, D.K. and Bally, A.W., 1972, Coal, Oil, Gas and industrial minerals of the interior plains, foothills and Rocky Mountains of Alberta and British Columbia. 24th Int. Geol. Cong. Field Guidebook A-25 to C-25, Montreal

Ogunyomi, O., and Hills, L.V., 1977, Depositional environments Foremost Formation, Late Cretaceous, Milk River area, Alberta. Can. Soc. Petroleum Geology Bull. V. 25, No. 5, p. 929-968

Pelletier, B.R., 1965, Paleocurrents in the Triassic of northeastern British Columbia, in, Middleton, G.V. Primary sedimentary structures and their hydrodynamic interpretation. Soc. Econ.

Paleontologists Mineralogists Spec. Pub. 12, p. 233-245

Potter, P.E., and Pettijohn, F.J., 1977, Paleocurrents and Basin Analysis. Second Edition, Springer-Verlag, Berlin

Powers, D.L., 1931, Subsurface study of the Pale Beds and Foremost Formation in the Lethbridge-Brooks area of southern Alberta. Am. Assoc. Petroleum Geologist Bull. V. 15, p. 1197-1213

Powers, M.C., 1953, A new roundness scale for sedimentary particles. Jour. Sed. Petrology, V. 23, p. 117-119

Price, R.A., Balkwill, H.R., Charlesworth, H.A.K., Cook, D.G., Simony, P.S., 1972, The Canadian Rockies and tectonic evolution of the southeastern Canadian Cordillera. 24th Int. Geol. Cong. Field Guidebook AC-15

Rahmani, R.A., and Lerbekmo, J.F., 1975, Heavy mineral assemblages of Upper Cretaceous and Paleocene sandstones in Alberta and Saskatchewan <u>in</u>, Caldwell, ed., The Cretaceous System in the Western Interior of North America. Geol. Assoc. Canada Spec. Pub. No. 13

Reading, H.G., 1980, Sedimentary Environments and Facies. First edition, Elsevier, New York

Reineck, H.E., and Singh, I.B., 1980, Depositional Sedimentary Environments. Second edition, Springer-Verlag

Rice, D.D., and Schurr, G.W., 1980, Shallow low permeability reservoirs of the Northern Great Plains. Am. Assoc. Petroleum Geologists Bull. V. 64, No. 7, p. 969-987

Rupke, N.A., 1980, Deep Clastic Seas <u>in</u> Reading H.G. (1980)(Ed.), <u>Sedimentary Environments and Facies</u>, First Edition, Elsevier, New York

Rose, B., 1920, Highwood coal field, Alberta. Geol. Surv. Canada Summ. Rept. 1919C

Russell, L.S., 1970, Correlation of the Upper Cretaceous Montana Group between southern Alberta and Montana. Canadian Jour. Earth Sci. V. 7, No. 4, p. 1099-1108

---------- and Landes, R.W., 1940, Geology of the southern Alberta plains. Geol. Surv. Canada Mem. 221, p.1-128

Ryer, T.A., 1977, Patterns of Cretaceous shallow marine sedimentation, Coalville and Rockport area. Geol.

Soc. America Bull. V. 88, p. 177-188

Schumm, S.A., 1963, A tentative classification of river channels. U.S. Geol. Surv. Cir. 477, 10p.

----------- 1972, Fluvial Paleochannels in, Rigby, J.K. and Hamblin, W.K., eds., Recognition of ancient sedimentary environments. Soc. Econ. Paleontologists Mineralogists Spec. Pub. 16, p. 98-107

Seilacher, A., 1967, Bathymetry of Trace fossils. Marine Geology, V. 5, p. 413-428

Shaw, E.W., and Harding, S.R.L., 1949, Lea Park and Belly River Formations of east central Alberta. Am. Assoc. Petroleum Geologists Bull. V. 33, No. 4, p. 487-499

Slipper, S.E., and Hunter, M.M., 1931, Stratigraphy of Foremost, Pakowki and Milk River Formations of southern plains of Alberta. Am. Assoc. Petroleum Geologists Bull. V. 15, No. 10, p. 1181-1196

Smedes, H., 1966, Geology and igneous petrology of the northern Elkhorn Mountains, Montana. U.S. Geol. Surv. Prof. Paper 510

Stanton, T.W., and Hatcher, J.B., 1905, Geology and paleontology of the Judith River beds. U.S. Geol. Surv. Bull. 257

Stelck, C.R., 1975, Basement control of Cretaceous sand sequences in Western Canada in, Caldwell, W.G.E., ed., The Cretaceous System in the Western Interior of North America. Geol. Assoc. Canada Spec. Pub. No. 13

Stott, D.F., 1963, The Cretaceous Alberta group and equivalent rocks, Rocky Mountain Foothills, Alberta. Geol. Surv. Canada Mem. 317

Stow, D.A., and Shanmugan, G., 1980, Sequence of structures in fine grained turbidites, comparison of recent and ancient examples. Sed. Geology, V. 25, p. 23-42

Surdam, R.C., and Boles, J.R., 1979, Diagenesis of volcanic sandstones. in, Scholle, P.A., and Schluger, P.R., eds., Aspects of Diagenesis. Soc. Econ. Paleontologists Mineralogists. Spec. Pub. 26, p. 55-79

Swift, D.P.J.W., Stanley, D.J., Curray, J.F., 1971, Relict sediments on continental shelves, a reconsideration. Jour. Geology, V. 79, p. 322-346

Tovell, W.M., 1956, Some aspects of the geology of the Milk River and Pakowki Formations, southern Alberta. unpublished Phd. dissertation, University of Toronto

Walker, R.G., 1979, Facies and Facies Models, in, Walker, R.G., ed., Facies Models. Geol. Assoc. Canada, Reprint Series 1

----------- Bullock, A., and Hunter, D.F., 1981, Wapiabi Belly River transition; Storm induced sediments with north oriented paleoflows, southern Alberta. Geol. Assoc. Canada, Abstracts, V. 6, Annual Meeting, Calgary

Wall, J.H., 1967, Cretaceous foraminifera of the Rocky Mountain Foothills, Alberta. Res. Council Alberta Bull. 20

Webb, C.F., and Hertlein, D.P., 1934, Zones in the Alberta shale, Benton group in the Foothills of southwestern Alberta. Am. Assoc. Petroleum Geologists Bull. V. 18, No. 11, p. 1387-1416

Weimer, R.J. and Hoyt, J.H., 1964, Burrows of Callianassa major, geologic indicators of littoral and shallow neritic environments. Jour. Paleontology, V. 38, p. 761-767

Wheeler, J.D., Campbell, R.B., Reesor, J.E., Mountjoy, E.W., 1972, Structural style of the southern Canadian Cordillera. 24th Int. Geol. Cong. Guidebook A-01 TO X-01 118 p., Montreal, Canada

Williams, M.Y., and Dyer, W.S., 1930, Geology of southern Alberta and southwestern Saskatchewan. Geol. Surv. Canada Mem. 163

Wilson, J.L., 1975, Carbonate Facies in Geologic History. Springer-Verlag, Berlin, First Edition

Woodcock, N.H., 1979, The use of slump structures as paleoslope estimators. Sedimentology, V. 26, No. 1, p. 83-100

Woolsely, J.R., Henry, V.J., and Hunt, J.L., 1975, Backshore heavy mineral concentrations on Sapelo Island, Georgia. Jour. Sed. Petrology, V. 45, No. 1, p. 280-284

Appendix 1

Outcrop Localities

Appendix 1

Outcrop Locations

Maycroft Section TWP 10 R2 W5

- start at Maycroft campground located at Highway #22 bridge crossing Oldman River approximately 15 miles north of Lundbreck
- 1/4 mile north of Maycroft campground, turn west onto A-7 ranch access and drive approximately 5 miles until reaching Texas gate, 50 meters north of the river
- Nomad Chungo contact is directly below gate; Thistle Chungo transition is exposed 1/4 mile east

Magnetite Beach Section TWP 8 R2 W5

- located approximately 6 miles west of the town of Lundbreck, turn north on the North Burmis Road
- for access permission, continue approximately 3 miles north; Mr. Diezech is owner of the property and lives in the second house on the left
- to find outcrop, turn west off the North Burmis Road approximately 1/4 mile north of the junction with Highway #3, drive through gate and continue for approximately 1/2 mile

Oldman River Section TWP 13 56 W5

- from the Oldman River campground on the Forestry Trunk

Road, drive 18 miles northwest; outcrop is located 500 feet south of the road and may not be visible from the road; camping facilities available approximately 1 mile further in where the road ends

<u>Bragg Creek Section</u> TWP 23 R5 W5

- located approximately 6.6 km west of T junction which is due south of Bragg Creek
- there is a fork in the road, take the right fork down the hill, outcrop is across the Elbow River, 100 yards from the road

<u>Trap Creek Section</u> TWP 17 R4 W5

- from Black Diamond turn south on Highway #7 towards Longview
- turn right (west) at the gravel road 1/4 mile north of Longview and continue for 10 miles to the second steel bridge crossing, turn right into the parking area
- outcrop starts in the Upper Thistle Member approximately 100 meters east of the bridge;
- main Chungo sandstone is located 150 meters west of bridge near the falls and the abandoned bridge foundations
- phone ahead for permission; Mr. Louis De Paoli, 558 2280

Highwood (2) River Section TWP 18 R4 W5

- located approximately 1 mile north of Trap Creek section described above
- park vehicle on small pasture access road, walk in approximately 200 yards along fenceline
- outcrop is located on west side of river and not visible from road

Sheep River Section TWP 19 R4 W5

- from Turner Valley, continue west on Highway #7, approximately 10 miles to Sandy McNab campground
- turn left into campground and follow to extreme eastern part of campground
- trail along the north side of river approximately 1 1/2 miles to outcrop
- may be difficult at high water stages
- watch out for sheep kicking stones

Longview Section TWP 18 R2 W5

- from Turner Valley, continue south along Highway #7 for approximately 9 miles
- turn right (west) at Husky Station on the outskirts of Longview
- outcrop is located on north side of Highwood River approximately 2 and 1/2 miles west of turnoff; outcrop is not visible from road

- park vehicle on pasture access turnoff and walk in along fenceline
- owner of property said to reside in Phoenix, therefore inaccessible, hopefully unarmed.

Ghost Dam TWP 26 R5 W5

- drive Highway 1A from Calgary
- approximately 9 miles past Cochrane (1 mile past Esso gas station) turn left into Ghost River damsite
- park vehicle on North side of dam, walk across bridge
- excellent Wapiabi-Belly River exposure along the entire spillway, measured section starts at east end where spillway empties into Bow River and continues west to where the river makes a sharp turn south
- dam now gated off, section inaccessible without prior arrangement. Phone Trans Alta Utilities at 932 5651

Barrier Lake TWP 25 R8 W5

- follow Highway 1 west from Calgary to the access road for Kananaskis campgrounds, turn south.
- continue south for approximately 5 miles
- turn right onto access road of a small powerhouse located at north end of Barrier Lake; locked gate may bar entry
- park vehicle and walk 1/2 mile or so to the spillway where the section is well exposed
- measured section starts about 200 meters south of

powerhouse (50 meters south of warning sign) and continues to the end of exposure at the end of the gorge

- WARNING- area below dam is subject to rapid rise in water levels

<u>Lundbreck Section</u> TWP 7 R2 W5

- exposure is located 2 km downstream from Lundbreck Falls, about 2 km west of town of Lundbreck
- outcrop is located between the main Highway #3 and the access road to Lundbreck
- lower part of the section is located on south side of the river while the upper part of the section is on the north side. The river is generally too deep to traverse and the north side should be reached by walking south from highway the main.

<u>Coleman Section</u> TWP 8 R4 W5

- main Crowsnest Highway #3 cuts directly through the exposure in the center of town of Coleman

Appendix 2

Tabulation of all Paleocurrent Data corrected for tectonic tilt, means and vector magnitude also indicated

FACIES 12

PEBBLE ORIENTATION DATA

All plots are direction of maximum dip after rotation about regional strike

1. SHEEP RIVER - CONGLOMERATE AT 130 METERS ABOVE BASE OF SECTION

001	073	146	245
004	075	148	253
008	076	148	260
014	088	148	266
014	097	148	290
015	097	150	293
022	100	150	294
024	102	157	304
029	101	157	304
029	107	158	308
030	110	158	309
031	122	162	320
032	124	173	321
035	126	185	327
037	128	189	328
042	128	191	328
050	132	195	336
050	134	206	338
050	140	216	343
054	140	220	345
054	140	224	346
058	143	228	349
064	143	230	349
066	143	234	354
067	145	238	358

n = 100
θ = 081° Az
r = 19.00
L = 19%

2. SHEEP RIVER - PEBBLY MUDSTONE AT 140 METERS ABOVE BASE OF SECTION

000	070	238	313
001	071	240	313
003	073	242	316
004	073	242	318
009	074	242	322
012	075	246	326
012	079	253	327
018	082	259	327
020	084	265	327
020	084	270	330
023	091	279	331
026	104	279	331
030	119	282	335
032	145	285	338
034	154	289	342
046	159	290	345
046	182	297	345
046	186	302	348
051	189	302	349
056	208	306	352
057	212	306	353
058	226	308	358
059	228	313	358
			359
			359

$n = 100$
$\theta = 348°$ Az
$r = 39.4$
$L = 39.4\%$

3. SHEEP RIVER - CONGLOMERATE AT 141 METERS ABOVE BASE OF SECTION

000	110	170	237	326
000	110	170	250	328
005	112	175	258	330
005	126	175	260	336
015	131	175	262	336
018	134	177	264	336
018	134	186	265	341
020	136	189	266	343
036	140	191	288	351
038	140	194	298	353
044	140	199	304	353
053	142	201	306	353
100	142	203	310	359
102	145	203	311	359
105	149	206	312	
107	155	213	315	
107	155	222	315	
107	155	224	322	
108	160	227	324	
110	161	236	324	

$n = 100$
$\theta = 212°$ Az
$r = 5.99$
$L = 6.0\%$

4. LONGVIEW, DIRECTION OF MAXIMUM DIP OF PEBBLES (facies 12)

004	079	156	256
005	082	164	258
007	086	166	261
013	091	170	264
018	098	170	264
019	101	176	267
021	104	178	269
024	105	183	272
026	106	186	278
037	107	186	285
044	108	188	288
046	110	192	301
048	110	200	306
050	111	201	316
053	111	209	327
054	114	210	332
055	116	213	336
067	118	214	342
069	119	222	348
070	119	224	351
071	126	238	355
072	128	239	358
074	130	244	359
077	135	245	
078	141	250	

sin = 40.1418
cos = 7.4149
n = 100
θ = 099° Az
r = 185
L = 18.5%

MAYCROFT SECTION (facies 12)

Direction of Maximum Dip of Pebbles

012	112
027	112
031	114
037	116
040	124
043	126
053	142
055	143
058	144
060	145
070	147
073	166
074	171
082	220
090	251
099	275
100	318
102	329
103	334
107	343
	348

$n = 42$
$\theta = 055°$ Az
$r = 25.42$
$L = 60.5\%$

1. MAYCROFT SECTION

A. THISTLE MEMBER

(i) ripple foreset lamination (facies 1,2,3)

161	091	013	051	027	050
103	069	059	058	051	028
074	072	065	061	030	
048	048	048	042	060	n = 27
044	048	046	038	086	θ = 056° Az
					r = 24.2
					L = 89.6%

125	110	111	109	110	092
066	086	131	147	071	314
096	094	086	084	306	043
127	090	090	085	043	
070	044	032	024	106	n = 33
062	070	073	103	100	θ=081.2° Az
					r = 26.0
					L = 81.5%

125	114	107	083	240	n = 20
100	095	088	150	110	θ = 102° Az
109	108	101	098	095	r = 16.2
085	082	092	115	351	L = 81%

Total Thistle Member
Maycroft
n = 80
θ = 077° Az
r = 63.65
L = 79.6%

The Thistle Member in the Maycroft section was organized into 3 coarsening upward sequences of thinly laminated shale, siltstone and sandstone. The paleocurrent data derived from this strata was grouped according to which sequence it was measured from, to determine whether any variation in the mean transport direction occurred vertically within the section.

B. CHUNGO MEMBER (i) ripple foreset lamination

(nonmarine overbank, facies 10)
351°
352°

2. LUNDBRECK SECTION

A. CHUNGO MEMBER

(i) ripple foreset lamination (facies 2, 5a, 1c)

001	014	341	013
340	011	332	351
334	356	328	325
294	356	037	306
011	351	331	032
055	028	022	005
359	353	397	046
022	022	004	357
353	343	030	022
012	002	353	352
327	348	036	327
007	010	002	351
034	032	005	016
006	088	034	030
005	027	013	056
344	021	004	352
313	018	009	360
352	011	353	034
009	360	350	023
355	035	031	360
012			

n = 80
θ = 005°
r = 72.1
L = 90.1%

(ii) solemarks (toolmarks)
(facies 5a, 6)

000/180
014/194
024/204
175/355
013/193
018/198
023/203
028/208

n = 8
θ = 015/195°
r = 7.4
L = 93%

LUNDBRECK (cont'd)

(iii) load fold axes
(facies 7)

032/49° Az
079/40° Az
004/259° Az

(iv) direction of maximum dip of swaley lamination
(facies 8)

055	044	348	188	191	070	128
069	045	156	198	204	075	131
076	060	005	222	204	080	138
082	065	020	229	210	082	148
083	067	056	236	213	083	150
087	070	059	258	213	092	167
091	082	060	313	222	100	171
092	085	061	338	222	102	173
095	086	063	346	232	104	215
103	091	068	053	240	108	252
108	102	078	084	242	109	272
111	110	079	086	245	107	299
118	113	082	091	250	110	300
119	114	083	096	270	112	010
132	118	085	097	272	113	056
136	134	088	101	293	113	074
138	138	093	101	025	116	077
149	136	098	129	044	116	080
168	156	110	135	054	116	096
190	236	116	172	061	119	100
236	276	183	189	063	120	106
126	118	115	115	115	114	110
137	137	139	148	174	180	188
			312	305	246	228

n = 163
θ = 113° Az
r = 81.4
L = 49.9%

3. SHEEP RIVER

A. THISTLE MEMBER

(i) ripple foreset laminations (Facies 1a, 1b, 1c, 2)

174	233	191	306
169	232	238	184
162	222	263	223
155	303	267	051
138	145	114	112
074	167	192	234
355	016	057	087
087	079	303	037
206	234	242	028
348	067	105	

n = 39
θ = 172° Az
r = 7.96
L = 20.4%

B. CHUNGO MEMBER (Lower coarsening upward sequence)

(i) ripple foreset laminations (Facies 5a, 5b)

064	263	260	n = 8
253	332	268	θ = 286° Az
253	050		r = 305
			L = 38%

(ii) tool marks 030/210°

(iii)crest axis, symmetrical wave ripples (Facies 5a,5b,6)

347/167	280/100	269/089	280/100	294/114
339/159	298/118	354/174	302/122	268/088
089/269	282/102	330/150	317/137	278/098
326/146	311/131	313/133	086/266	282/102
314/134	307/127	312/132	268/088	296/116
307/127	329/149			

n = 27
θ = 148° Az
r = 16.6
L = 61.5%

(iv) load fold axis (Facies 7)

0/324° Az

SHEEP RIVER (cont'd)

(v) Direction of maximum dip of swaley lamination (Facies 8)

012	137	207	261	320
032	146	213	269	334
057	150	224	275	340
086	185	228	276	340
091	185	228	282	346
091	192	239	282	355
100	198	245	286	356
112	207	248	289	358
127	207	253	289	359
133	207	255	308	
139	207	258	320	

n = 53
θ = 252° Az
r = 13.5
L = 25.9%

B. CHUNGO MEMBER - (Upper coarsening upward sequence)
(i) ripple foreset laminations (Facies 5a,5b)

270	085	165	099	196	223
133	090	167	102	197	254
169	155	170	116	198	256
173	160	174	117	208	118
178	162	183	130	210	
060	164	035	163	216	
072	165	038	181	220	

n = 39
θ = 159° Az
r = 23.4
L = 65.6%

(ii) crest axis, symmetrical wave ripples (Facies 5a,5b,6)

343/163	294/114	298/118	192/012	200/020
346/166	296/116	277/097	351/171	292/112
355/155	333/153	340/160		

n = 13
θ = 328/148
r = 6.4
L = 49.5%

SHEEP RIVER (cont'd)

(iii) toolmarks (Facies 5a,5b,6)

239/059	251/071	204/024	231/051
243/063	244/064	205/025	

(iv) parting lineations (Facies 6)

222/042
235/055

n = 11
θ = 028/218
r = 8.7
L = 87%

(v) oriented wood (Facies 6)

238/058

(vi) trough cross bed foresets (Facies 11)

081	028	072	043	040	071	067	064
044	148	047	284	090	069	024	

n = 15
θ = 061° Az
r = 10.7
L = 71.6%

4. GHOST DAM SECTION

A. THISTLE MEMBER

(i) ripple foreset lamination (Facies 1a,1b,1c,2)

360	146	186	169	033	148
134	161	122	208	164	177
347	192	195	210	195	122
360	182	209	157	186	173
210	182	213	068	201	248

n = 30
θ = 175° Az
r = 17.6
L = 58.7%

B. BASAL BELLY RIVER FORMATION

(ii) direction of maximum dip of beach lamination (Facies 9)

102	105	108	108	110
112	116	130	130	

n = 9
θ = 113° Az
r =
L =

5. BARRIER LAKE SECTION

A. THISTLE MEMBER

(i) ripple foreset laminations (Facies 1a,1b,1c,2)

122	156	108	222	194	151
162	169	126	090	183	199
161	199	237	158	206	020
173	162	114	078	223	190
346	197	176	135	120	210
211	164	223	087	147	240
242	176	194	135	082	134
142	182	157	179	040	355
064	220	174	224	116	092
111	090	178	208	138	160
081	146	200	192	190	132
155	191				

n = 68
θ = 162° Az
r = 43.4
L = 63.7%

358	182	019	133	196
360	140	160	144	174
240	202	133	189	182
142	070	150	077	152
192	360	030	189	094
132	178	222	241	191
134	014	187	235	

n = 34
θ = 160° Az
r = 15.6
L = 45.8%

total Thistle Member
Barrier Lake
n = 102
θ = 160° Az
r = 58.9
L = 57.8%

6. TRAP CREEK

A. THISTLE MEMBER

(i) ripple foreset lamination (Facies 1a,1b,1c,2)

016	046	090	008	069
035	344	030	064	007
084	350	044	012	026
360	092	063	068	355

n = 20
θ = 038° Az
r = 16.9
L = 84%

141	199	148	193	248
143	052	172	108	122
147	102	176	148	135
123	116	037	176	152
147	126	155	300	179
170	103	110	198	057

n = 30
θ = 148° Az
r = 20.3
L = 67.5%

total Thistle Member
n = 50
θ = 095° Az
r = 23.6
L = 47%

B. CHUNGO MEMBER

(i) ripple foreset lamination (Facies 5a) 104, 150

(ii) parting lineation (Facies 6) 225/45

(iii) crest axis, symmetrical wave ripple (Facies 6) 295/115

(iv) trough crossbed foresets (nonmarine Facies 11 sandstone) 078° Az

(v) flutes on base Facies 11 nonmarine sandstone channel

306	310	316	265	279	310
330	292	245	270	295	
299	272	230	300	196	
299	295	282	255	301	

n = 21
θ= 289° Az
r = 19.2
L = 91%

7. LONGVIEW SECTION

A. CHUNGO MEMBER

(i) ripple foreset laminations (Facies 5a, 5b)

264	170	n = 4
155	178	θ = 187° Az
		r = 3.0
		L = 75.4

(ii) tool marks (Facies 5a) 125/305

8. OLDMAN RIVER SECTION

A. CHUNGO MEMBER

(i) ripple foreset lamination (Facies 5a, 5b)

085	093	024	042	216
076	041	096	059	
306	013	030	158	

n = 13
θ = 059° Az
r = 7.3
L = 56%

(ii) tool marks

358/178	n = 4
015/195	θ = 0.12° Az
015/225	r = 1.4
177/357	L = 35.5%

(iii) flute marks (Facies 5a) 77° Az

(iv) long axis of crests of symmetrical wave ripple (Facies 5a)

130/310	n = 4
132/312	θ = 318/138
137/317	r = 3.8
154/334	L = 95%

9. HIGHWOOD RIVER SECTION

A. CHUNGO MEMBER

(i) ripple foreset lamination (Facies 2,5a,5b)

004	043	138	208
008	054	144	214
020	056	158	
021	076	170	
042	134	188	
042	135	191	

n = 20
θ = 092° Az
r = 7.3
L = 36.5%

(ii) trough cross bed foresets (Facies 9 shoreface sandstone)

027	224	260	114
066	228	272	172
072	230	316	175
078	238	350	216
086	240	104	

n = 19
θ = 197° Az
r = 3.2
L = 16.8%

(iii) planar tubular cross cross bed foresets (Facies 11 nonmarine channel sandstone)

053	140	138	135	231
054	296	071	120	
135	067	162	192	
039	088	305	079	

n = 17
θ = 106° Az
r = 7.6
L = 44.5%

(iv) Oriented logs, direction of dip of long axis (Facies 11)

102	147	132	074	131	121
104	157	142	074	145	132
112	131	074	125	114	

n = 17
θ = 122° Az
r = 14.5
L = 90

B. NOMAD MEMBER

(i) ripple foreset laminations (Facies 5a)

218	033	243	n = 5
079	333		θ = 327° Az
			r = .81
			L = 16.1%

(ii) crest axis of symmetrical wave ripples (Facies 5a)

300° Az

10. COLEMAN SECTION

(i) crest axis, symmetrical wave ripples (Facies 5a,6)

080/260 106/286

(ii) flutes on base HCS beds (Facies 6)

345	350	352	356
346	351	354	

(iii) tool marks on base hummocky beds (Facies 6)

340/160	348/168	003/183
342/162	360/180	

n = 5
θ = 347/167°
r = 4.9
L = 80%

APPENDIX 3

Staining Technique for Feldspars

Staining Technique for Feldspars

1. Etch the uncovered thin section for 10 seconds over hydrofluoric acid at room temperature.

2. Immerse the section in saturated sodium cobaltnitrate solution for 15 seconds. The K feldspar is stained light yellow.

3. Rinse the section in tap water to remove cobaltnitrate.

4. Dip the slide quickly in and out of barium chloride solution (5%).

5. Rinse the slide quickly with distilled water.

6. Cover the thin section with rhodinozate reagent from a dropping bottle. Plagioclase feldspar is stained pink.

7. Wash in tap water, dry, and mount with cover glass.

APPENDIX 4

Petrographic data sheets

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
HRII-35 top non marine channel sand (Facies 11)	46.3	9.5	1.4	12.4	1.1	5.3		14.8	9.2		fg well sort. subang. mnr ang. and subrnd

Comments:
This sample is diagenetically banded with alternating laminae being cemented to different degree
(i) Chlorite carbonate bands - The high relief blue fluorescing cruddy cement is probably chlorite. It appears to have been earlier than, and partly replaced by, a later carbonate cemen
(ii) Carbonate bands - These bands are dominated by porefilling carbonate cement. Wispy inclusions of chlorite cement, as above, indicates that the carbonate has almost completely replaced the chlorite cement.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
HRII-49 non (Facies 10) marine overbank	23.4	6.8	1.9	24.2	0.4	0.4	1.5	9.8	32.1		fg mod. to well sort. dom. ang. mnr. subang.

Comments:
Ubiquitous carbonate is present as porefilling cement and also as replacement of discrete grains probably feldspar.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
HRII-56 hummocky (Facies 6)	32.8	11.5	1.9	7.6	2.7	5.7		10.7	27.1		vfg well sort. subang. abdt ang. and subrnd

Comments:
Ubiquitous carbonate cement is present as pore filling cement and replacement of discrete grains. No evidence of earlier cement, but the carbonate was probably early as discrete grains show no evidence of compaction. Quartz grains have sharp angular to subangular non corroded margins.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	Detrital Mica	Detrital Carb.	Opaques	Other Lithics	Sparry Carb.	Matrix	Grain Size Sorting Angularity
XL 10a top beach (Facies 9)	28.6	12.8	.7	4.2		1.9		2.7	48.8		Uvfg-Lfg well sorted dom. ang. minor sub-ang.

Comments:
Under plane or polarized light, it appears that the carbonate has replaced almost all detrital grains except quartz and chert. Some of the replaced carbonate retains vestiges or ghosts of original grains. Under CL, at least 3 generations of cementation and replacement exist.
(i) Earliest stage is replacement of discrete feldspar grains by a high relief, almost isotropic, blue fluorescing "cruddy" material probably chlorite. Overall, this is rare in the sample.
(ii) Second stage produced corrosion and rimming of the chlorite grains, formed in stage (i), by a bright red fluorescing carbonate. This component is also quite rare.
(iii) Third stage produced ubiquitous carbonate cement, dark red fluorescing, distinctly different color than stage (ii). It appears to have filled in all porosity early as very few of the discrete grains show evidence of deformation and compaction.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	Detrital Mica	Detrital Carb.	Opaques	Other Lithics	Sparry Carb.	Matrix	Grain Size Sorting Angularity
L-17 hummocky (Facies 6)	44	16.3	3.1	7.8	1.2	7.3		16.0	7.8	1.6	well sort. dom. sub-ang. minor sub rnd ang.

Comments:
Sample is generally too fine grained to differentiate primary and diagenetic textures. Under plane light or cross nicols, it appears that many of the lithics are deformed around competent grains. However, under CL, it is apparent that the grains were cemented early by a red fluorescing carbonate cement and that little deformation and compaction of lithic grains occured.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	Detrital Mica	Detrital Carb.	Opaques	Other Lithics	Sparry Carb.	Matrix	Grain Size Sorting Angularity
L-24 loaded (Facies 7)	29.2	3.6	0.7	3.6	3.6	3.6		11.7	43.8		Lvfg well sort. subang. abdt subang.

Comments:
Sample is generally too fine grained to see textural and diagenetic relationships. It appears that most of the chert and feldspar is replaced by carbonate.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	Detrital Mica	Detrital Carb.	Opaques	Other Lithics	Sparry Carb.	Matrix	Grain Size Sorting Angularity
L-33 non (Facies 11) marine channel sand	41.2	16.6	4.0	11.2	2.2	1.1		15.9	7.6	0.4	subang. abdt subrnd.

Comments:
Rock appears to have a fairly high porosity as epoxy is common. A red fluorescing carb content appears to have cemented the rock early, prior to deformation and compaction of lithic fragments.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	Detrital Mica	Detrital Carb.	Opaques	Other Lithics	Sparry Carb.	Matrix	Grain Size Sorting Angularity
L-39 non (Facies 11) marine channel sand	36.0	18.8	3.8	7.9	5.1	1.0	0.7	13.0	11.6	1.4	Lfg minor fg and mg mod. to well sort. overall ang.

Comments:
Rock looks to be weakly cemented with high porosity as epoxy cement is very common. Two discrete stages of cementation/replacement are present:
(i) First stage is a rare (less than 5%) pore filling cement which has high relief, blue fluorescence, probably chlorite.
(ii) Second stage is a rare (5%) red carbonate cement, approximately 2% forms by replacement of discrete grain and the rest is pore filling cement.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
GD-44 beach (Facies 9)	12.8	10.5	2.3	12.4	0.8	3.4	0.4	13.5	44.0	0	Uvfg-Lfg well sort. dom. ang. muv.subang.

Comments:
Very extensive carbonate cement dominates the sample and most of the quartz margins appear to be corroded, resulting in most of the grains having a very angular texture. This is probably a diagenetic feature. Under CL, wispy vestiges of an earlier cement, with high relief, blue fluorescing, probably chlorite, are present between the discrete grains but it appears that this cement is almost completely replaced by the later carbonate cement. The cement was probably early as none of the lithic grains show evidence of compaction.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
SR-10 loaded (Facies 7)	37.4	18.7	2.8	3.6	1.6	1.6	2.0	13.5	18.3		vfg, mnr fg well sort. subang. mnr sr

Comments:
Sample is generally too fine grained to distinguish the primary and diagenetic textures. The feldspars are heavily altered and it is difficult to distinguish them from lithic fragments. The dominant cement appears to be a clay carbonate mixture.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
SR-11 base (Facies 8) swaley facies	42.0	8.5	0	0.7	1.7	3.0	3.8	12.5	16.3	1.04	vfg traces fg well sort.

Comments:
Most feldspars appear to be weakly altered to a fine micaceous "crud". Sparry carbonate cement is common as a late pore filling phase and is more commonly associated with more quartzose laminae. No high relief blue fluorescing "chlorite" cement is present although it is common in the next sample only meters higher in the section.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
SR-12 top swaley facies (Facies 8)	22.2	2.7	0	0.4	2.3	2.3	1.0	15.2	35.0	0.4	vfg traces Lfg well sorted ang. minor sub-ang. to subrnd.

Comments:
Two distinct phases of alteration and cementation:
(i) Earliest phase involves the almost complete alteration of discrete feldspar grains to a dark high relief blue fluorescing cement, probably chlorite. This phase involves discrete grains only and does not act as a pore filling cement also.
(ii) A later stage produces a ubiquitous carbonate cement which was apparently very aggressive as most quartz grains have moderately corroded margins.

SR-31 (Facies 11) channel sand	42.5	7.1	0	2.1	1.1	2.9	0.4	30.0	7.1	8.2	fg traces mg ang. mnr subang.

Comments:
Feldspar appear to be altered to very fine grained micaceous "cruddy" material which is very difficult to distinguish from lithic fragments. At least 3 discrete stages of alteration and cementation occur:
(i) Earliest cement is a rare (less than 5%)high relief blue fluorescing pore filling cement probably chlorite.
(ii) Second stage has produced transparent to light brown green intermediate to high relief cement; this phase has produced the most prevalent cement in the sample.
(iii) Last stage is a very rare pore filling carbonate cement which appears to have reduced effective porosity to nil.

Sample # (Facies)	Quartz	K. felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
SR-40 beach (Facies 9)	25.3	16.7	1.9	10.4	0	1.9	1.1	13.0	10.4	8.9	fg well sort. subang. mnr subrnd and v. ang.

Comments:
Sample has a noticeably higher chert content than other samples lower in the section. Two distinct stages of alteration and cementation are present:
(i) Earliest stage has produced high relief dark, vermicular cement, probably chlorite.
(ii) Second stage has produced a ubiquitous lacy pore filling carbonate cement. Most quartz grain margins bordering with the carbonate cement appear to be heavily corroded.

Sample # (Facies)	Quartz	K. felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
HRII-13 (Facies 9) Beach	39.6	24.5	4.5	1.9	1.1	4.5		9.8	14.0		Uvfg-Lfg well sort. subang.

Comments:
Sample was probably very porous as abundant epoxy is visible. Two distinct stages of alteration and cementation:
(i) Earliest stage is a rare, dark high relief "cruddy" cement, probably chlorite which acts as a pore filler only and does not replace discrete grains.
(ii) Later stage produced a ubiquitous red fluorescing carbonate cement which was dominantly pore filling but also forms as a replacement of discrete grains, probably feldspar. Many of the quartz grain margins are extensively corroded.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
HRII-14 upper beach (Facies 9)	24.5	16.4	2.2	2.6	0.7	11.9		5.9	37.5		Uvfg-Lfg mod. to well sort. subang. mnr ang.

Comments:
Two discrete stages of alteration and cementation:
(i) Early cement is a high relief vermicular blue fluorescing cement which has replaced all of the feldspars and filled in app. half of the pore space, producing amorphous "blobs" of chlorite that may retain ghost outlines of the replaced grain.
(ii) A later, very aggressive carbonate cement appears to have replaced discrete grains, and also filled in the remaining pore space.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
HRII-28 lag at base, non marine channel (Facies 11)	39.6	3.8		1.5	1.9	1.5		41.9	16.9	3.1	vfg-Lfg well sort. subang.

Comments:
Under CL, 3 distinct stages of alteration and cementation:
(i) Earliest event formed abundant pore filling cement, which has high relief, is almost isotropic, and has a blue fluorescence (probably chlorite).
(ii) The second event appears to have altered feldspar to carbonate or carbonate-mica aggregates.
(iii) Last event is a ubiquitous green fluorescing carbonate which filled in the remaining porosity and in part, replaced some discrete grains.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
HRII-60 loaded (Facies 7)	31.7	25.9	3.2	2.9	14.4	0.7	0.7	13.7	11.2	1.1	vfg-Lfg well sort. ang. to subang.

Comments:
The sample appears very porous as epoxy resin is very ubiquitous. Most feldspars are only weakly altered with minor alteration to carbonate along margins and cleavage. Under CL, the sample appears to have a high matrix content as the grains are surrounded by an heterogenous textured weakly fluorescent material. Late carbonate cement is generally rare (less than 5%) and forms lacy aggregates which appear to have filled in the last vestiges of porosity, remaining after compaction of lithic fragments and matrix.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
BL 27	51.3	3.4	0.7	15.0		5.2	15.0	1.9	3.7	3.7	vfg, mnr lfg well sort. subang. to ang.

Comments:
Sample is generally too fine to allow observation of primary and diagenetic textures. Much of the carbonate appears as discrete grains which may be either detrital carbonate grains or feldspars which were replaced by carbonate grains.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	De-trital Mica	De-trital Carb.	Opa-ques	Other Lith-ics	Spar-ry Carb.	Matrix	Grain Size Sorting Angularity
TC-21 non (Facies 11) marine channel	31.0	18.6	0.4	3.5	0.8	2.3	0.8	8.5	30.6	3.5	vfg, Lfg thinly laminated subang. to ang.

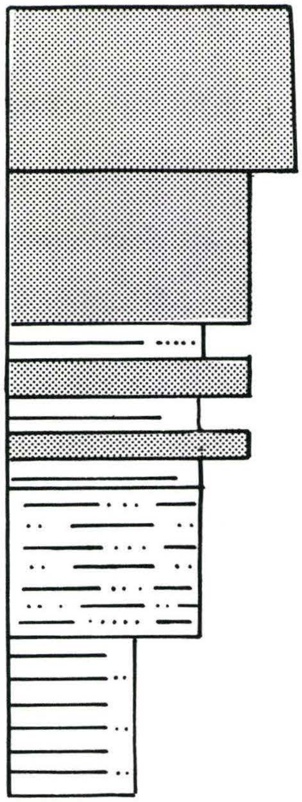
Comments:
Sample has alternating laminae, to 5 mm thick, consisting of very fine grained and fine grained sand. Two discrete stages of cementation and alteration:
(i) Earliest stage cement is pore filling cement, comprising 5 to 10% of the sample, high relief, blue fluorescing, probably chlorite.
(ii) Later stage has produced ubiquitous carbonate cement which has filled in the remainder of the porosity. Most quartz grains have extensively corroded margins.

Sample # (Facies)	Quartz	K-felds.	Plag.	Chert	Detrital Mica	Detrital Carb.	Opaques	Other Lithics	Sparry Carb.	Matrix	Grain Size Sorting Angularity
TC-32 (Facies 11) channel	20.1	0.6		1.2	1.7	0.6	10.3	42.5	1.7	21.3	mod. sort ang. to v. ang.

Comments:
Note: the abundant carbonaceous material in this sample was included under opaques in the point counting process. The sample appears to have a very high matrix content although it is very difficult to differentiate between lithic fragments and matrix. Under CL, the matrix and lithics have a very irregular weakly fluorescent texture. Two ages of cement were observed, but both comprise a small proportion of the sample and the grains are essentially cemented by matrix.
(i) First cement is a light fluorescing, low to intermediate relief, homogenous textured clay cement, composition unknown.
(ii) Traces of very late sparry carbonate cement comprise less than 5% of the sample. This sample looks to be texturally very immature.

LEGEND

LITHOLOGY (see facies descriptions for details)



MEDIUM GRAINED SANDSTONE

VERY FINE TO FINE GRAINED SANDSTONE

INTERBEDDED SANDSTONE /MUDSTONE

BIOTURBATED SANDY MUDSTONE

SHALE/SILTSTONE

TROUGH CROSS STRATIFICATION (TXB)

PLANAR TABULAR CROSS STRATIFICATION

HUMMOCKY CROSS STRATIFICATION (HCS)

SWALEY CROSS STRATIFICATION (SCS)

RIPPLE FORESET LAMINATION (RFL)

SYMMETRICAL WAVE RIPPLES (LONG AXIS RLA)

LOAD STRUCTURES

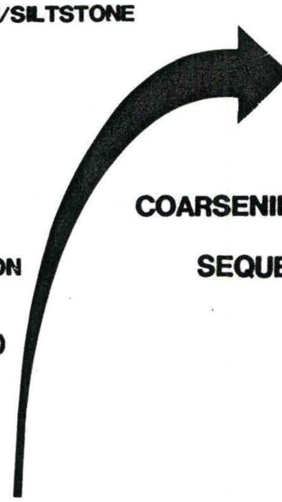
ROOT TRACES

COAL

BIOTURBATION

CARBONACEOUS

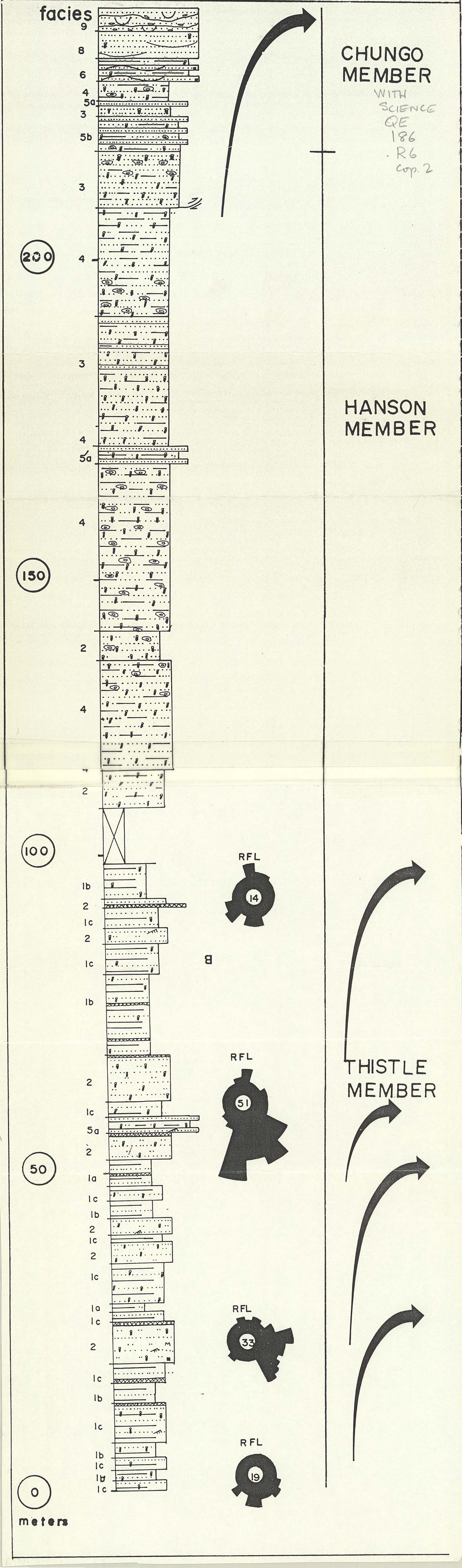
LOG CAST



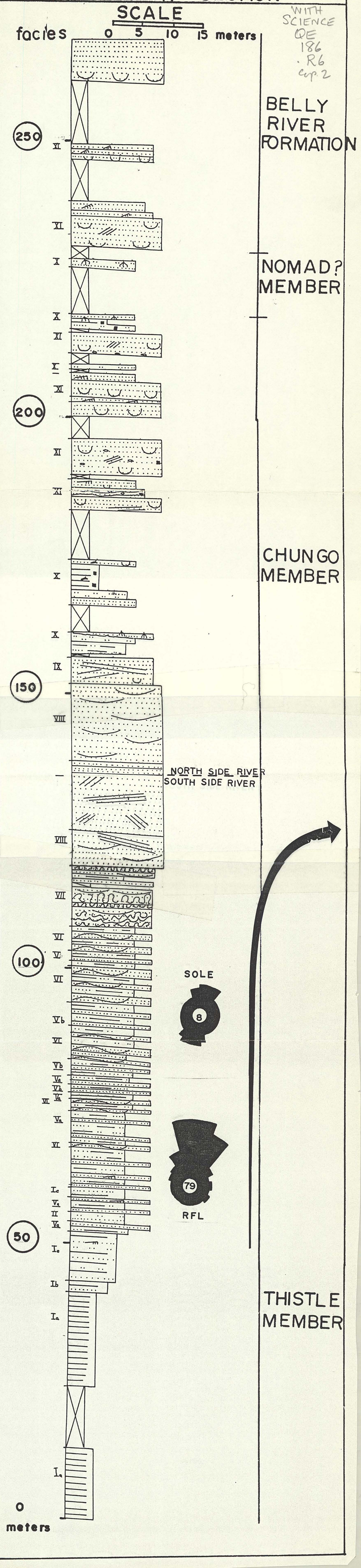
COARSENING UPWARD SEQUENCE


TRAP CREEK SECTION
0 5 10 15
meters
F-1
BELLY RIVER FORMATION
NOMAD MEMBER
CHUNGO MEMBER
HANSON MEMBER
THISTLE MEMBER
facies
350
300
250
200
150
100
50
flutes on base channel
RFL
RLA, PL
21
4
20
37
?

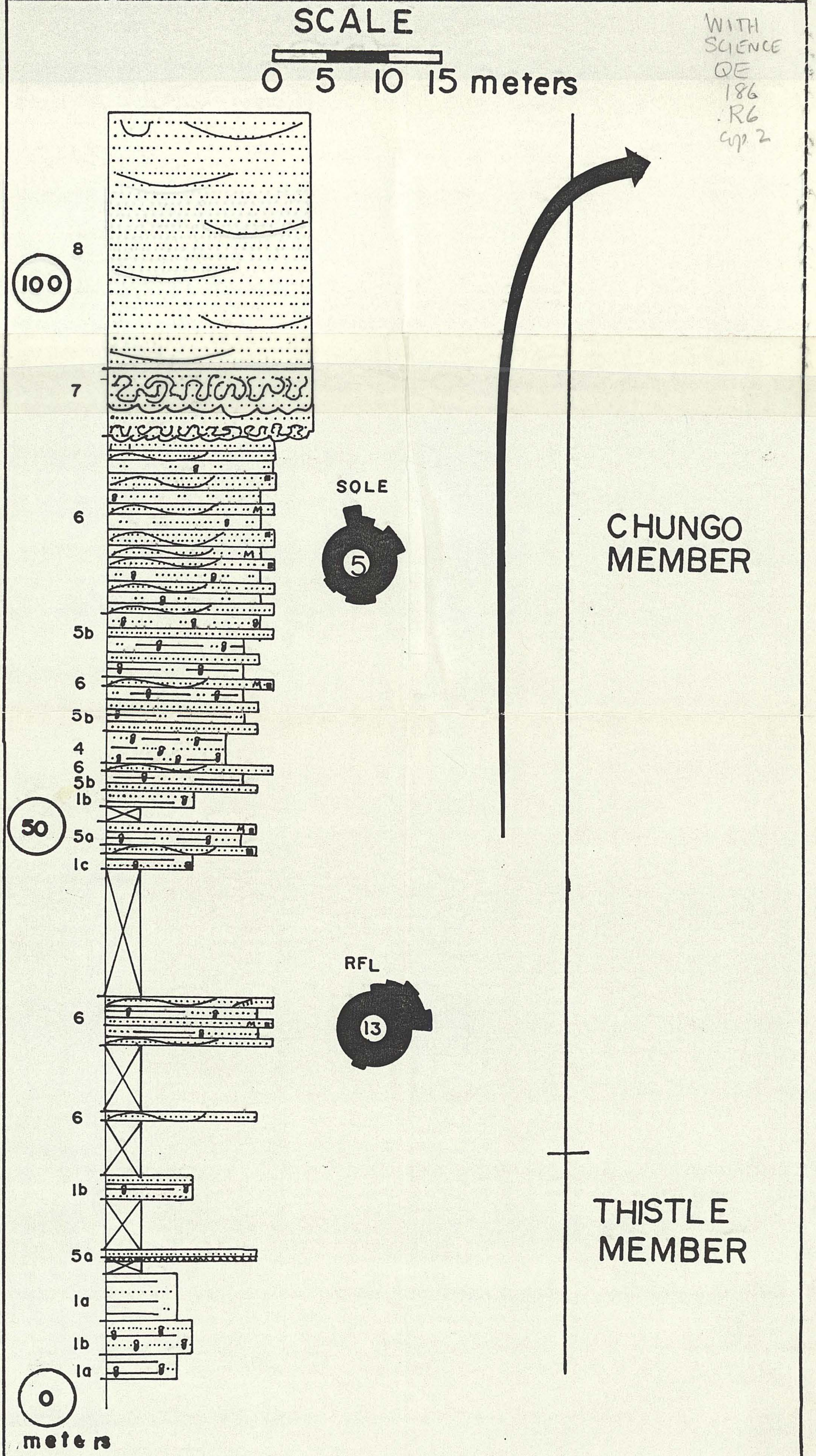
BARRIER LAKE SECTION F-2



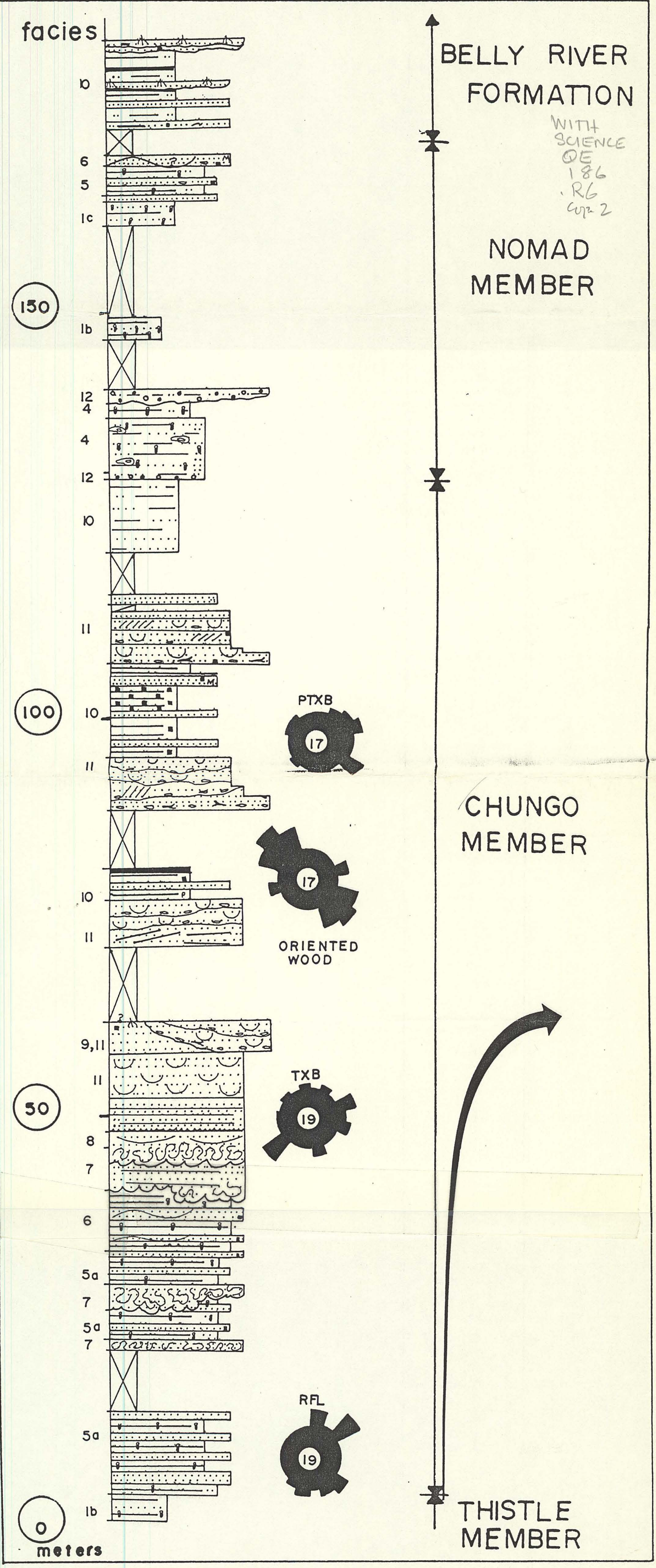
F-3 LUNDBRECK SECTION



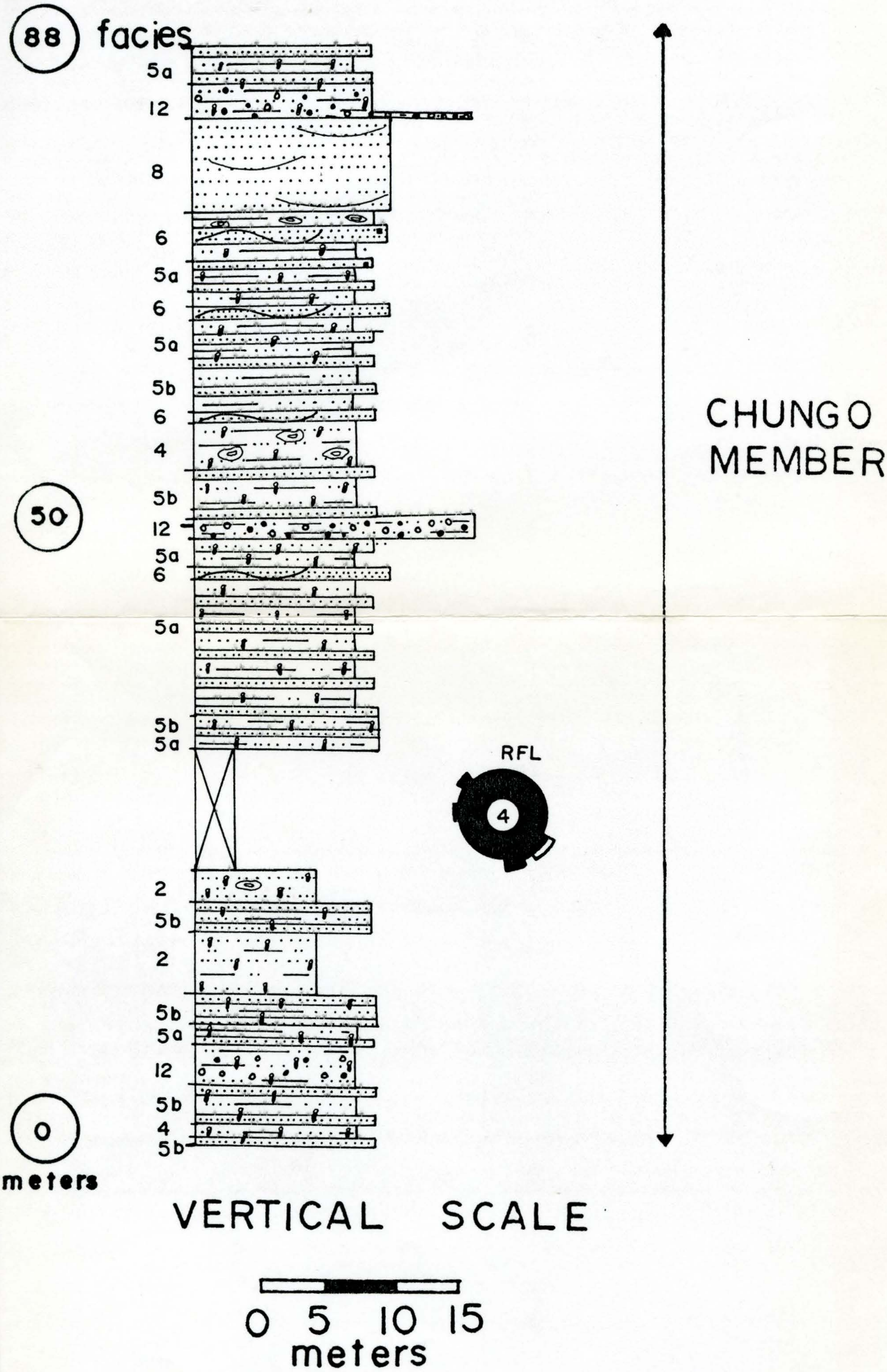
F-4 OLDMAN RIVER SECTION



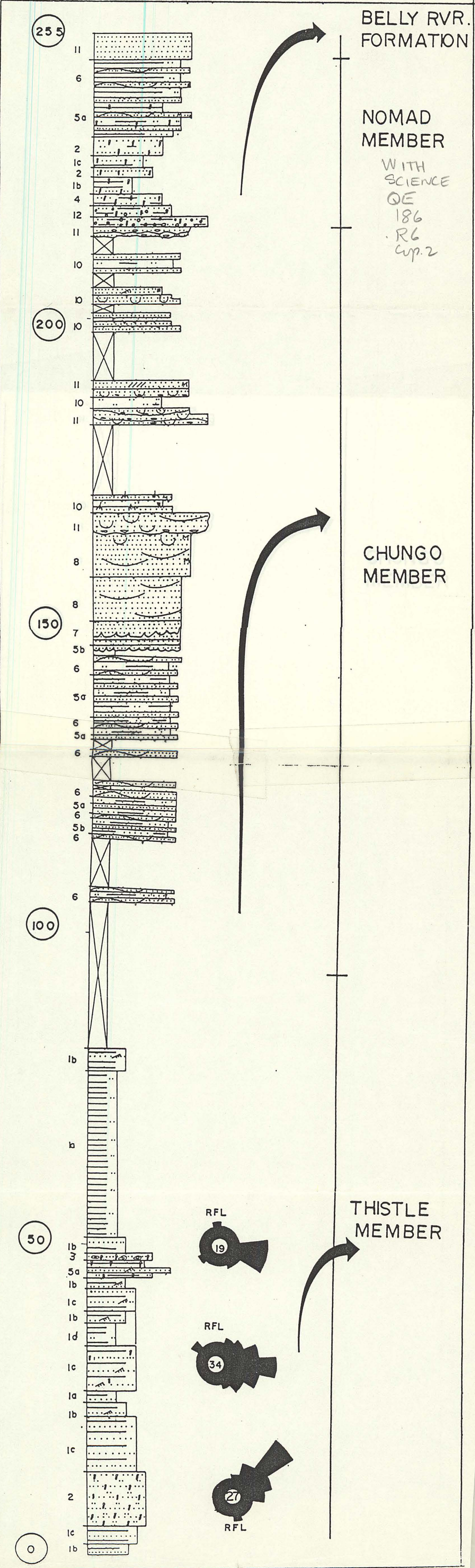
HIGHWOOD 2 SECTION F-5



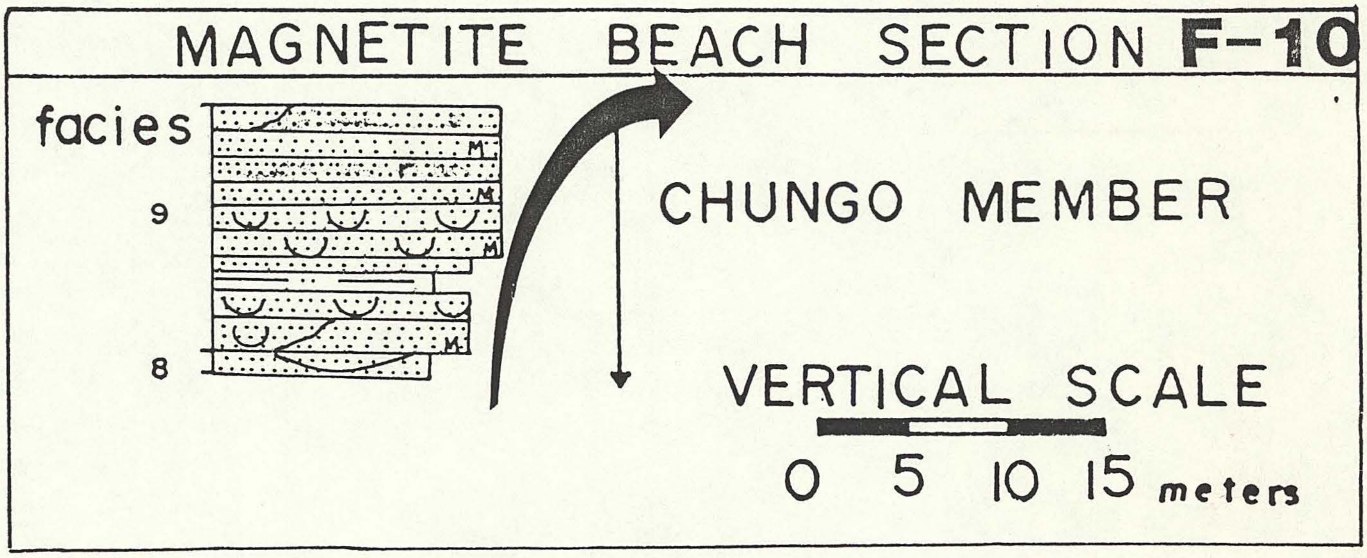
F-7 LONGVIEW SECTION

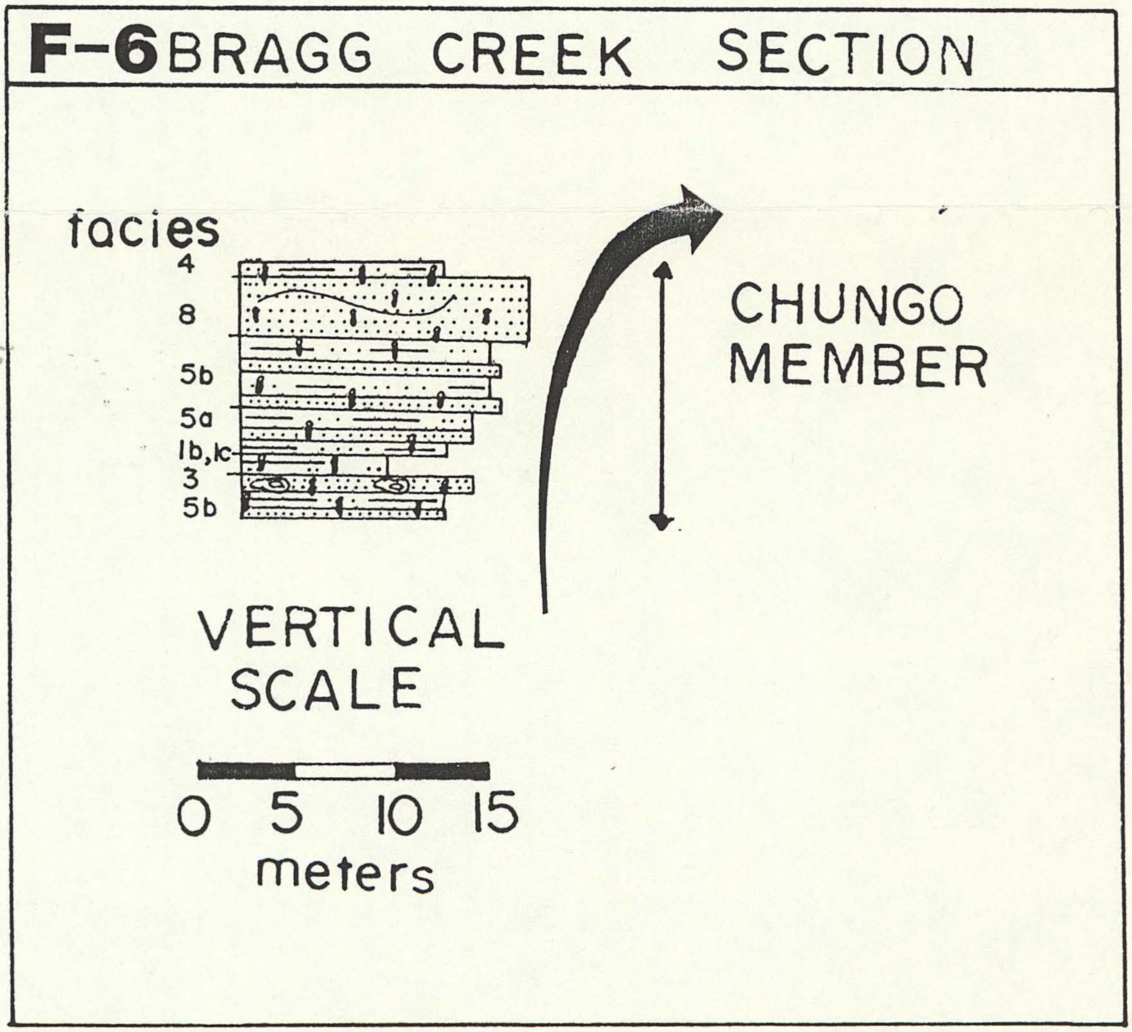


F-8 MAYCROFT SECTION

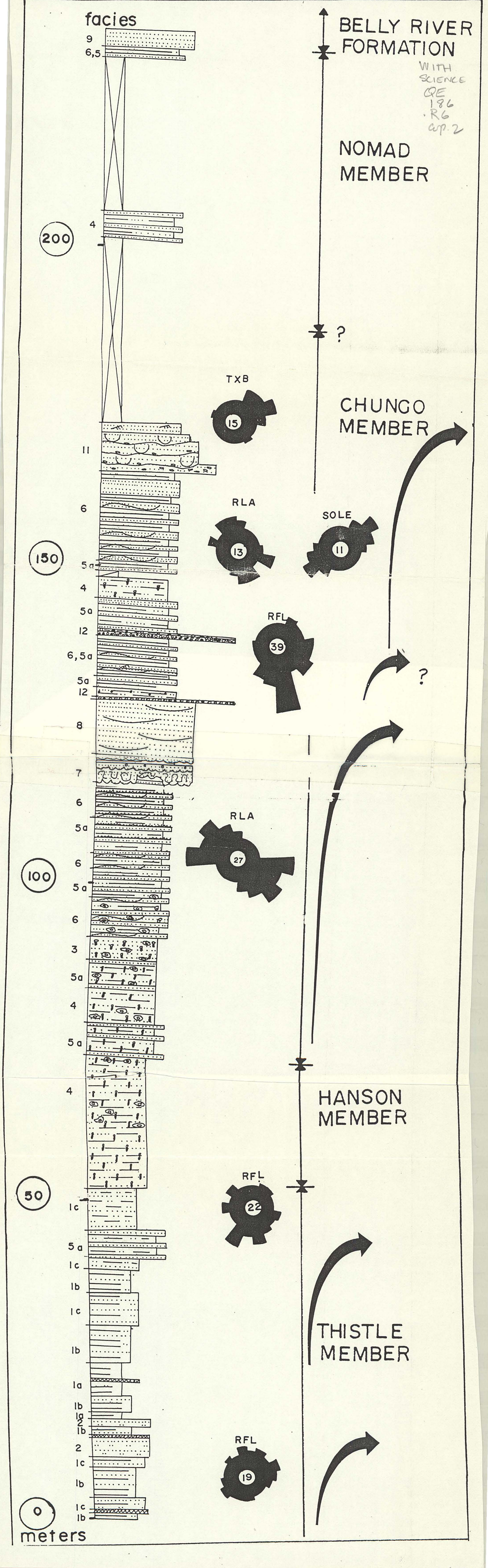


F-9 GHOST DAM SECTION

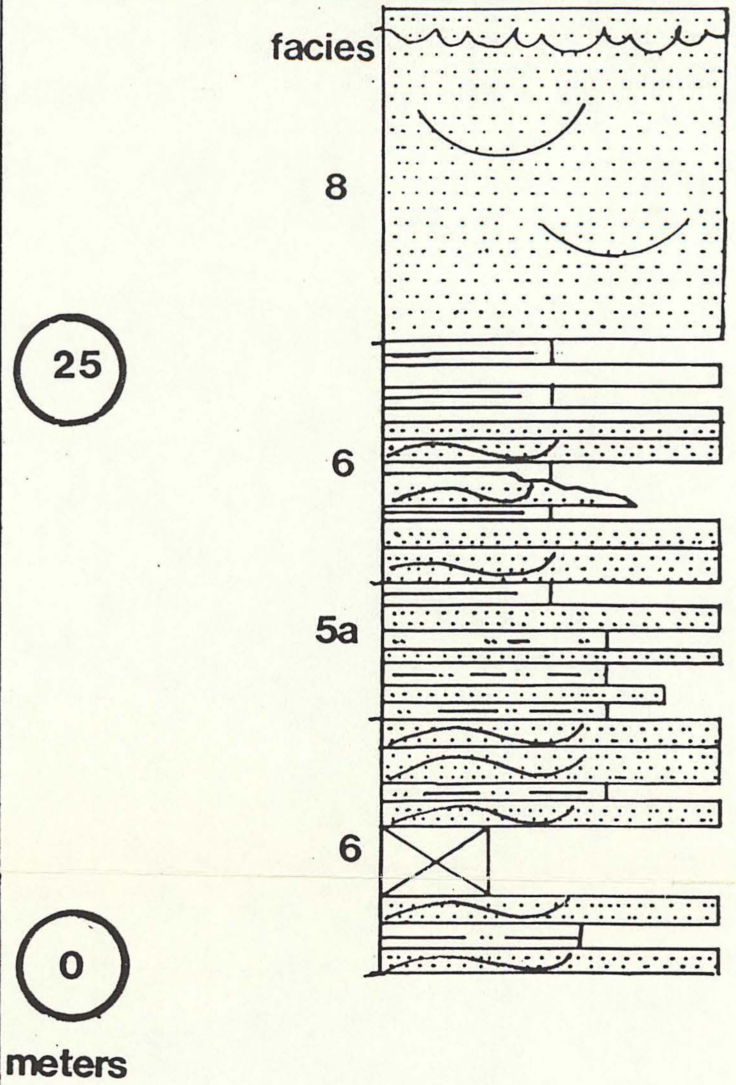

MAGNETITE BEACH SECTION F-10
facies
9
8
M
CHUNGO MEMBER
VERTICAL SCALE
0 5 10 15 meters


F-6 BRAGG CREEK SECTION
facies
4
8
5b
5a
1b,1c
3
5b
CHUNGO MEMBER
VERTICAL SCALE
0 5 10 15
meters

SHEEP RIVER SECTION F-11



COLEMAN F-12



FOLDOUT F-13
LUNDBRECK
MAYCROFT
OLDMAN RIVER
TRAP CREEK
HIGHWOOD TWO
SHEEP RIVER
LONGVIEW
BRAGG CREEK
BARRIER LAKE
GHOST DAM
BELLY RIVER FM.
BELLY RIVER FM.
NOMAD
NOMAD
NOMAD
CHUNGO
CHUNGO
CHUNGO
HANSON
HANSON
THISTLE
THISTLE
THISTLE
RFL
SOLE
RLA
TXB
PL
SOUTH
North
STRATIGRAPHIC LOCATION OF PALEOCURRENT DATA WAPIABI-BELLY RIVER FMS. SOUTHWESTERN ALBERTA
VERTICAL SCALE 1cm. = 20 m
NO HORIZONTAL SCALE IMPLIED
LEGEND
Facies 12
Facies 10,11
Facies 7,8,9
Facies 5,6
Facies 1,2,3,4
RFL - ripple foreset laminae
SOLE - solemarks
RLA - ripple long axis

APPENDIX 5

Microfossils Identifications/Interpretations

Micropaleontology report on 21 outcrop samples from the Upper Cretaceous Wapiabi Formation of the southern Alberta Foothills, collected by Mr. Lorne Rosenthal and submitted by Dr. Roger Walker of McMaster University in June, 1982 (NTS 82-G/9, 82-J/8, 82-O/2).

The relevant parts of any manuscript prepared for publication that paraphase or quote from this report should be referred to the Paleontology Subdivision, Calgary, for possible revision.

Introduction

Mr. Rosenthal, graduate student at McMaster University, processed and picked the samples for microfauna, with the slides being delivered to the I.S.P.G. by Dr. Walker, Professor of Geology at McMaster, who at the time was on sabbatical leave at Amoco Canada Petroleum Company, Limited, Calgary. The samples were collected from various members of the Wapiabi Formation at the Ghost Dam, Trap Creek and Lundbreck localities. The microfaunal content is listed individually for each sample. The microfossils listed are arenaceous foraminifera unless otherwise noted. If a taxon is represented by less than three specimens, the number observed is given. General comments on the microfaunal recoveries, associations, age and environmental interpretations are offered.

Field No. and Stratigraphy	Locality and Microfossils
GD-9 Dowling Mbr 28 m above base of section and 12m below top of mbr.	Ghost Dam, Sheet 82-0/2 Sec. 13, Tp. 26, Rge. 6 W 5th Mer. *Saccammina* sp. - one *Ammodiscus* sp. - one fragment *Reophax contricta* (Reuss) - one *R.* sp. cf *R. minuta* Tappan - one *R. pepperensis* Loeblich - two *R.* sp - one *Haplophragmoides crickmayi* Stelck and Wall *H.* sp 2 of Wall 1967 - one *H.* sp. *Evolutinella* spp. *Trochammina* sp. - one *Dorothia smokyensis* Wall
GD-13, Thistle Mbr 46 m above base of section and 6m above base of mbr	same locality as GD-9 *Reophax constricta* (Reuss) - one *R. minuta* Tappan - one *R. pepperensis* Loeblich - one *R.* sp., poorly preserved - one *Haplophragmoides crickmayi* Stelck and Wall - two *H.* sp. *Evolutinella* spp. *Ammobaculites* spp., poorly preserved - two *Trochammina* sp. ex gr. *T. wetteri* Stelck and Wall - one *T.* sp. 2 of Wall 1967 - one *Dorthia smokyensis* Wall
GD-19, Thistle Mbr 80 m above base of section and 40 m above base of member	same locality as GD-9 *Ammodiscus* sp., small - two *Reophax pepperensis* Loeblich - one *R.* spp., incomplete - two *Haplophragmoides* spp. *Evolutinella* spp. *Pseudobolivina rollaensis* (Stelck and Wall) - one *Trochammina wetteri* Stelck and Wall - two *T.* sp. 2 of Wall 1967 *Dorothia smokyensis* Wall

Field No. and Stratigraphy	Locality and Microfossils
GD-26, Thistle Mbr 101 m above base of section and 61 m above base of member	same locality as GD-9 no recovery, entities in slides are not microfossils
GD-31, Thistle Mbr 160 m above base of section and 120 m above base of member	same locality as GD-9 *Reophax minuta* Tappan - one *R.* sp., incomplete - one *Haplophragmoides* sp., poorly preserved *Evolutinella* sp., poorly preserved *Pseudobolivina rollaensis* (Stelck and Wall) - two *Spiroplectammina* sp., small, poorly preserved - one *Trochammina* sp., small, poorly preserved - two
GD-38, Hanson Mbr 254m above base of section and 79 m above base of member	same locality as GD-9 *Reophax* spp. *Evolutinella* sp. *Pseudobolivin rollaensis* (Stelck and Wall) - one *Trochammina* spp., poorly preserved - two *Verneuilinoides bearpawensis* (Wickenden)
GD-40, Hanson Mbr 300m above base of section and 125m above base of member	same locality as GD-9 *Haplophragmoides* sp. *Trochammina* sp., same as in Haywick spl. BR 1-9 (Wall, 1982) *Verneuilinoides bearpawensis* (Wickenden)
GD-42, Nomad Mbr 318m above base of section	same locality as GD-9 *Saccammina* sp. - two *Haplophragmoides* sp. *Trochammina* sp.- same as in Haywick spl. BR 1-9 - dominant *Verneuilinoides bearpawensis* (Wickenden)

Field No. and Stratigraphy	Locality and Microfossils
LTC-2, Thistle Mbr base of section and 240 below Hanson contact	Trap Creek, Sheet 82-J/8 Sec. 36, Tp. 17, Rge 4 W 5 Mer. Foraminifera (areaceous): *Haplophragmoides* spp. *Ammobaculites* sp. *Spiroplectammina* sp. cf. *S. semi-complanata* (Carsey) - one *Pseudobolivina rollaensis* (Stelck and Wall) - one *Dorothia smokyensis* Wall Foraminifera (calcareous): *Cibicides?* sp. cf. *C?* sp. of Wall 1967 *Anomalinoides* spp. - two *Anomalina?* spp. - three species with total of four specimens Echinoidea? Debris (spines?) - appears to be same material as in Haywick sample BR 1A-7B (not reported in Wall 1982).
LTC-4, Thistle Mbr 38m above base of section	same locality as LTC-2 *Haplophragmoides* sp. - one
LTC-5, Thistle Mbr 50m above base of section	same locality as LTC-2 one questionable small arenaceous foraminifer
LTC-10, Thistle Mbr 90 m above base of section	same locality as LTC-2 two poorly preserved arenaceous foraminifera, probably *Haplophragmoides*
LTC-12, Thistle Mbr 120m above base of section	same locality as LTC-2 one poorly preserved arenaceous foraminifera, probably *Haplophragmoides*

Field No. and Stratigraphy	Locality and Microfossils
LTC-16, Thistle Mbr 162m above base of section	same locality as LTC-2 no recovery, entities in slides are not microfossils
LTC-17, Thistle Mbr 157m above base of section	same locality as LTC-2 no microfossils recognized; entities in slides appear to be largely modern insect debris.
LTC-20, Thistle Mbr 190m above base of section	same locality as LTC-2 entities in slides are modern megaspores belonging to genus *Selaginella* (identified by Dr. A.R. Sweet, I.S.P.G.)
LTC-43, Nomad Mbr near top	same locality as LTC-2 Foraminifera (arenaceous) *Reophax?* sp., incomplete - one *Haplophragmoides* sp. - 10 specimens Foraminifera (calcareous) *Dentalina* sp. - one
L-1, Thistle Mbr base of section	Crowsnest River near Lundbreck Falls, Sheet 82-G/9 Sec. 27, Tp.7, Rge 2 W 5th Mer. *Reophax* sp. - one *Haplophragmoides* spp. - three specimens *Ammobaculites* sp. - one *Trochammina* sp. - one
L-7, Thistle Mbr top shale be just below base of main sand of Chungo Mbr	same locality as L-1 Foraminifera (arenaceous) *Haplophragmoides* sp. - six specimens *Ammobaculites* sp. - one *Trochammina?* sp. - one Megaspores *Erlansonisporites?* sp. (identified by Dr. A.R. Sweet, I.S.P.G., who states these spores are likely *in situ*)

L-32, Nomad Mbr — same locality as L-1

no recovery, entities in slides are not microfossils

Comments

The microfossil recoveries from these samples vary from mediocre to poor, but this is not unexpected in view of previous investigations of the faunal content of the upper part of the Wapiabi Formation in the Foothills Belt. The species identified for this report are mostly long-ranging and unsuitable for accurate dating. However, the age span of the interval under study, from the upper part of the Dowling Member to the Nomad Member, is known on the basis of megafossils to be about mid-Santonian to mid-Campanian. The general composition of these assemblages matches fairly well that shown by those obtained from the same stratigraphic units elsewhere in the Foothills. Specifically, it has been observed previously that <u>Haplophragmoides crickmayi</u> is associated with the upper Dowling and lower Thistle, and that <u>Verneuilinoides bearpawensis</u> is a common component of the Hanson Member, as demonstrated in the Ghost Dam section.

Only a very generalized interpretation of the depositional environments of these assemblages seems possible. All seem to have lived in the shelf zone and probably not beyond the inner shelf, in maximum water depths of 50 to 75 metres. In paleoecological studies, it is generally assumed that those assemblages with the greatest diversity of foraminifera likely represent environments more distal of the shoreline, as far seaward as the upper bathyal zone. On this basis, the assemblage in sample LTC-2 from the Thistle Member at Trap Creek, with calcareous as well as arenaceous species, would suggest greater water depth than the others. Assemblages from samples GD-9, GD-13, and GD-19 at Ghost Dam are moderately diverse but lack any calcareous components. If the absence of calcareous forms is not due to post-depositional factors such as weathering or leaching, then these assemblages are probably indicative of a more proximal position than the one in sample LTC-2 at Trap Creek.

The interpretation of the environment for the assemblage from sample LTC-43 in the Nomad Member at Trap Creek is difficult as the presence of only one calcareous foraminifer in an otherwise poor arenaceous fauna may or may not be significant. This microfauna is likely of quite shallow water origin. The probable presence of in situ megaspores along with a weak arenaceous foraminiferal fauna in sample L-7, just below the base of the Chungo Member at Lundbreck, may indicate a shallow, marginal, possibly brackish, marine environment. The absence or extreme scarcity of formaminifera in most of the Thistle Member at Trap Creek may be due to unfavorable bottom conditions created by the rapidity of deposition of this sequence of closely interbedded shales and sandstones or siltstones. My experience has been that this typical sequence in most of the Thistle Member is usually devoid of microfossils, but this could be caused in part by the dilution effect of the coarser clastics in the residues of the processed material.

References

Wall, J.H.

1967: Cretaceous foraminifera of the Rocky Mountain Foothills, Alberta; Research Council of Alberta, Bulletin 20, 185p.

1982: Micropaleontology report on 12 outcrop samples from the Upper Cretaceous of the Bow River valley, southern Alberta Foothills, collected by Mr. D. Haywick in 1981 and submitted by Dr. R. Walker of McMaster University in April, 1982 (NTS82-0/29; Geological Survey of Canada, Internal Service Report No. 2-JHW-1982.

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