SEDIMENTATION OF THE WAPIABI-BELLY RIVER TRANSITION (UPPER CRETACEOUS) AT LUNDBRECK FALLS, ALBERTA

SEDIMENTATION OF THE WAPIABI-BELLY RIVER TRANSITION (UPPER CRETACEOUS) AT LUNDBRECK FALLS, ALBERTA

By

ANDREW BULLOCK

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AUTHOR: Andrew Bullock

SUPERVISOR: Dr. R.G. Walker

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ABSTRACT

An outcrop of the transition from the Wapiabi Formation to the Belly River Formation was studied in detail at Lundbreck Falls, Alberta. The observed vertical succession of sediments is as follows: 1) interbedded dark shales and Bouma B, BC and C type turbidites; 2) hummocky cross-stratified sandstones and bioturbated silts; 3) swaley cross-stratified sandstones; 4) parallel laminated sandstones; 5) mudstones interbedded with trough cross-stratified sandstone. The turbidites and hummocky cross-stratified sandstones are storm-generated density current deposits. The swaley cross-stratified sandstones have formed below parallel laminated beach deposits and above storm deposits. The section is capped by fluvial deposits containing evidence of subaerial exposure.

Paleoflow directions in the lower portion of the section indicate that the regional paleoslope dipped northward. Density currents may have flowed down a topographically significant north-south trending trough. Net sediment transport in the shallow marine portion of the section was towards the east north-east.

Petrographic studies indicate that the sandstones are similar to the "barren" basal Belly River sandstones of the Burmis area, studied by Mellon (1961).

Another section consisting of continental clastics of the Blairmore Group was studied at Daisy Creek, Alberta. The lower part of the section contains interbedded grey mudstone and cross-stratified sandstone. These are erosively overlain by a 25 m thick, cross-stratified sandstone which caps the section. The sediments have been interpreted in terms of a meandering fluvial system.

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CHAPTER 1

INTRODUCTION

OBJECTIVES

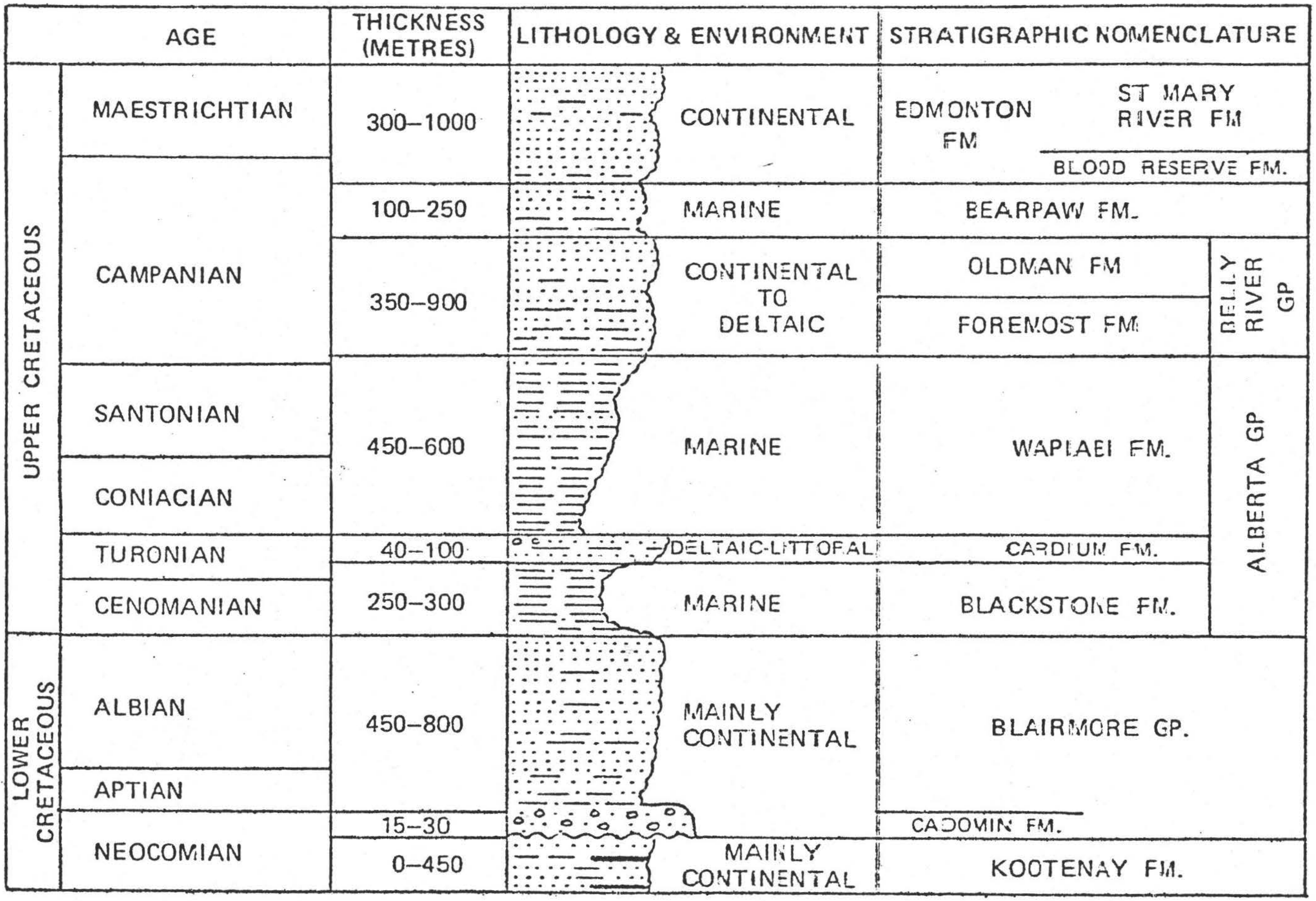
Wapiabi-Belly River Transition

Similarities between the Wapiabi-Belly River transition, subject of this study, and the Fernie-Kootenay transition have been noted by Hunter (1980). The Fernie-Kootenay transition, previously interpreted as deltaic in origin (Jansa, 1972), was reinterpreted in terms of storm-dominated shallow marine deposits characterized by hummocky cross-stratification, which are overlain by beach deposits (Hamblin and Walker, 1979). The results of the above study then prompted a re-evaluation of the Wapiabi-Belly River transition at Highwood River and Trap Creek. The transition was thought to represent a prograding deltaic environment (Glaister and Nelson, 1975). At these outcrops Hunter (1980) and Walker *et al.* (1981) have observed hummocky cross-stratified sandstones, turbidites, northerly flow indicators and a marine tongue. Another outcrop of the Wapiabi-Belly River transition at Lundbreck Falls has been interpreted by Lerand and Oliver (1975,1980) as representing a transitional regressive sequence formed by prograding delta front environments. The primary objective of this study is to remeasure the Lundbreck Falls section with the possibility of northerly paleoflow indicators, hummocky cross-stratified sandstones, and a marine tongue in mind.

The Upper Cretaceous (Campanian) Belly River Formation of Alberta consists of a sequence of sandstones, siltstones and varicolored shales (Figure 1-1). The sediments at the base were deposited in a marine environment while the remaining sediments are fluvial in origin. The formation is thickest in the Alberta Foothills (900 m) and thins to the south and east where it interfingers with shales of the underlying Wapiabi Formation. The Wapiabi Formation (450m-600m) consists of dark commonly bioturbated shales and interbedded thin, fine-grained sandstones with sharp bases and tops. Stott (1963) interpreted it as having been deposited in a quiet and relatively deep marine environment.

The Belly River is overlain by the Bearpaw Formation (100m-250m) which consists of marine sediments similar to those of the Wapiabi Formation. Under the Plains and in the Southern Foothills the Bearpaw separates the Belly River and continental sediments of the St. Mary's River and Edmonton Formations. The Bearpaw does not extend north into the central Foothills where the Belly River and Edmonton Formations are inseparable.

FIGURE 1-1: Cretaceous stratigraphic nomenclature of southwestern Alberta, from Shawa (1975).



AGE		THICKNESS (METRES)	LITHOLOGY & ENVIRONMENT	STRATIGRAPHIC NOMENCLATURE	
UPPER CRETACEOUS	MAESTRICHTIAN	300–1000	CONTINENTAL	EDMONTON FM ST MARY RIVER FM BLOOD RESERVE FM.	
	CAMPANIAN	100–250	MARINE	BEARPAW FM.	
		350–900	CONTINENTAL TO DELTAIC	OLDMAN FM	BELLY RIVER GP
				FOREMOST FM	
	SANTONIAN	450–600	MARINE	WAPIABI FM.	ALBERTA GP
	CONIACIAN				
	TURONIAN	40–100	DELTAIC-LITTORAL	CARDIUM FM.	
	CENOMANIAN	250–300	MARINE	BLACKSTONE FM.	
LOWER CRETACEOUS	ALBIAN	450–800	MAINLY CONTINENTAL	BLAIRMORE GP.	
	APTIAN				
	NEOCOMIAN	15–30		CADOMIN FM.	
		0–450	MAINLY CONTINENTAL	KOOTENAY FM.	

The transition from Wapiabi shale to Belly River sandstone is usually called the Transition Zone of the Wapiabi Formation. The upper part of the Wapiabi is composed of interbedded dark grey, silty shale and grey calcareous, fine-grained laminated sandstone beds a few cm thick to tens of cm thick. The proportion and thickness of sandstone beds increases upward until they coalesce into a single sandstone unit about 30±10 metres thick, which is called the basal sandstone of the Belly River Formation.

Blairmore Group

As a contrast to the Lundbreck Falls section, a nearby outcrop of continental clastics belonging to the Blairmore Group (Lower Cretaceous) was briefly examined. In the Foothills the base of the Blairmore Group unconformably overlies the Kootenay Formation (Figure 1-1). Marine shales of the Blackstone Formation overlie the Blairmore Group.

PREVIOUS WORK

Belly River Formation

The Belly River Formation of Alberta was first described by Dawson (1883) who mapped the Cretaceous sediments along the Belly River in southeastern Alberta. In a later report, Dawson (1884) described the Formation at several localities (Milk River, St. Mary, Upper Belly and Waterton Rivers). Dawson (1884) divided the Formation into an upper pale portion and a lower yellowish portion. The lower portion was thought to be marine and the upper portion dominantly freshwater, based mainly on faunal assemblages. Tyrrell (1886) mapped the Belly River in central Alberta where he noted that the yellow sandstone beds of the lower portion had become white and clayey. Dowling (1917) concluded that the pale beds (Upper Belly River) represent freshwater deposits and renamed the yellow beds "Foremost beds" including dark shales in the Foremost beds. Slipper and Hunter (1931) divided the Foremost into Lower, Middle and Upper units. The lower unit was interpreted as beach sands, the mid-upper as lagoonal deposits and the pale beds as deltaic deposits. The Foremost was believed to consist of sediments derived from the southwest and deposited during a regression of the Lea Park sea. Russel and Landes (1940) renamed the pale beds "Oldman" and raised Oldman and Foremost to Formational status.

Crockford (1949) examined these formations in southern Alberta and interpreted the Oldman as continental deposits and the Foremost as freshwater in origin. Shaw and Harding (1949) subdivided the Belly River in east-central Alberta into 10 members through use of electric-logs, core data and microfauna. The depositional environments of the members alternates between continental-marine (deltaic) and marine (neritic). None of the marine (neritic) members extends west of longitude 113°.

Lerbekmo (1963) studied the petrology of the Belly River Formation at Drywood River in the southern Alberta Foothills. He determined that the source region lay to the south and west in the northwestern States and southern British Columbia. The petrology, lithology and fauna, showed the deposition site to have been a low-lying coastal plain distant from the average shoreline, but occasionally inundated by marine waters.

A section of lower Belly River sediments at Trap Creek in the Foothills region has been interpreted by Nelson and Glaister (1975), Glaister and Nelson (1978) as prodelta, distributary mouth bar and delta plain deposits. The Belly River outcrop near Lundbreck Falls (topic of this thesis) has been studied by Lerand and Oliver (1975,1980) and interpreted in terms of a prograding delta.

The Oldman and Foremost are exposed 52 km east of Lethbridge along Chin Coulee and have been studied by Shawa and Lee (1975). The Foremost was interpreted as freshwater in origin and the Oldman as large fluvial channel deposits. The Foremost and Oldman have been examined by Ogunyomi and Hills (1977) in the Milk River area of southern Alberta. Eighteen stratigraphic sections were measured and extensive micropaleontological studies were done. The Foremost was considered to contain depositional cycles. A complete cycle would exhibit the following sequence of environments from the base upward: 1) offshore transition; 2) barrier island; 3) lagoon, saltmarsh; 4) freshwater marsh (Ogunyomi and Hills, 1977). The Oldman was considered to be fluvial in origin.

Recently (Hunter, 1980) the Wapiabi-Belly River transition at Highwood River in the southern Foothills was examined. The transition contains deep marine, storm-generated density flow deposits interbedded with shales in the upper Wapiabi. These are overlain by shallow marine sandstones which are in turn overlain by fluvial deposits. The sequence ends in marine sandstones and shales which are above the fluvial deposits. This marine tongue is unique, in that no marine tongues have been reported from the Foremost of the southern Alberta Foothills.

Previous work indicates that the Belly River Formation in eastern Alberta consists of alternating marine and nonmarine units overlain by nonmarine, dominantly fluvial sediments. In central and western Alberta no marine alterations have been recorded. The basal Belly River sandstone has been interpreted as representing deltaic, barrier island and shallow marine environments.

STRATIGRAPHY

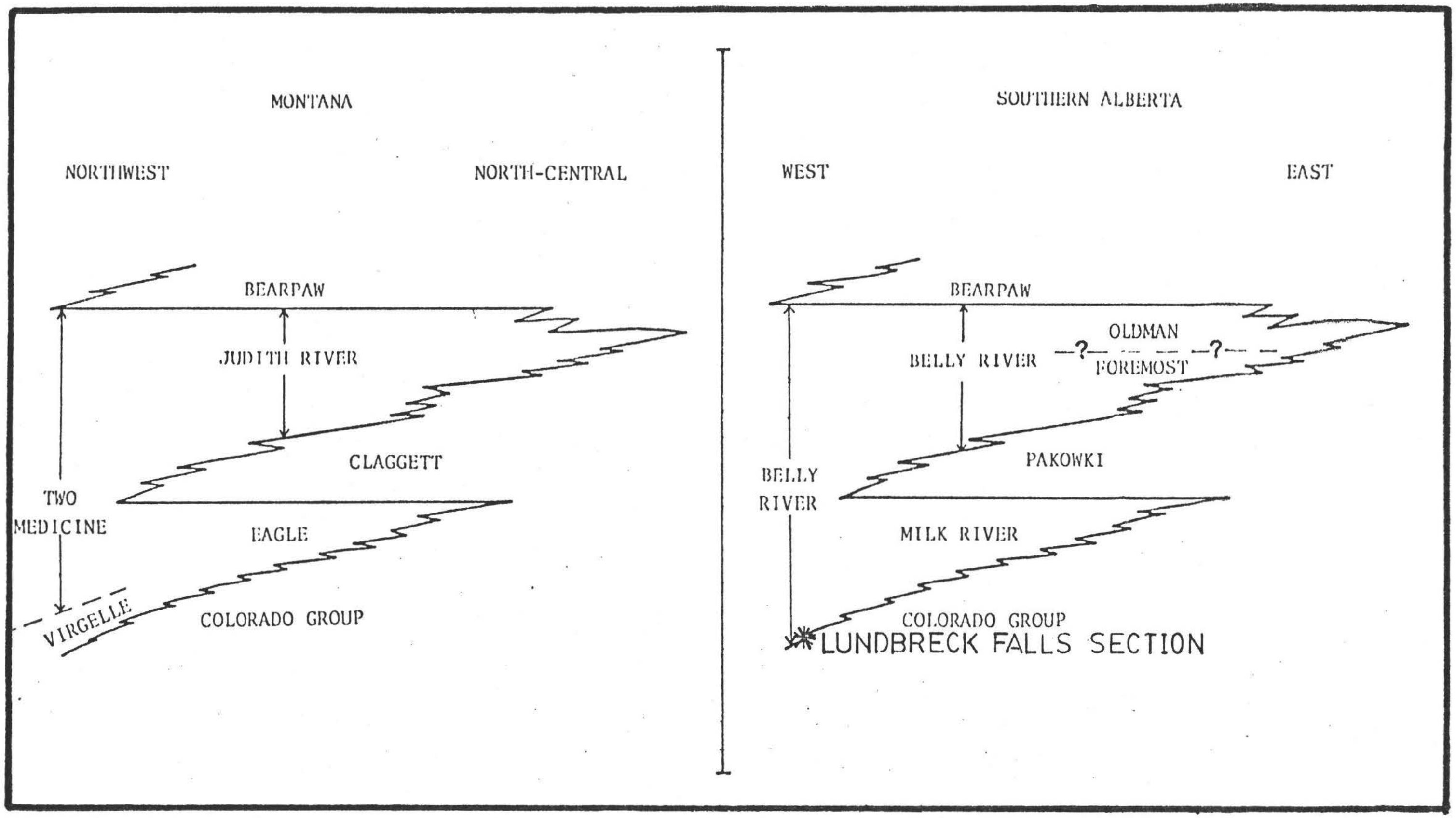
Belly River Formation

During Upper Cretaceous time a broad, shallow epeiric sea covered most of the western interior of North America and at times connected with the Arctic Ocean to the north and the Gulf of Mexico to the south. The sea was flanked to the west by the uplands of the central cordillera and to the east by the western flank of the Canadian Shield (William and Burk, 1966). Periodic uplift of the Cordillera was the dominant factor affecting the shoreline position during the Upper Cretaceous, worldwide sea level changes were of secondary importance. Erosion of the uplifted Cordillera supplied vast amounts of clastic sediments some of which were deposited in the epeiric sea.

The Belly River is thickest in the southern Alberta Foothills, the name "Belly River" refers to the interval between the Wapiabi shales and the Bearpaw shales. To the east, the Belly River of the Foothills interfingers with marine shales and the major marine tongues is called the Pakowski Formation. The sandstone below this tongue is called the Milk River Formation. Above the Pakowski Formation in central and southern Alberta exist numerous alterations of marine and non-marine sediments formed by transgressions and regressions produced by tectonism during the early and mid-Campanian. The sediments deposited during these fluctuations make up the Foremost and have individually been given member status. A period of regression then occurred which produced the fluvial sediments of the upper Belly River (Oldman). The marine shales of the overlying Bearpaw Formation were deposited during a short transgressive phase. Subsequent uplift and erosion in the Cordillera then produced the continental clastics of the Edmonton Formation in central and southern Alberta, and the equivalent St. Mary River Formation in the southwestern Alberta Foothills.

There has been considerable controversy over the nomenclature for the stratigraphic interval between the top of the Pakowski, Clagget, Lea Park or Wapiabi Formations and the bottom of the Bearpaw Formation in Alberta, Saskatchewan and Montana. This interval has been given the names "Belly River", in western and east-central Alberta, "Oldman and Foremost" in southeastern Alberta, "Judith River" in southwestern Saskatchewan and northwestern Montana (Figure 1-2). McLean (1971,1977) has reviewed all previous literature on the lithostratigraphic nomenclature and suggested the retention of "Judith River" and the elimination of the Formational names "Foremost", "Oldman" and "Belly River". He suggests that the name "Belly River" be retained in the southwestern Alberta Foothills where it pertains to the interval between the Wapiabi Formation and the Bearpaw Formation. McLean (1977) reasons that the Oldman and Foremost cannot always be distinguished in eastern Alberta, and therefore should not have different names. He states that the distinction between Oldman and Foremost is not made in western Alberta since the marine members of the Foremost do not extend that far. However, Hunter (1980) has recognized a marine member of the Foremost in the southern Alberta Foothills. Studies by

FIGURE 1-2: Nomenclature of Belly River Formation in Montana and southern Alberta, from McLean (1977).


MONTANA
NORTHWEST
NORTH-CENTRAL
BEARPAW
JUDITH RIVER
CLAGGETT
TWO MEDICINE
EAGLE
VIRGELLE
COLORADO GROUP
SOUTHERN ALBERTA
WEST
EAST
BEARPAW
OLDMAN
BELLY RIVER
?
?
FOREMOST
PAKOWKI
BELLY RIVER
MILK RIVER
COLORADO GROUP
LUNDBRECK FALLS SECTION

Russell and Landes (1940) indicate that the Foremost and Oldman Formations are mappable units in the southern Alberta Plains. The two formations are distinguishable over most of Central Alberta (Oliver 1966). The Foremost and Oldman Formations can therefore be recognized in central, southern and southwestern Alberta. It seems illogical to abolish the current nomenclature merely because it is not applicable to parts of eastern Alberta.

Blairmore Group

The Lower Cretaceous Blairmore Group in the southern Alberta Foothills ranges from 450m to 800m in thickness and is composed of mainly continental clastics. Mellon and Wall (1963) divided the Blairmore Group of the Crowsnest Pass region into three formational units, the lower, middle and upper Blairmore Formations. The upper boundary of the group was revised to include the Crowsnest volcanic beds as a member of the "upper Blairmore" Formation and was placed at the contact with the overlying marine shale of the Alberta Group (Mellon, 1967). These formations are characterized by differences in lithology, sandstone composition and floral content, and can be traced along the strike of the southern Foothills to just north of the Bow River. Mellon (1967) proposed the formational names, "Gladstone", "Beaver Mines", and "Mill Creek" for the lower, middle and upper Blairmore Formations, respectively. The lithology, sandstone composition and fossil content of these formations is summarized in Table 1-1.

TABLE 1-1: Lithologic divisions of the type Blairmore group and adjacent strata in the Crowsnest Pass region, southwestern Alberta, from Mellon (1961).

Group	Formation	Member	Lithology	Sandstone Composition	Fossil Content
ALBERTA	BLACKSTONE	SUNKAY	dark grey marine siltstone, shale	quartzose, cherty	*Dunveganoceras* spp. *M. manitobensis*
BLAIRMORE	MILL CREEK[1]	CROWSNEST	tuff, agglomerate	feldspathic, tuffaceous	dicotyledonous ("upper Blairmore") flora
			nonmarine varicolored shale, grey sandstone	quartzose, cherty	
	BEAVER MINES[1]		nonmarine varicolored shale, green sandstone; igneous pebble conglomerate	feldspathic; abundant volcanic detritus and chlorite cement	non dicotyledonous ("lower Blairmore") flora; freshwater invertebrates
	GLADSTONE[1]	"calcareous" member	dark grey calc. shale, freshwater limestone		
			nonmarine varicolored shale, grey sandstone	quartzose, cherty, dolomitic	
		basal member	sandstone, conglomerate	quartzose, cherty	
	KOOTENAY		nonmarine dark grey shale, sandstone; coal	quartzose, cherty	non-dicotyledonous flora

LOCATION

The transition from the Wapiabi shales to the Belly River sandstones was studied at an outcrop in the Foothills District of southern Alberta. The section is exposed on the eastward dipping limb of a small anticline located in the valley of the Crowsnest River, 1 km downstream from Lundbreck Falls (Figure 1-3). The outcrop can be seen from Highway 3, 2 km west of the town of Lundbreck, Alberta. The section can be measured on both sides of the Crowsnest River but the most complete section has been obtained by measuring the lower 109 m on the southside of the river and the last 7 m on the northside of the river. The detailed section is 116 m thick but an additional 60 m is roughly described.

Sediments of the Blairmore Group are exposed on the side of a ridge overlooking the Daisy Creek valley situated on the west side of the Livingstone Range (Figure 1-4). The outcrop may be reached by following a cart track along the north side of Daisy Creek for 1.6 km then climbing eastward at the first clearing. The top sandstone unit forms a 15 m thick, prominent cliff and is at an elevation of 1800 m. The cart track joins the Kananaskis Forestry Trunk Road 50 m north of the bridge over Daisy Creek. The section is 113 m thick and contains two covered intervals near the top.

FIGURE 1-3: Location of outcrop containing Wapiabi-Belly River transition near Lundbreck Falls.

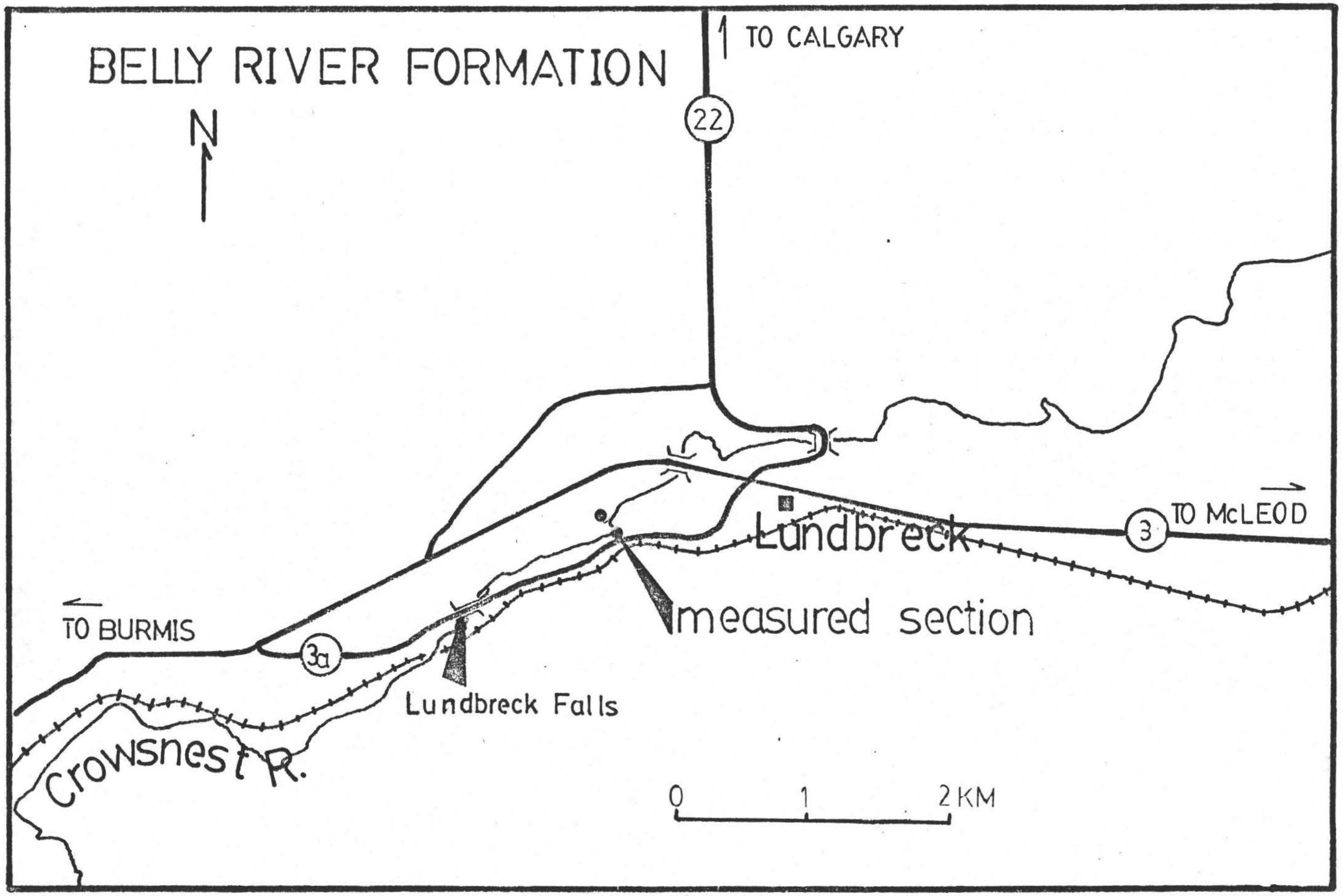
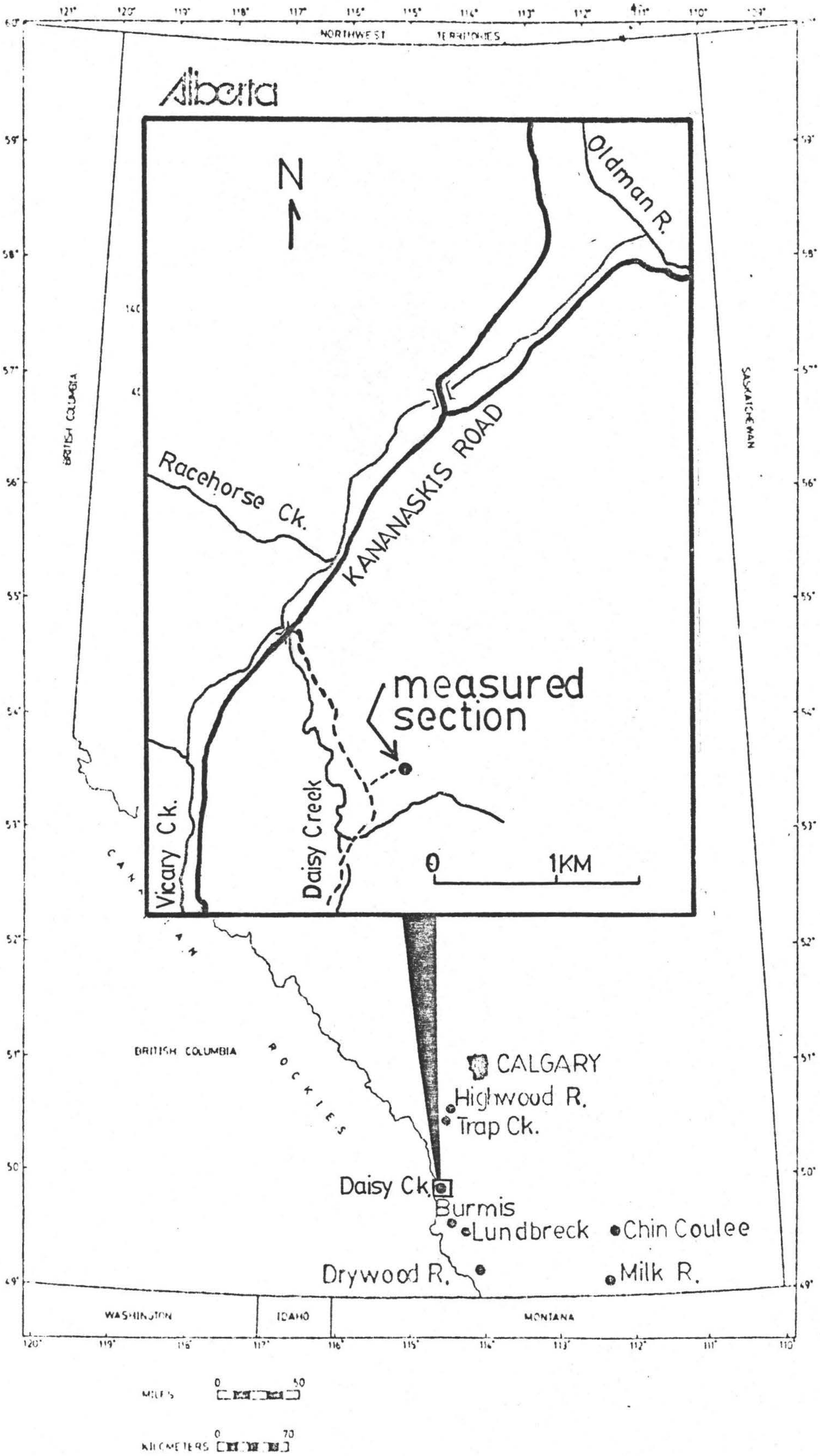

BELLY RIVER FORMATION
N
TO CALGARY
22
TO McLEOD
3
Lundbreck
measured section
TO BURMIS
3a
Lundbreck Falls
Crowsnest R.
0
1
2 KM

FIGURE 1-4: Map of southern Alberta showing location of Daisy Creek and town of Lundbreck. Also shown are the locations of outcrops mentioned, Burmis (Mellon, 1961); Drywood River (Lerbekmo, 1963); Trap Creek (Nelson and Glaister, 1975; 1980); Chin Coulee (Shawa and Lee, 1975); Milk River (Ogunyomi and Hills, 1977); and Highwood River (Hunter, 1980). Adapted from Duke (1980).


NORTHWEST TERRITORIES
Alberta
N
Oldman R.
KANANASKIS ROAD
Racehorse Ck.
measured section
Vicary Ck.
Daisy Creek
0
1KM
BRITISH COLUMBIA
SASKATCHEWAN
CANADIAN ROCKIES
CALGARY
Highwood R.
Trap Ck.
Daisy Ck.
Burmis
Lundbreck
Chin Coulee
Drywood R.
Milk R.
WASHINGTON
IDAHO
MONTANA
MILES 0 50
KILOMETERS 0 70

CHAPTER TWO

FACIES DESCRIPTIONS AND INTERPRETATIONS

The sediments of the Wapiabi-Belly River transition at Lundbreck Falls have been divided into 12 units or facies, which can be differentiated from each other on the basis of bedding, composition sedimentary structures and ichnofossils (Figure 2-1).

The outcrop of the Blairmore Group was divided into 19 units which were described in the field. Some of these units have similar composition, bedding, colour and sedimentary structures. As a result, similar units have been grouped into facies which are described in this chapter (Figure 2-2).

Wapiabi-Belly River Transition - Unit 1

The lowermost part of the outcrop consists of 47m of grey-black, fissile shales of the Wapiabi Formation. Lenticular, sharp based, ripple cross-laminated siltstones and very fine-grained sandstone beds occur at irregular intervals throughout the shales. The siltstone and sandstone beds average 2-3 cm in thickness (maximum 7 cm) and form resistant ribs which protrude from the shales. Multiple ripple cross-laminated sets are found in the thicker siltstones and sandstones, but most beds contain only a single set.

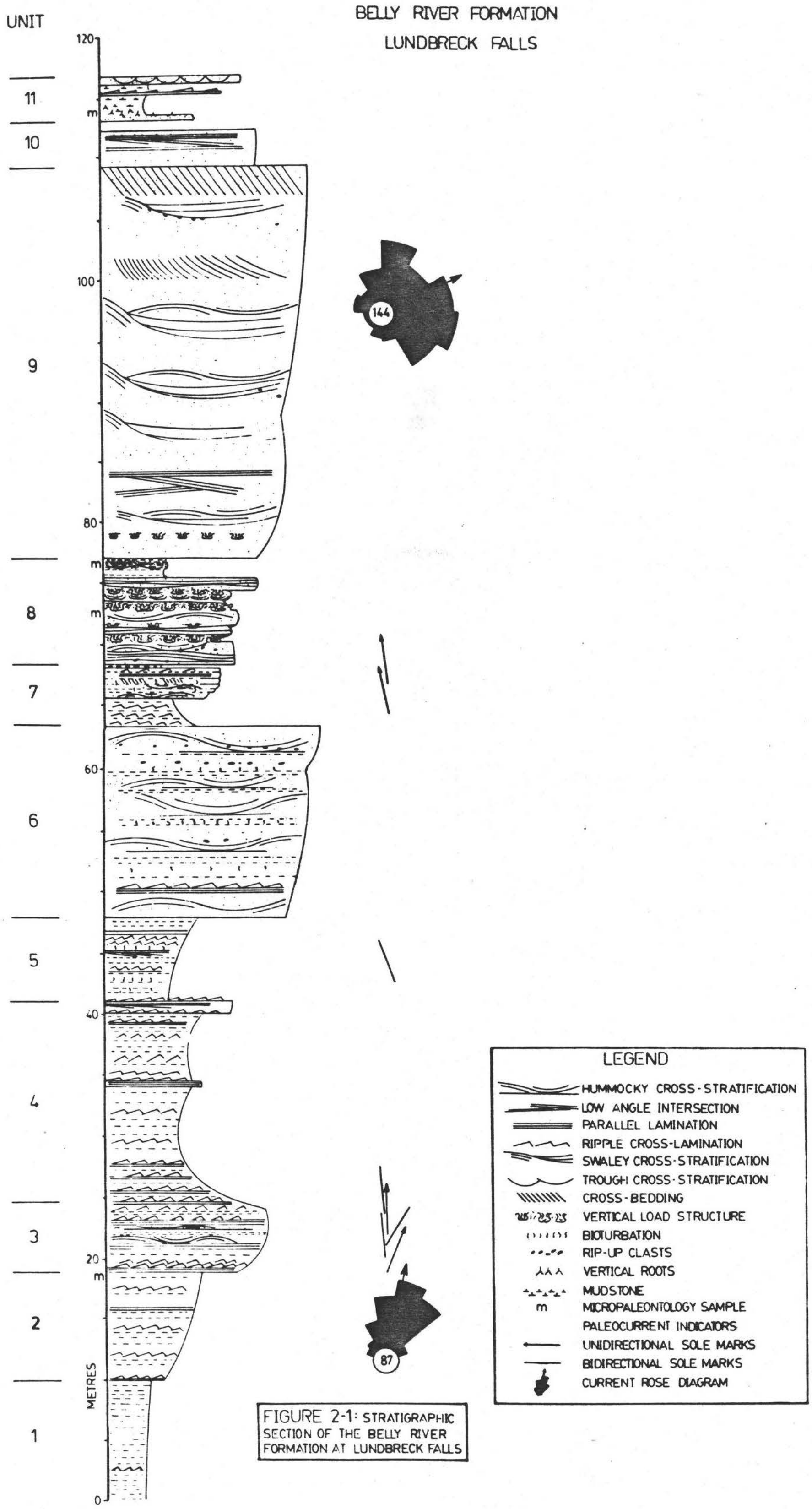


FIGURE 2-1: STRATIGRAPHIC SECTION OF THE BELLY RIVER FORMATION AT LUNDBRECK FALLS

A few of the sharp based sandstones contain parallel lamination at the base which grades upward into ripple cross-lamination or convolute lamination. The parallel laminated sandstones have thicknesses similar to those of the ripple cross-laminated beds, with parallel lamination generally occupying the lower three-quarters of the bed.

The siltstones and sandstones are separated by shale intervals that average 40 cm in thickness (range 15 cm to 10 m). The top 10 m of this unit is starved of siltstones or sandstones.

The thicker stratified beds have sharp bases with rare solemarks, consisting of poorly formed prod marks and fine tool marks. The thicker beds (4 cm-7 cm) also contain comminuted carbonaceous particles but one larger fragment 5 cmx10 cm in plan view is present.

Bioturbation structures are absent throughout the unit. Horizontal and vertical traces do not occur on any beds. The shales exhibit no signs of organic activity.

Five limestone beds 2 cm-6 cm thick occur within this unit. Two of them contain 3 cm thick shell hashes on their upper surfaces. The shell hashes are mainly composed of disarticulated bivalve shells.

INTERPRETATION

Marine shales of the Wapiabi Formation are thinly interbedded with sharp based sandstones and siltstones. The presence of sharp bases implies that the silts and sands were episodically deposited on top of the shales. Slight erosion of the underlying sediment during this depositional event will have produced the sole-marks.

Rapid currents are necessary to generate the parallel lamination. A gradual decrease in the current velocity accompanied by continued sediment supply is responsible for the upward transition from parallel lamination into ripple cross-lamination. The absence of medium scale cross-bedding implies that no subsequent reworking due to wave or tidal action took place.

The currents responsible for the observed sedimentary structures also actively transported sediments. These rapid sediment laden currents were probably turbidity currents. This statement will be further justified in greater detail after other units have been described.

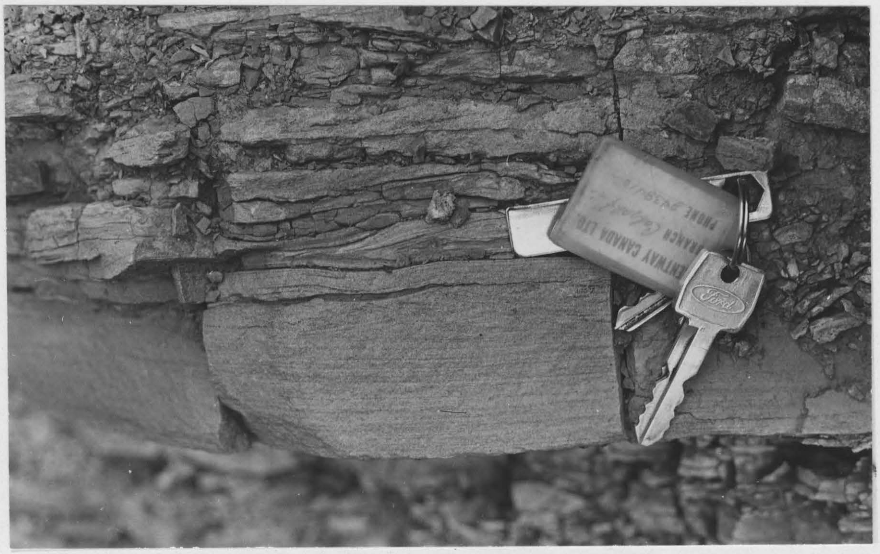
Unit 2

An abrupt increase in the sandstone/shale ratio defines the boundary between Unit 1 and Unit 2. The top 10 m of Unit 1 is starved of sandstones and siltstones whilst Unit 2 has a sandstone/shale ratio of approximately 1:5.

Unit 2 is characterized by interbedded fine-grained sandstones and fissile shales (Plate 2-1). The sandstones have variable thick-

PLATE 2-1: a) Sharp based Bouma BC and C sandstones interbedded with shale.

b) Parallel lamination grading upward into ripple cross-lamination in Bouma BC turbidite.



nesses and sedimentary structures. At the base of the unit , numerous 1-3 cm thick, sharp-based ripples are isolated along bedding planes. These sandstone ripples are separated by 4-6 cm intervals of unbioturbated shales. Neither the sandstones nor the shales exhibit evidence of bioturbation throughout the unit. The rippled sandstones contain carbonaceous particles which help to define individual laminae. Three metres above the base of the unit, isolated ripples begin to coalesce along bedding planes to form continuous sharp-based, ripple cross-laminated sandstone beds.

Thicker sandstone beds occur throughout the unit but are more abundant towards the top thus producing the thickening upward sequence observable in the field. These sandstone beds average 4 cm in thickness but range from 2 to 10 cm. The 4 cm thick beds are sharp based and contain either parallel lamination grading upward into ripple cross-lamination or are ripple cross-laminated throughout (Plate 2-1). The thicker beds (10 cm) contain 3-4 cm of parallel lamination grading upward into 4-6 cm of ripple cross-lamination. All sandstone beds have sharp bases but distinguishable solemarks are absent.

INTERPRETATION

The sedimentary structures of the sandstones in Unit 2 are nearly identical to those of Unit 1. The presence of sharp based sandstones interbedded with shales implies that the sands were episodically deposited over the shales. Rapid currents are necessary to generate the parallel lamination and a decrease in current velocity results in the upward transition from parallel lamination into ripple cross-lamination within a single, ungraded bed. The absence of medium scale cross-bedding in this unit implies that no subsequent reworking due to wave or tidal action occurred.

As in Unit 1, the most probable process responsible for the observed features of this facies is a turbidity current. The thickening upward trend can be produced by an advancing sediment lobe. In classical turbidites, a prograding wedge of turbidites can result in a thickening and coarsening-upward sequence (Mutti and Ghibaudo, 1972).

Unit 3

There is a relatively abrupt transition from Unit 2 into Unit 3 (Plate 2-2). Unit 3 consists of interbedded, very fine-grained sandstones and blocky shales. The sandstones average 8-12 cm thick with a maximum thickness of 15 cm. The sandstone / shale ratio has increased to approximately 2:1. There is a thickening upward trend throughout the lower 8 m of this 10 m thick unit. In the uppermost 2 m of the unit, there is a gradual decrease in bed thickness. The top of the unit is defined by the last thick laminated sandstone bed which contains the general horizontal trace fossil, Planolites.

The sandstone beds are all sharp based but five types may be recognized based on primary sedimentary structures. In order to clarify anticipated environmental interpretations, the terminology of Bouma (1962) will be adopted where applicable. Bouma terminology applies to four of the five bed types in Unit 3, namely:

1) Type A - massive bedded
2) Type B - parallel lamination throughout
3) Type BC - parallel lamination on the base which grades upward into ripple cross-lamination or climbing ripple cross-lamination
4) Type C - ripple cross-lamination throughout

The fifth bed type contains hummocky cross-stratification, which consists of laterally continuous gently curving laminae which are convex-downward and convex-upward (Harms et al., 1975).

Bed types B, BC and C are found in Units 1 and 2. In Unit 3 they are thicker and solemarks are more abundant. Tool marks are common on the bottoms of many sandstones and fluted burrows also are present. Paleoflow readings were attained using these features, and their significance will be discussed in more detail later.

Two hummocky cross-stratified beds occur 2 m above the bottom of the unit. These beds contain no solemarks of traces within the limited exposure. The H.C.S. beds are separated by 5 cm of grey blocky shale.

Bed type A, massive bedded, occurs only once throughout the unit. Comminuted carbonaceous particles are absent in this bed but are concentrated along laminae in other beds.

Vertical (*Skolithos*) and horizontal (*Planolites*) traces are well defined on bed types B, BC and C. No traces were associated with bed type A and the H. C. S. sandstone bed. The majority of the shales are blocky and bioturbated but fissile shales are also present.

INTERPRETATION

Sharp based beds of types A, B, BC and C were probably formed by the same processes responsible for the formation of sandstone beds in Units 1 and 2. Rapidly flowing turbidity current created the parallel lamination and massive beds. Partial erosion of the underlying shales produced tool marks, scour marks and fluted burrows. Rapid currents which slowly diminished in velocity while transporting sediment are responsible for the parallel lamination grading upward into ripple cross-lamination (Bouma BC bed). Cross bedding indicative of reworking by other currents is absent throughout Units 1, 2 and 3.

The thickening upward trend of these turbidites could have been created by a prograding sediment lobe. The two H. C. S. beds are now considered to have formed in storm-dominated shallow marine environments below fairweather wave base (Bourgeois, 1980; Hamblin and Walker, 1979). The implications of this bed form will be discussed in association with Unit 6.

Unit 4

Unit 4 consists of 15.2 m of thinly interbedded very-fine grained sandstones and fissile shales. Sandstone beds in the lower 8.2 m of the unit have an approximate average thickness of 2 cm and a range of 1 cm to 8 cm. A thickening and coarsening upward sequence occurs in the top 7 m of the unit (Plate 2-3). Sandstone beds in this sequence range from 4 cm to 30 cm in thickness. The lowermost sandstones have sharp bases and contain parallel lamination which grades upward into ripple cross-lamination; alternatively, the entire bed is ripple cross-laminated. These are Bouma BC and C beds. No solemarks or biogenic structures occur in these sandstones but much of the exposure is inaccessible. Carbonaceous particles occur in the sandstones and are concentrated along individual laminae.

The thickening and coarsening upward trend is gradual with a 30 cm thick sharp based sandstone near the base. This prominent sandstone contains parallel lamination grading upward into ripple cross-lamination, *Skoliths* and *Planolites*, and is overlain by a bioturbated shale. Another trace fossil identified as *Spirophycus* (R. Yeo, Pers. Comm.) was found just above this bed. *Spirophycus* is a compressed burrow, twice as wide as high.

PLATE 2-2: Sharp contact between Unit 2 and Unit 3; top is to the right. Turbidites in Unit 3 are thicker than in Unit 2 and sand/shale ratio increases.

PLATE 2-3: Thickening and coarsening upward sequence at top of Unit 4.

Sandstone beds within the coarsening upward sequence are Bouma BC and C beds. The average grain size of these beds is 0.1 mm (very fine-grained) except for the last three sandstone beds which have an average grain size of 0.2 mm (fine grained).

These three beds are 14 cm, 28 cm and 24 cm thick respectively. Each bed is sharp based, burrowed throughout the top 1-2 cm and contains horizontal traces on the base. The lowermost bed (14 cm) is parallel laminated in the lower 6 cm and ripple cross-laminated in the top 8 cm. The middle bed (28 cm) is parallel laminated throughout with some minor low angle convergence. The uppermost sandstone bed (24 cm) contains 9 cm of parallel lamination at the base which grades upward into 15 cm of ripple cross-lamination. These beds are separated by 8-15 cm of interbedded grey black shale and thin ripple cross-laminated, fine-grained, sandstones.

INTERPRETATION

The recurring association of sharp based, Bouma BC and C beds can once again be attributed to turbidity currents which rapidly and suddenly introduced sediment into the basin. The thickening and coarsening upward could be the result of turbidite lobe progradation. This progradation could be related to a relative lowering of sea level, increased sediment supply, lobe switching or any combination of these factors.

The Spirophycus appears to be fecal strings which are created when the organism packs its burrow with fecal pellets. Spirophycus is widespread in Cretaceous and Lower Tertiary rocks of North America and has been reported most commonly from bathyal turbidite deposits (Kern and Warme, 1974). However, a similar trace has been reported from Tertiary shallow-water deposits of New Zealand (Cullen, 1967). The presence of Spirophycus suggests that these sandstones were deposited in deep water and therefore, supports the interpretation of the sharp based Bouma BC and C beds, as sudden and rapid sand influxes, i.e. turbidity current deposits.

Unit 5

Unit 5 consists of interbedded, commonly bioturbated, very fine-grained sandstones, siltstones and shales. The first 75 cm of the unit consists of a blocky, silty, grey shale which directly overlies the top of the last thick sandstone in Unit 4. The remaining 6.25 m contains thick sandstone beds interbedded with recessive shales and bioturbated siltstones. Unit 5 ends at the base of the first of many hummocky cross-stratified beds which characterize Unit 6.

The sandstone beds of Unit 5 range in thickness from 6 cm to 55 cm. The thinner sandstone beds occur near the base of the outcrop and range from 6 cm-18 cm in thickness. These beds contain parallel lamination, low angle intersections, parallel lamination grading upward into ripple cross-lamination or appear massive. Both the tops and bottoms of beds are burrowed, and completely bioturbated interbeds of siltstone are present. A well preserved horizontal biogenic structure, Gyrochorte is visible on the bottom of one sandstone bed. Carbonaceous material helps to define the laminae in unbioturbated beds. Solemarks are not preserved on the bases of beds. There are two thick sandstone beds in the last two metres of the unit. The lower bed is 55 cm thick and the upper, 40 cm thick. These beds are separated by 45 cm of moderately bioturbated siltstone rich in carbonaceous particles. A similar bioturbated siltstone 60 cm thick is the last bed in the unit. The lower sandstone is parallel laminated at the base but ripple cross-laminated throughout most of the bed. The top is bioturbated and no carbonaceous material is present. The uppermost sandstone is sharp based and parallel laminated throughout. Solemarks and biogenic structures are absent.

INTERPRETATION

Most of the sandstone beds in this unit are massive bedded or contain parallel lamination which sometimes grades upward into ripple cross-lamination (Bouma A, B and BC). These features combined with the presence of sharp bases are indicative of deposition by turbidity currents. A few beds contain low angle intersections but no cross-bedding indicative of wave reworking is present. Burrowing on the bases of some sandstones and bioturbated siltstone beds are encountered for the first time in this section. The thickest sandstone beds yet described also occur in this unit. A plausible explanation for the occurrence of these features can be made after the unit's context has been established.

Unit 6

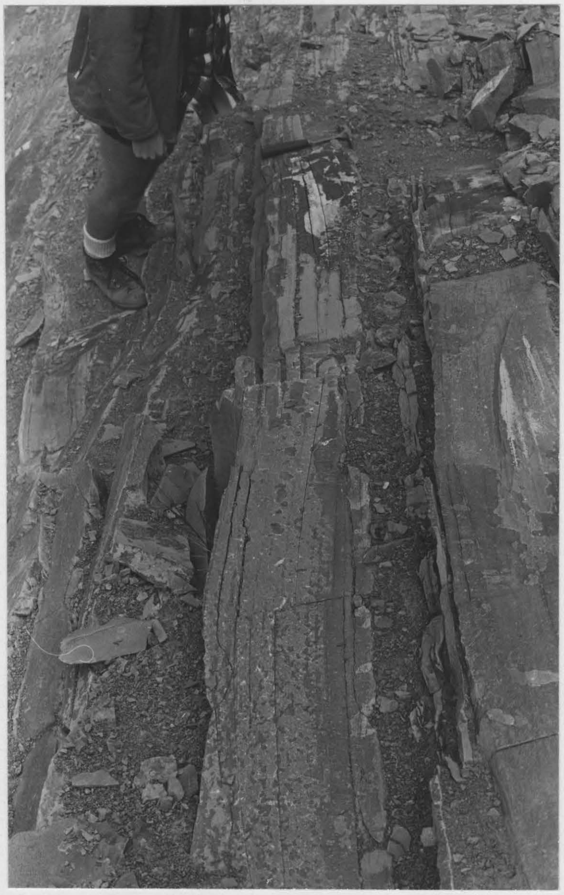
Unit 6 is characterized by the presence of numerous, very fine-grained, sharp based, hummocky cross-stratified sandstone beds which dominate the sedimentation for 15 meters (Plate 2-4). The H. C. S. beds are separated by thin recessive zones (5 - 10 cm) of moderate to heavily bioturbated sandstones and blocky or fissile shales. Stratification has been obscured in the bioturbated sandstones. Sandstone beds containing H. C. S. and undulating lamination range in thickness from 15-150 cm.

Most of the sandstone beds in this unit are hummocky cross-stratified but the degree of formation and preservation is variable. Laminae in some H. C. S. beds are well defined and can be traced for over 10 m. Within a single H. C. S. bed the convex upward (hummocky) portion of H. C. S. is preserved at one location but eroded to leave only the convex downward (swaley) portion at another location. The amplitudes defined in any one bed by one individual lamina, range from 15 cm to 40 cm and wavelengths range up to 4 m.

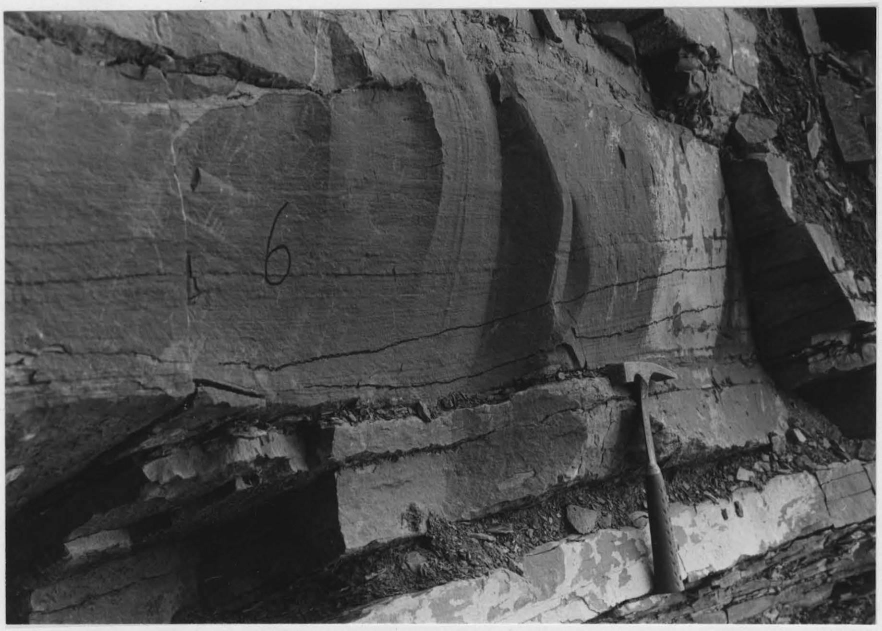
PLATE 2-4: a) Excellent example of sharp based hummocky cross-stratified sandstone bed, 25 cm thick (Unit 6). Top is to the right.

b) Hummocky cross-stratified sandstone of Unit 6 interbedded with shale

a)



b)



Several beds have lamination which superficially resembles H. C. S. Individual lamina undulate and form very low amplitude (1 cm to 2 cm) hummocks. These small-scale hummocks are not continuous along bedding planes and laminae are non-parallel. Beds contain many undulating non-parallel laminae which are commonly out of phase with respect to each other. Hummocks defined by one lamina sit vertically above the swales defined by the underlying lamina. Undulating lamination is scoured by broad gentle swales or in some instances it grades laterally into low angle divergences.

Rip-up clast molds are present on the soles of thick (40 cm) H. C. S. beds at the top of the unit. The soles of other beds contain *Planolites* and *Gyrochorte*. Only one bed has oscillation ripples preserved on its base. Tool and scour marks are rare and poorly developed. There is a high concentration of comminuted plant debris, which is dispersed throughout the bioturbated sandstones or concentrated within laminae. Carbonaceous particles are absent on the tops of H. C. S. beds where a thin (2 cm) burrowed zone commonly exists. Symmetrical ripples are also present on the tops of H. C. S. beds.

INTERPRETATION

The ubiquitous nature of the hummocky cross-stratification indicates the environmental interpretation. The most commonly accepted interpretation of H. C. S. is one that was initially proposed by Harms *et al.*

(1975), with amplifications by Hamblin and Walker, (1979), Bourgeois (1980), and W. L. Duke and B. H. Ainsworth (pers. commun's. 1980). Beds containing H. C. S. are invariably sharp based and contain tool and scour marks. Biogenic traces occur on the base of H. C. S. beds and the top few centimetres of the beds are commonly burrowed. H. C. S. beds in this unit contain all these features. The presence of sharp bases and directional solemarks indicate that sudden, rapid flows are responsible for sediment transport.

The present interpretation of H. C. S. attributes its formation to relatively large storm waves. Storm influenced deposits are therefore associated with features generated by sudden, rapid, sediment flows. Storms may have generated these sediment flows and formed the H. C. S. deposits. The bioturbated very fine-grained sandstones and shales which are interspersed with H. C. S. represent hydraulically quiet times or slower rates of deposition.

Unit 7

Unit 7 consists of interbedded, very fine-grained sandstones and fissile to bioturbated shales. The unit is bounded above and below by sharp contacts with thick sandstone beds.

The sandstone beds of Unit 7 average 10 cm in thickness and range from 5 cm to 48 cm. All beds have sharp bases and are bioturbated to varying degrees. Planolites is common on the tops and bases of beds. The tops and or bases of other sandstones have been thoroughly bioturbated to a depth of approximately 1.5 cm, thus obscuring stratification. Fluted vertical burrows (Skolithos) are present on the bases of a few unbioturbated sandstones. Comminuted plant debris and a few larger wood fragments, 2 cm x 5 cm, are dispersed throughout the sandstones and define individual laminae.

The sandstone-beds at the base of this unit contain hummocky cross-stratification or parallel lamination (Bouma B). The top of the unit contains four ripple cross-laminated beds (Bouma C) which range from 5 cm to 10 cm in thickness. Symmetrical ripples occur on the tops of hummocky cross-stratified, parallel laminated and ripple cross-laminated beds. Ripples have crest to crest distances of 5 cm to 8 cm and heights of approximately 2 cm. One lenticular sandstone bed occurs in this unit. No internal stratification is visible but the bed is geometrically similar to a hummocky cross-stratified bed. It has a sharp, horizontal base and a top composed of convex upward domes and convex downward swales. The bed is 20 cm thick in the bottom of swales and 48 cm thick in the hummocky portion.

INTERPRETATION

The presence of Bouma B and C beds, interbedded with shales, can once again be attributed to the action of episodic, turbidity currents. Hummocky cross-stratified sandstones were probably deposited by storm-generated density currents and then modified by storm waves. Post-storm reworking by waves has formed oscillation ripples which occur on the top of H. C. S. beds. These ripples are more abundant in Unit 7 than in Unit 6. This suggests that Unit 7 was affected by fair weather processes more often than Unit 6. Unit 7 may therefore have been closer to fair weather wave base.

Unit 8

Unit 8 is an 8.75 m section of fine-grained, hummocky cross-stratified sandstone that contains several zones of soft sediment deformation and a few beds of fissile shale. The zones of soft sediment deformation commonly occur between and grade into beds of undeformed hummocky cross-stratified sandstone. There are five zones of soft sediment deformation which range in thickness from 15 cm to 75 cm. The total thickness of these zones is 2.0 m. The shale occurs as interbeds in the top 2 m of this unit, ranging from 10 cm to 60 cm in thickness. The sandstone beds average 1.0 m in thickness and range from 3 cm to 125 cm. Carbonaceous and micaceous particles are concentrated along sandstone laminae and platy partings are created by weathering.

The hummocky cross-stratified sandstone beds not underlain by deformation zones have sharp bases. Mudclasts and Planolites are commonly present on the bases. Tool and scour marks are absent. The first sandstone bed in the unit is hummocky cross-stratified and has a sharp base. The top of the bed is burrowed and directly underlies another H. C. S. bed which has mudclasts, Planolites and wood fragments on its base.

Five zones of soft sediment deformation occur between essentially undeformed beds of hummocky cross-stratified sandstone. The soft sediment deformation consists of ball-and-pillow structures (Potter and Pettijohn, 1977). These ball-and-pillow structures occur both attached to, and detached from the overlying sandstone beds. Three of the five deformation zones contain detached ball-and-pillows. Very fine-grained ball-and-pillows whose internal laminae conform to the pillow boundaries sit in a matrix of siltstone (Plate 2-5). The ball-and-pillows are ellipsoidal or hemispherical, ranging from 15 cm to 45 cm in width. The detached pillows are vertically symmetrical and exhibit no evidence of rotation. These three zones grade into thick, undeformed, hummocky cross-stratified sandstone beds with undulating bases.

PLATE 2-5: a) Vertical penecontemporaneous load structure (pillow) attached to base of sandstone bed.

b) Detached load structure surrounded by siltstone.

a)

b)

The fourth zone consists of a 1.0 m thick sandstone bed with broad pillows at the base which grade upward into slightly distorted laminae, followed by hummocky cross-stratification. The top of this bed is flat and overlain by a 1.25 m thick sandstone containing H.C.S.

The fifth deformation zone consists of a 15 cm thick, deformed sandstone bed which is interbedded with shales. This bed contains broad, shallow, vertically symmetrical pillows with slightly concave tops and internal lamination which conforms to the pillow shape.

INTERPRETATION

The H.C.S. sandstone beds in this unit are thick (average 1.0 m), very fine-grained, and have sharp bases which commonly contain rip-up clasts and Planolites. These beds were probably deposited by storm-generated density currents and then modified by storm waves. The H.C.S. beds in this unit are thicker than any described from Units 3, 7 and 8. Exceptionally large turbidity currents may have produced the thick beds. Alternatively, the thickness may indicate that deposition is occurring closer to the sediment source.

The soft sediment deformation is restricted to the base or immediately below the base of hummocky cross-stratified sandstone beds. Other beds in the unit are sharp based, hummocky cross-stratified and undeformed. The ball-and-pillow hummocky cross-stratified beds and deformation structures are vertically symmetrical and contain laminae which conform to pillow boundaries. These features suggest that the deformation was created by the relatively rapid deposition of sediment transported by rapid currents. Storm wave action resulted in the formation of H. C. S. after deformation.

Unit 9

Unit 9 consists of 33 m of light grey, fine- to medium-grained, laminated sandstone. Carbonaceous and micaceous material is concentrated on individual laminae and weathering produces distinctive platy partings which accentuate stratification. Distinct sandstone beds with sharp bases and non-erosive tops are absent. Beds consist of tabular and wedge-shaped sets of cross-strata with sharp, erosional boundaries. Shales are absent throughout the unit, but rare mud clasts occur at the base of broad troughs and along inclined planes of lamination. One loaded zone 30 cm thick exists above the base of the unit. The sandstones are unbioturbated and only one trace fossil, Planolites, was observed near the base of the unit.

Three distinct types of cross-stratification are recognizable in this unit, namely:

1) swaley cross-stratification

2) hummocky cross-stratification

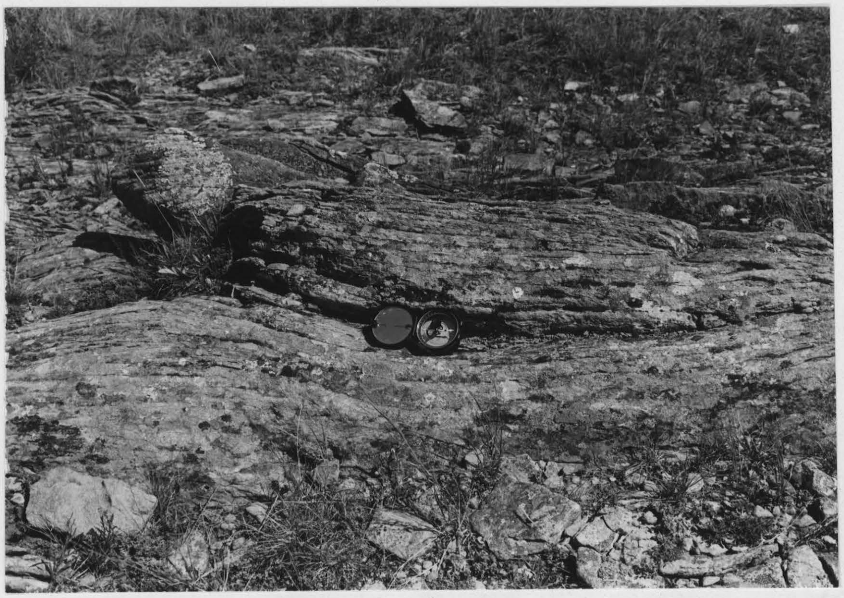
3) planar to curved cross-stratification in tabular or wedge-shaped sets.

Swaley cross-stratification is the most common type. It consists of lamination which is broadly concave upward (swaley) on a large scale (Plate 2-6). These swales are typically 5 m wide and 0.5 m deep but very few complete swales are preserved. The swales erosionally truncate each other vertically and laterally. As a result, the most commonly preserved feature consists of low angle intersections of dipping laminae which appear parallel over short distances. The average dip of laminae is 15° from the horizontal with a range from 5° to 25°. The swaley cross-stratification can be viewed in three dimensions at a few places within the unit. This perspective reveals that swaley cross-stratification has the same form whether viewed in vertical cross-sections parallel to regional strike, or perpendicular to strike.

The similarity of the stratification regardless of the orientation of the cross-section reveals that swaley cross-stratification has distinct features differentiating it from normal trough cross-stratification. The troughs (swales) are too consistently shallow,

PLATE 2-6: Swaley cross-stratification near top of Unit 9 (width 4 m, height 0.6 m) showing characteristic broad, upward concavity.

PLATE 2-7: Well developed hummocky cross-stratification 15 m above base of Unit 9 (wavelength 1.75 m, height 20 cm).



symmetrical and broad, and lamination intersections are too low angle for this to be described as trough cross-stratification. The name swaley cross-stratification was first proposed for this structure by W. L. Duke (1980) and it commonly occurs in the Cardium Formation of Alberta (Duke, 1980).

Parallel lamination and hummocky cross-stratification are generally restricted to the lower 18 m of the unit and truncate the swaley cross-stratification laterally and vertically. The H. C. S. occurs in only a few places and is often surrounded by swaley cross-stratification (Plate 2-7). Wavelengths of H. C. S. range from 1. 5 m to 3. 0 m and amplitudes from 8 cm to 15 cm. The parallel lamination occurs in beds with erosional boundaries and thicknesses ranging from 0.4 m to 1. 0 m (Plate 2-8). The maximum lateral extent of the parallel laminated beds is approximately 5 m.

Cross-bedding near or at the angle of repose is restricted to the top 12 m of the outcrop and is dominant in the last 4 m. The cross-beds occur in tabular and wedge-shaped sets, 40 cm to 60 cm thick (Plate 2-9). Most of the cross-strata within sets are planar. One exception occurs in which the planar cross-strata in a tabular set have asymptotic contacts with the lower boundary of the set. Tabular and wedge-shaped sets have lateral extents of up to only 2. 5 m before they become truncated by other

PLATE 2-8: Parallel lamination in the lower portion of Unit 9.

PLATE 2-9: Angle of repose cross-bedding, foresets have asymptotic contacts with the lower planar boundary. Set is 50 cm thick and occurs near the top of Unit 9.

cross-bed sets and swaley cross-stratification. One trough occurs near the top of the unit which is 5.5 m wide and 1.5 m deep. The bottom of the trough is scoured and contains mud clasts. Laminae within the trough conform to the trough shape but gradually become less concave upward until they are essentially parallel.

INTERPRETATION

The context and stratification characteristics of Unit 9 permit the development of an environmental interpretation. In the previous unit (8), there are thick sandstones which were deposited by storm generated turbidity currents then molded by storm waves to form H. C. S. These beds are inferred to have formed below fairweather wave base because they contain no evidence of reworking by fairweather processes. In the unit just described (9), the presence of H. C. S. indicates that storm waves formed H. C. S. in the lower 18 m of the unit. The H. C. S. in Unit 9 differs from that of Unit 8, in that it only occurs as isolated, discontinuous beds surrounded by swaley cross-stratification. The H. C. S. sandstone beds in Units 6 and 8 are sharp based but those of Unit 9 are not. These features indicate that the H. C. S. of Unit 9 is being affected by the process responsible for the formation of the swaley cross-stratification. Since H. C. S. is only extensively reworked above fairweather wave base, the swaley cross-stratification may have formed above fairweather wave base. The presence of cross-bedding and swaley cross-stratification in the same horizon supports this interpretation. If cross-bedding is formed by fairweather processes, then the S.C.S. may have also formed above fairweather wave base. This does not necessarily mean that the process responsible for the formation of S.C.S. is a normal fairweather process. Swaley cross-stratification may be produced by storm processes which interact with normal fairweather processes and influence sedimentation.

The parallel lamination is restricted to the lower 18 m of the unit. It was probably formed by upper flow regime currents. These may be produced by storm generated or fairweather currents.

Unit 10

Unit 10 is a 2 m thick interval of fine-grained, reddish-brown sandstone beds which range from 2 cm to 20 cm in thickness. The beds contain parallel lamination with planar, very low angle (4°) intersections (Plate 2-10). The sandstone is very hard and fracturing has produced sub-vertical cracks in many beds. The platy partings characteristic of the underlying unit are absent. No shale interbeds or biogenic traces are present. The lamination, hardness, reddish-brown colour, and lack of platy partings distinguish this unit from Unit 9. There is a 75 cm covered interval between the top of Unit 10 and the base of Unit 11.

INTERPRETATION

The parallel lamination and planar low angle intersections of this unit are typical of beach swash and surf zones. The position of this

PLATE 2-10: a) Parallel lamination and low angle intersections of fine-grained beach sandstone (Unit 10).

b) Upper surface of Unit 10 which is hard and resistant to weathering.

a)

b)

unit below non-marine sediments and above the shallow marine sands of Unit 9 supports this interpretation.

The reddish-brown coloration of Unit 10 may result from the weathering of chlorite in the sandstone. Chlorite is abundant in basal Belly River beach sandstones and always weathers to a reddish-brown (Mellon, 1961).

Unit 11

Unit 11 contains 4.05 m of interbedded sandstones and mudstones. The unit begins with a 30 cm thick, light grey, argillaceous, fine-grained, massive sandstone which is penetrated by vertical roots in the top 4 cm. This bed is overlain by 2 m of mudstone which contains vertical roots in the lower 0.5 m and plant fragments throughout the upper 1.5 m. There is a sharp contact between the top of the mudstone and the next sandstone bed. This bed is a 70 cm thick, fine-grained sandstone which contains parallel lamination and ripple cross-lamination. The lower 40 cm of the bed contains parallel lamination which grades upward into 30 cm of ripple to ripple cross-lamination.

The uppermost sandstone contains trough cross-stratification and is located above crevasse splay and floodplain deposits. These facts imply that the sandstone bed may be a small fluvial channel deposit or another crevasse splay.

Unit 12

Most of the Belly River Formation above Unit 11 is covered, with the exception of three thick sandstone intervals and one section of shales. Unfortunately, time permitted only a brief inspection of these exposures. A general summary of the gross sedimentary structures of these exposures follows.

The three sandstone intervals protrude from a fairly steep, grass covered river bank. Their bases are roughly 10 m, 30 m and 60 m respectively above the top of Unit 11. The lowermost sandstone interval is approximately 3 m thick and is trough cross-stratified. The middle sandstone exposure is approximately 3 m thick. This section is cross-stratified in the lower and upper portions but parallel laminated for a vertical distance of 1.5 m in the middle portion. Roughly 7 m of covered section occur above this sandstone and then some shales are exposed. The shales cover approximately 5 m and contain two sharp based sandstone beds. One bed is 20 cm thick and the other is slightly thinner. Lamination within these beds is ill-defined and the bed may be affected by faulting. The shales are overlain by a covered interval then the third thick (>4 m) sandstone exposure occurs. The internal structures of this sandstone were not examined.

INTERPRETATION

The first two sandstone exposures above the top of the measured section (Unit 11) have not been studied in sufficient detail to permit an accurate environmental interpretation. The first sandstone interval contains trough cross-stratification and may be tentatively interpreted as fluvial in origin. The second exposed interval contains parallel laminated sandstone intercalated with trough cross-stratified sandstone. This unit may be tentatively interpreted as fluvial sandstones or alternatively, beach deposits associated with either shallow marine or fluvial troughs.

The shales above the second sandstone unit were sampled and the microfauna analysed. The shales contain forams commonly associated with coastal subaqueous environments (Wayne Brideaux, Pers. Comm.). In this instance coastal subaqueous is equivalent to the marine zone shoreward of 200 m depths including lagoonal environments. Micropaleontology therefore indicates that transgressive marine interval occurs in this outcrop. Further field work will be required to evaluate this hypothesis.

Blairmore Group

MUDSTONE FACIES (M)

The section has been subdivided into twenty units, nine of which may be included in the mudstone facies (M). These nine units average 4 m in thickness and range from 2.5 m to 23 m thick. The units have similar lithologies and sedimentary structures. They are composed of indurated, light grey to dark grey mudstone which is generally massive, although fine undulating lamination is sometimes observed (Plate 2-11). Comminuted plant debris is scattered throughout the mudstone and commonly defines delicate laminae within the mudstone. Siltstone beds which are resistant to weathering protrude from the mudstone. The siltstones range in thickness from 15 cm to 40 cm (average 25 cm) and have gradational upper and lower contacts. The siltstones are structurally massive with the exception of a 25 cm thick, ripple cross-laminated siltstone in Unit 11. Very fine-grained sandstone beds occur only in Units 3 and 5. Unit 3 contains one 25 cm thick, ripple cross-laminated sandstone which contains roots at the top. Unit 5 contains three fine-grained sandstone beds. The lowermost sandstone bed in the unit is 25 cm thick, massive and contains carbonaceous plant debris and vertical roots. The middle sandstone bed is 40 cm thick, and contains trough cross-bedding and carbonaceous particles.

THE BLAIRMORE GROUP - DAISY CREEK

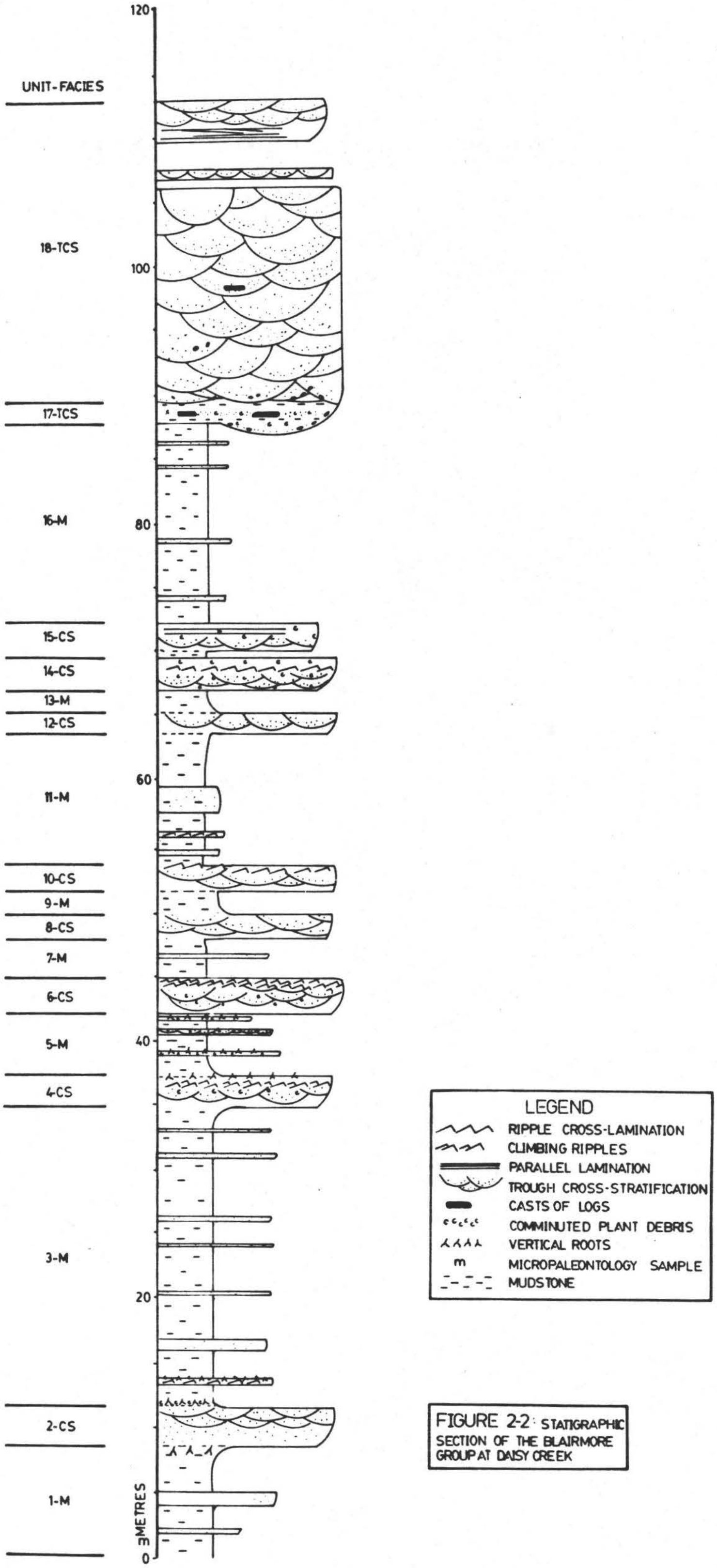


FIGURE 2-2: STATIGRAPHIC SECTION OF THE BLAIRMORE GROUP AT DAISY CREEK

The uppermost sandstone is 20 cm thick, massive, with carbonaceous particles throughout and vertical roots on the top. Vertical roots also occur at the top of Unit 1.

The mudstone facies is interbedded with relatively thick (1.75 m - 3.0 m) sandstone beds which have either gradational or sharp lower contacts. These sandstones are contained within another facies, the cross-stratified sandstone facies (CS).

Cross-stratified Sandstone Facies (CS)

Eight, fine- to medium-grained sandstone beds which range in thickness from 1.7 m to 3.0 m occur in the lower 87.5 m of the section (Units 2, 4, 6, 8, 10, 12, 14, 15). The individual beds are of uniform thickness over the length of the exposed outcrop except for Unit 2 which is lenticular and only 10 m wide, approximately. These sandstones are characterized by angle of repose trough cross-bedding. Cross-bedding grades upward into ripple cross-lamination or ripple drift cross-lamination in fifty percent of the sandstones (Units 4, 6, 10, 14) (Plate 2-12). Units 8 and 12 are cross-bedded throughout. In Unit 15, cross-bedding grades upward into parallel lamination.

Comminuted plant debris is scattered throughout Units 4, 6, 14 and 15. Vertical roots were observed in the tops of Units 2 and 4. These are also the only Units with gradational lower contacts with the underlying mudstone. The other units have sharp erosive contacts with

PLATE 2-11: Mudstone facies (M) containing silty bed with gradational contacts.

PLATE 2-12: Cross-bedded sandstone facies (Unit 14) with planar cross-bedding grading upward into climbing ripples.

the underlying mudstone. All the sandstone beds grade upward into the mudstone facies.

Thick Cross-stratified Sandstone Facies (TCS)

The top of the Daisy Creek outcrop consists of a 21 m thick, fine- to medium-grained sandstone (Unit 18) which forms a steep cliff (Plate 2-13). The facies is characterized by large scale planar tabular and trough cross-bedding and well developed basal scours (Plate 2-14).

The base of the facies contains massive, medium- to coarse-grained sandstone beds interbedded with a brittle, coarse sandy siltstone (Unit 17). This unit (17) has variable thickness, ranging from less than 50 cm to more than 2.5 m. The unit is thickest where the underlying mudstone has presumably been eroded. The sandstone beds in this unit average 15 cm in thickness (range 8 cm - 20 cm). These beds contain numerous carbonaceous fragments and the casts of large logs (15 cm x 40 cm) are commonly preserved on the top of beds. Where the unit is thinnest sandstone beds are absent. The siltstone interbeds average 15 cm in thickness (approximate range 10 cm to 50 cm) and are very friable.

Large scale (1 m - 4 m) planar tabular and trough cross-bedding is well developed throughout the rest of the facies. The troughs

PLATE 2-13: Thick cross-bedded sandstone facies with erosive base.

PLATE 2-14: Scoured interval (Unit 17) at base of thick cross-bedded sandstone facies.

truncate one another and in some instances contain clay rip-up clasts and large logs (maximum dimensions 1 m x 0.35 m) at their bases or along foresets. Low angle, planar, erosional surfaces up to 4 m long are commonly observed. Two meters below the top of the facies a 1.5 m thick interval containing parallel to slightly undulating lamination (plane bed) occurs. The top 2 m of the facies is trough cross-stratified.

CHAPTER THREE

PALEOCURRENTS

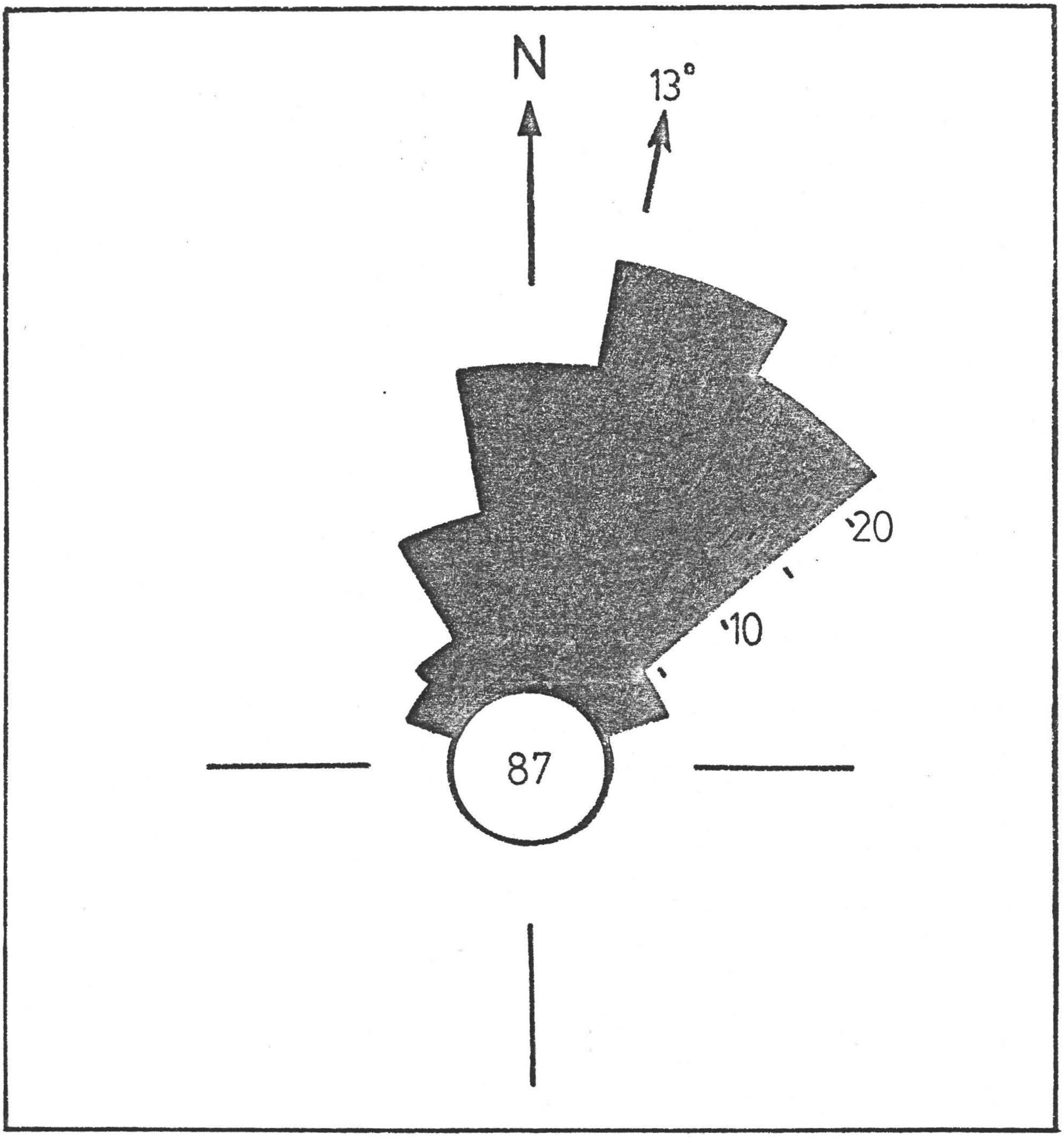
Paleocurrent measurements were taken in the field and corrected for regional dip in the laboratory. A stereonet was used to remove the regional dip from 87 measurements of attitudes of foresets in current ripples, and 151 measurements of attitudes of dipping laminae. Field measurements of solemark directions were corrected using Ten Haaf's (1959) method. The vector mean and standard deviations were calculated using a computer program (Martini, 1965).

Wapiabi-Belly River Transition

Unit 2

Thin (2-3 cm) Bouma C beds occur throughout the unit, becoming more abundant upward. The attitude of foresets (87) were recorded and regional dip was removed (Figure 3-1). The vector mean is 013°, with a standard deviation of 33°.

FIGURE 3-1: Direction of maximum dip of 87 foresets from current ripples of Bouma BC and C beds in Unit 2. Vector mean 013°, standard deviation 33°.


N
13°
20
10
87

Unit 3

Fluted burrows, and tool and scour marks are preserved on the bottoms of sharp based sandstones. Two fluted burrows yield paleoflow directions of 022° and 0° (Figure 3-2). The tool and scour marks yield directions of 176°-356°, 175°-350°, and 23°-203° (Figure 3-2).

Unit 5

One of the sharp based sandstones observed in Unit 5 contained a solemark (tool, scour, or prod) which yielded a paleoflow direction of 159°-339° (Figure 3-2).

Unit 7

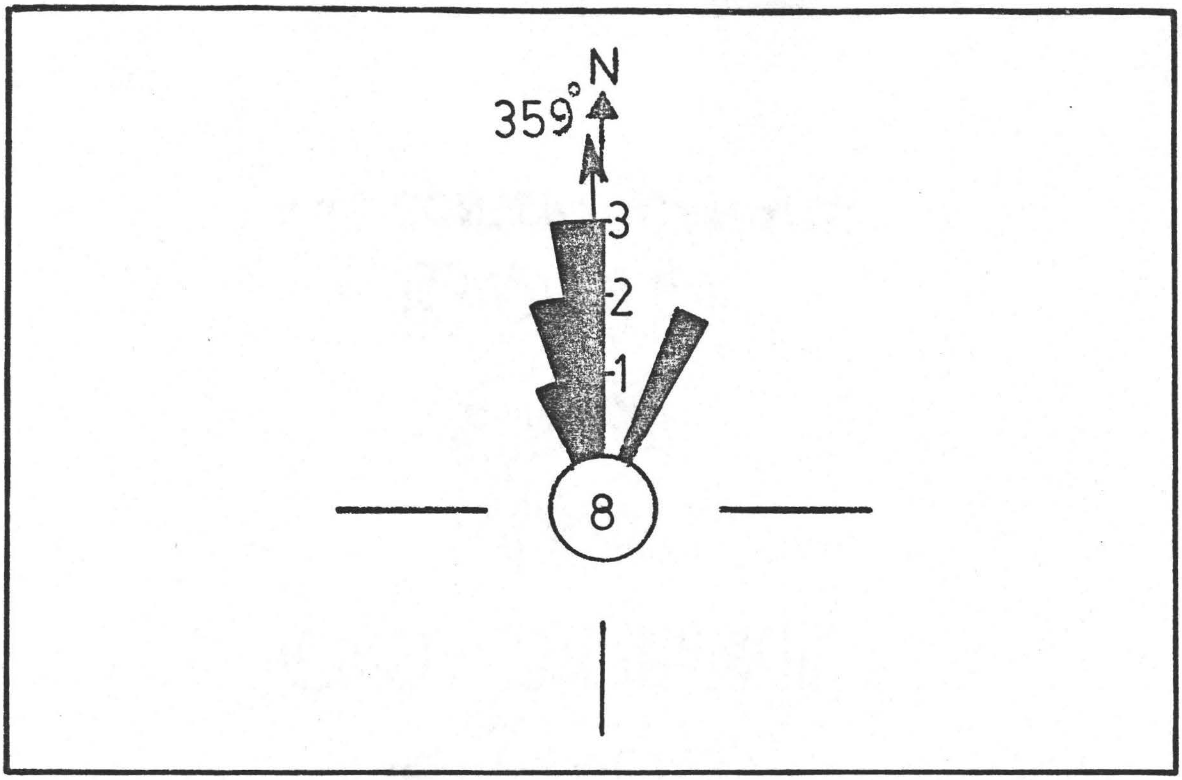
Two fluted burrows in this unit gave paleoflow directions of 350° and 355° (Figure 3-2).

Unit 9

The direction of maximum dip of 144 inclined layers contained within swaley cross-stratified sandstones have been plotted on a rose diagram (Figure 3-3). The vector mean is 68.4° and standard deviation 70°. The average dip of reoriented inclined layers is 15.5°. The direction of maximum dip of five trough crossbeds has been plotted in Figure 3-2. These crossbeds occur in the top 4m of Unit 9. The vector mean is 104.5° with a significance level of 97.5 percent with two degrees of freedom and a standard deviation of 25°.

FIGURE 3-2: a) Paleocurrent directions as indicated by fluted burrows and sole markings from Units 2,3,5 and 7. Bidirectional flow indicators are assumed to indicate northerly flows. Vector mean is 359°.

FIGURE 3-2: b) Direction of maximum dip of foresets from cross-beds in upper 4 m of Unit 9. Vector mean equals 104°, with a significance level of 97.5 per cent and two degrees of freedom, standard deviation 25°.


N
359°
3
2
1
8

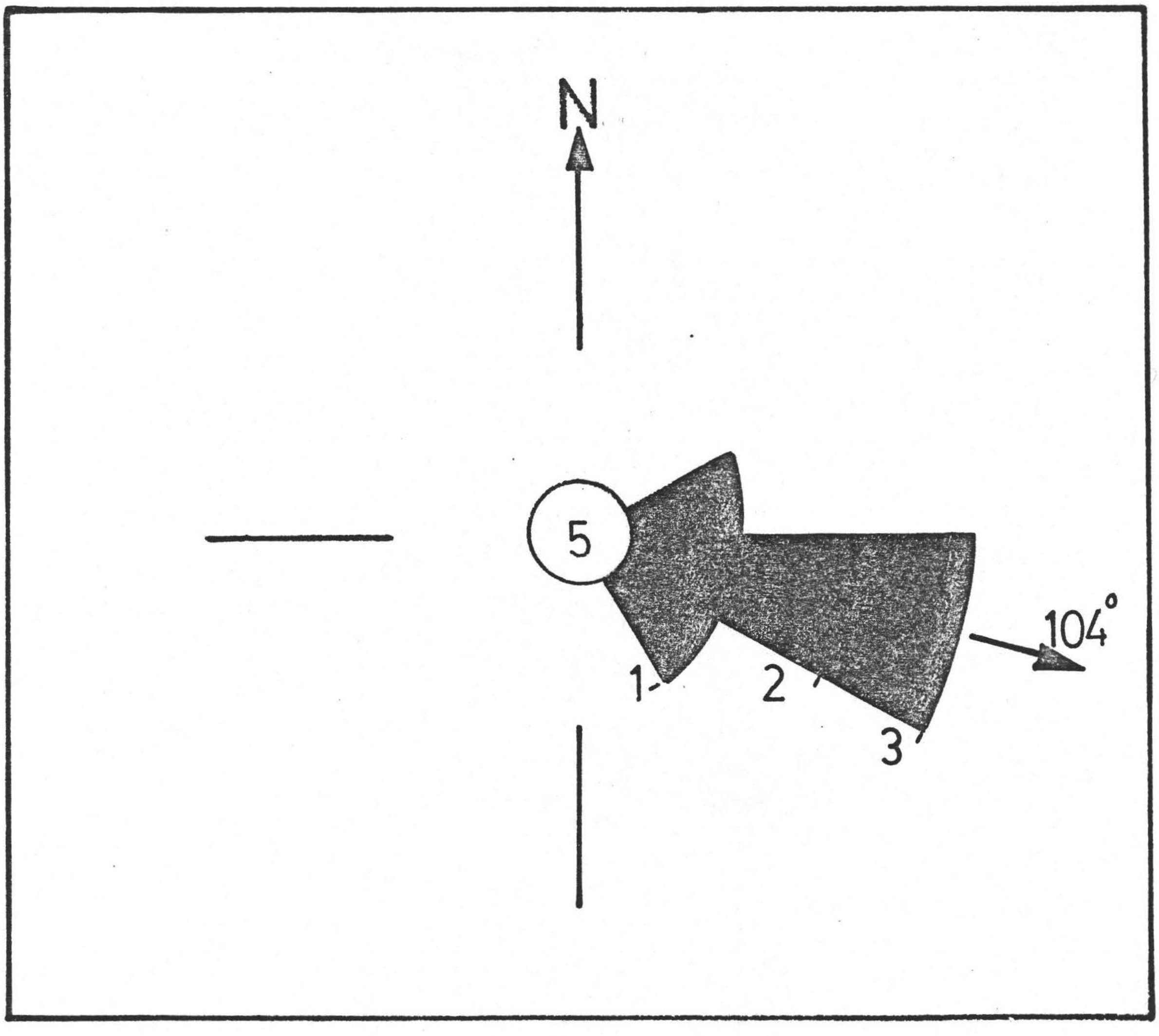
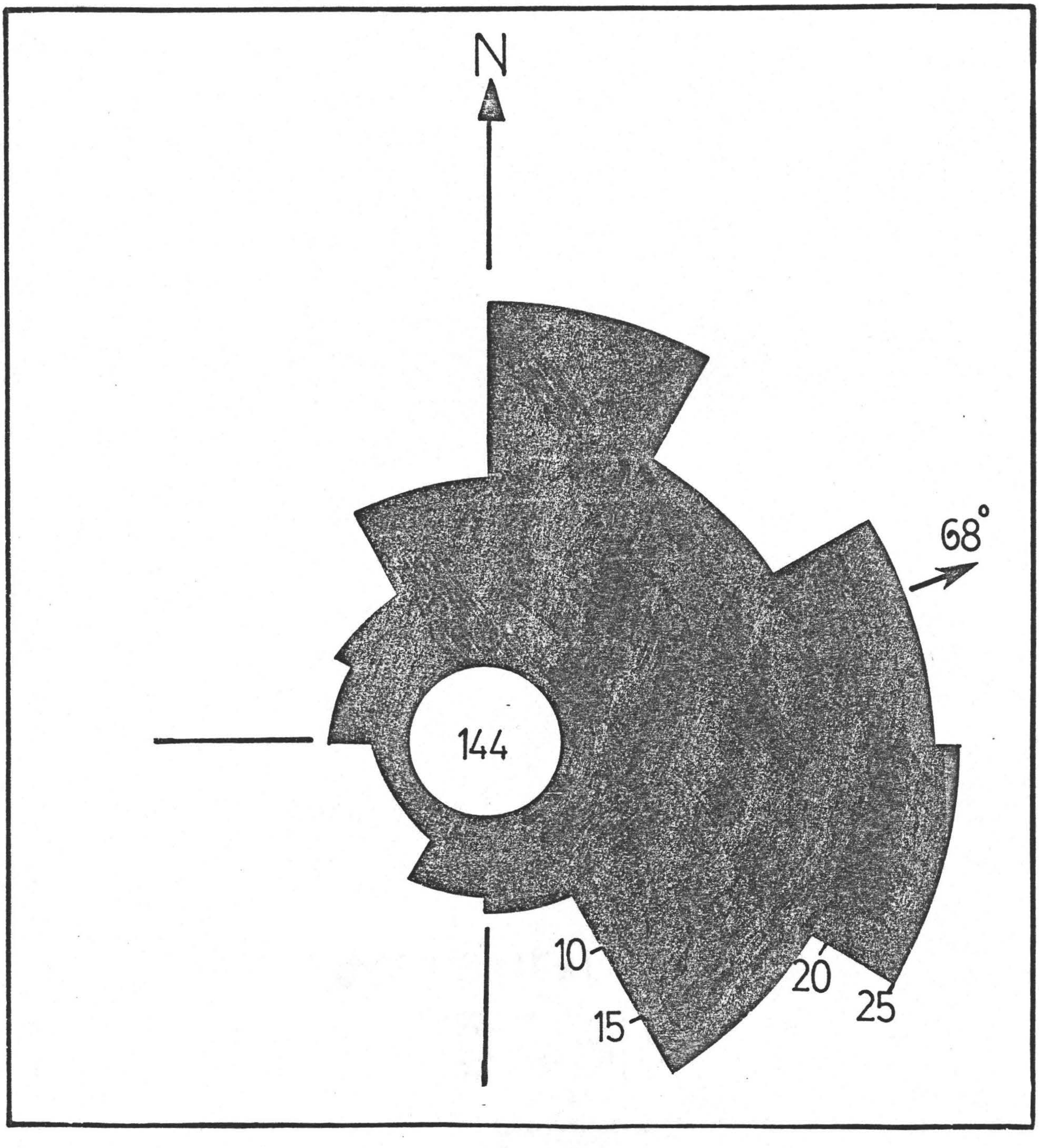

N
5
104°
1
2
3

FIGURE 3-3: Direction of maximum dip of inclined layers within swaley cross-stratified sandstones. Vector mean equals 68°, standard deviation is 70°.


N
68°
144
10
15
20
25

Paleocurrent directions as indicated by solemarks in Units 3-7 have a vector mean of 359.28° (n=8), (Figure 3-2). Bidirectional solemarks are assumed to represent northerly flows. This northerly paleoflow direction is supported by the paleoflow direction (013°) implied by current ripple foresets in Unit 2 (Figure 3-1). These paleoflow indicators all occur on the tops or bottoms of sharp based Bouma B, C or BC beds. These beds were probably deposited by turbidity currents which flowed down the regional paleoslope. The preceding paleocurrent data indicate that the turbidity currents flowed northward. In order to generate northerly flowing turbidity currents, a northward dipping paleoslope is required. Therefore, a northward dipping regional paleoslope may have existed during Campanian time. The implications of such a paleoslope are discussed in Chapter 5.

A complicated polymodal rose diagram is generated by plotting the direction of maximum dip of swaley cross-strata. The pattern may have been distorted by several inherent sources of error, namely 1) variations in local strike and dip (148/62E - 150/59E) which may result in over or under rotation of original data; 2) a plunging fold axis which will effect reorientation; 3) swaley cross-strata which strike parallel to regional strike will appear to be flat planes when viewed perpendicular to regional strike. The dipping layers box the compass but there is a preferred dip towards the eastern hemisphere. This suggests that either swales accreted towards the east or the geometry of the swales is such that more dipping layers are exposed on the east side of the swale. In order to satisfy the latter condition, the swales must be elongate rather than circular thus exposing a greater proportion of dipping planes situated along the long dimension of the swale. Therefore, swales may have been elongated in a north-south direction thus exposing the easterly dipping face. The easterly accretion of swales is favoured by the rose diagram indicating that net transport was to the northeast (68°).

The most complicated cross-bedding patterns have been found in shallow marine sandstones and/or coastal barriers and beaches which were affected by tidal or storm-generated currents (Potter and Pettijohn, 1977). Since Unit 9 has been interpreted as a shallow marine sandstone situated between beach and storm deposits, a complicated pattern may be expected. The pattern (Figure 3-3) may reflect the interaction of storm-generated, longshore and rip currents. Net sand transport in Unit 9 has been in an east northeasterly direction since the vector mean is 68.4°. This direction is supported by the few cross-beds that occur at the top of the unit and indicate that sediment transport was towards the east (Figure 3-2).

CHAPTER FOUR

PETROGRAPHY

METHOD

Samples were collected in the field from both the Lundbreck Falls and Daisy Creek outcrops. At Lundbreck Falls, eight samples were collected for petrographic analysis. One sample was taken from each of Units 2, 3, 6, 8, 11 and three samples were taken from Unit 9. All the thin sections were stained for calcite. Seven samples were taken for grain size analysis.

Twelve samples were taken from the Daisy Creek section. Ten samples were used to obtain grain size estimates. Two samples were taken in order to determine the mineralogical composition of two trough cross-stratified channel sandstones.

Thin sections were made and examined under a microscope in order to determine petrographic compositions. A stage point counter was used to examine at least 300 points in each thin section. The results have been tabulated in Table 4-1, along with a summary of the results of Hunter (1980), Lerbekmo (1963), Ogunyomi and Hills (1977) and Mellon (1961).

Unit - Sample	Quartz	Chert	Total Carbonate	Feldspar	Clay & Mica	Lithic Fragments	Volcanic Fragments	Total Rock Fragment	Iron Oxide	Others
Lundbreck Falls										
2-1	42	6	6	8	21	5	1	6	11	
3-1	43	16	8	3	15	8	1	9	6	
6-1	36	7	15	5	18	9	1	20	9	
8-1	51	9	3	2	19	7	2	8	9	
9-1	34	15	11	4	9	20	2	22	5	
9-2	43	14	8	8	8	7	2	9	10	
9-3	47	13	9	10	6	5	2	7	8	
Average	40	11	7	6	13	-	-	11	9	X
Mellon (1961)	26	8	12	17	11			22		X
Lerbekmo (1963)	50	10-30	X	15	X			10-30		X
Ogunyomi and Hills (1977)	32-42	3-24	X	14-41	X			1-7	X	
Hunter (1980)	39	10	25	8	10			1	2	X
Daisy Creek										
4-1	24	26	24	6	9	5	1	6	5	
14-2	38	21	2	7	20	7	1	8	4	

TABLE 4-1: Percentages of mineral constituents from Lundbreck Falls and Daisy Creek plus averages from other studies. Minor constituents are indicated by X.

GENERAL PETROGRAPHIC DESCRIPTION

Belly River Formation, Lundbreck Falls

The detrital component of the thin sections consists of quartz, chert, feldspar, carbonate, lithic and volcanic rock fragments, plus other minor constituents. The matrix consists of carbonate, iron oxide and clay. Authigenic cements occur as quartz overgrowths on detrital quartz grains, clay (kaolinite) as interstitial patches and calcite as large, optically continuous patches filling pore spaces and surrounding grains.

Detrital grains are subrounded to subangular. Quartz grains tend to be subangular while chert and calcite are subrounded. The clay content is fairly high in all sections (8 % - 4 %) and as a result the sandstones are classified as being texturally immature to submature (Folk, 1977). Sorting is poor to moderate.

No statistically significant mineralogical trends are recognizable within the few samples taken. There is an overall grain size increase upward. The lower units (1-7) are very fine-grained while Unit 9 is fine-to medium-grained and sandstone beds of Unit 11 are medium-grained.

Belly River Formation: Comparison

The petrography of the Belly River formation has been studied by Mellon (1961), Lerbekmo (1963), Ogunyomi and Hills (1977) and Hunter (1980).

Mellon (1961) studied the sedimentary magnetite deposits of the basal sandstone member of the Belly River Formation in the folded foothills belt of southwestern Alberta. The sandstones studied from Lundbreck Falls have a low magnetite concentration. Therefore, the mean mineral composition of four samples from the magnetite poor ("barren") lower part of the Belly River Formation which were examined by Mellon (1961) have been used for comparison (Table 4-1).

Three of the four samples came from an outcrop near the town of Burmis (Figure 1-4) close to Lundbreck Falls. The detrital fraction is composed of quartz, feldspar, fine-grained rock fragments with lesser amounts of chert, detrital dolomite and biotite. The intergranular space is filled by either kaolinite and/or calcite. Authigenic quartz is abundant as irregularly shaped, optically continuous overgrowths on detrital quartz grains.

Lerbekmo (1963) studied the petrography of a complete Belly River section at Drywood River (Figure 1-4), sampling at 200 ft. intervals. The sandstones are composed of about one-half quartz (and quartzite), one-third rock fragments (including chert), and one sixth feldspar (Lerbekmo, 1963). The minor constituents are carbonates, chlorite, biotite, glauconite and heavy minerals. Bentonites and coal beds occur in the Drywood section but are absent in the exposed section at Lundbreck Falls. Calcite is the usual cement. The sandstones are fine- and medium-grained and poorly sorted. The mineralogy of the sandstones suggests that the source region was composed of sedimentary rocks, low-grade metamorphic rocks derived from deltaic sediments, and igneous rocks. The source region probably lay to the south and west in the northwestern States and southern British Columbia. This interpretation is based on the presence of bentonite beds, abundant plutonic quartz and feldspar grains, comparisons of K/Ar age dating from feldspars with those of nearby plutons, and on paleocurrent indicators.

Ogunyomi and Hills (1977) have examined the petrology of the Belly River Formation in the Milk River area. The sandstones are composed of 32%-42% quartz, 3%-24% chert, 14%-41% feldspars, and 1%-7% volcanic rock fragments. Muscovite, biotite, sedimentary and metamorphic rock fragments, and glauconite, are minor constituents. The matrix material ($<20\mu m$) is composed of clays mixed with quartz, feldspar, silt and iron-oxide. Calcite cements most sandstones. The sandstones are mineralogically immature, texturally submature and moderately sorted. Quartz and feldspar grains are angular to subangular. Chert and sedimentary rock fragments are subrounded to subangular. All the postulated source terrains for the sandstones are located to the southwest and west of the Milk River study area. This agrees with the results of Lerbekmo (1963).

The mineralogy of the lower part of the Belly River Formation at Highwood River has been studied by Hunter (1980). The sandstone is composed of quartz (39%), feldspar (8.5%), detrital chert (10.4%), carbonate (9.7%) and volcanic rock fragments (1.0%), and a carbonate/iron oxide/clay matrix. The grains are generally subrounded to subangular.

All of the above sections and the Lundbreck Falls section have similar compositions. The sandstones studied by Mellon (1961) most closely resemble the Lundbreck Falls sandstones. Both sandstones have similar detrital fractions, matrices and cementing mechanisms. The sandstones from Highwood River have more carbonate and less rock fragments and iron oxides than those of Lundbreck Falls.

Blairmore Group: Daisy Creek

The two trough cross-stratified sandstones are composed of detrital chert, quartz, feldspar, rock fragments and carbonate/clay matrix, plus other minor constituents. The quartz and chert grains are subrounded to subangular. Sorting is moderate. There is a noticeable difference in the matrices of the two samples. The matrix of sample 1 is composed essentially of calcite (24%) which infills interstitial spaces. The matrix of sample 2 is composed of 20% clay size particles and only 2% calcite.

CHAPTER FIVE

INTERPRETATION AND DISCUSSION

Wapiabi-Belly River Transition

In Chapter Two environmental interpretations were given for the individual units. An integrated interpretation which accounts for the observed vertical succession of units may now be made.

The sediments of the Wapiabi-Belly River transition were deposited during a regression in the Late Santonian/Early Campanian (William and Burke, 1966). This regression was periodically halted by transgressions responsible for the interdigitation of marine and non-marine sediments. The vertical succession of units may therefore be interpreted in terms of a shallowing trend punctuated by periodic transgressions.

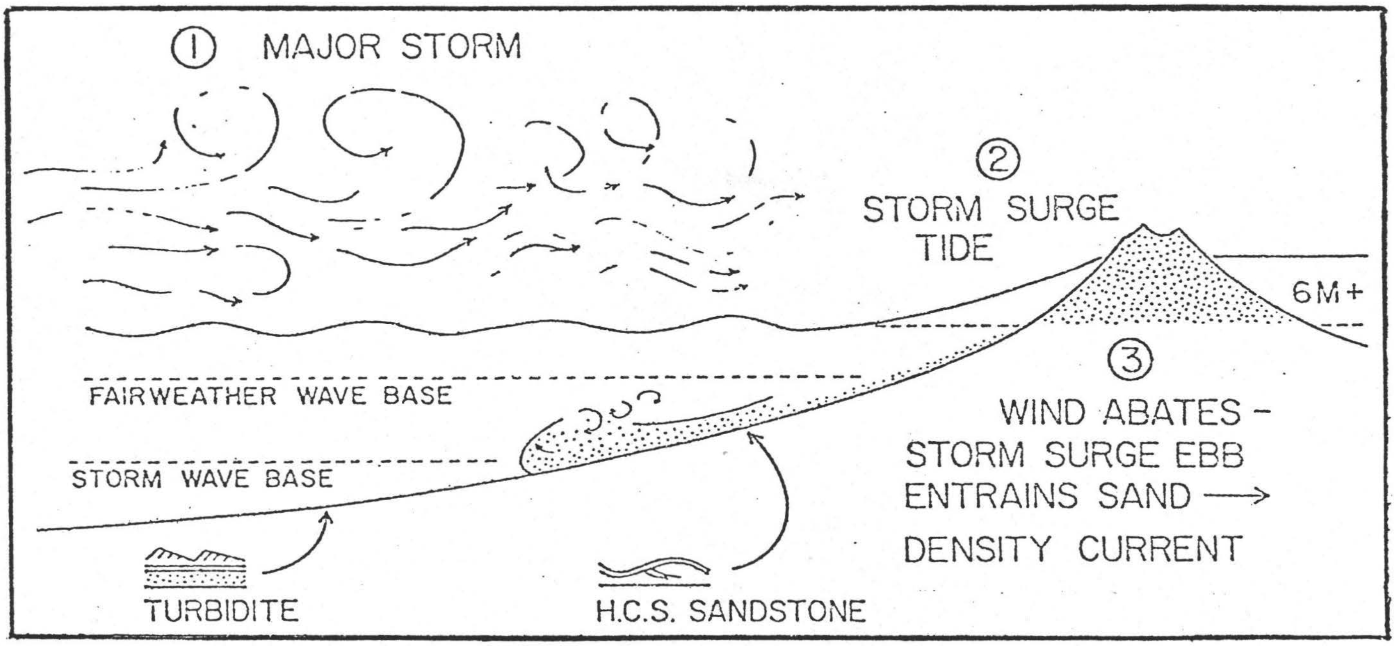
Sediments in the lower part of the outcrop (Units 1-5) were probably deposited in a relatively deep marine environment. The units are characterized by the presence of thin, sharp based, Bouma B, BC and C turbidites. The thickness of individual Bouma beds and the sandstone/shale ratio increases vertically from Units 1 to 3. This thickening upward trend may be produced by prograding turbidite lobes. A regional regression will result in a seaward shift of marine facies and classical turbidite sequences will contain distal turbidites overlain by thicker proximal turbidites. The thickening upward trend may therefore represent a shallowing trend but the seauence will be affected by sediment supply (lobe switching) and the size of turbidity currents. This interpretation is supported by the presence of two sharp-based hummocky cross-stratified sandstone beds interbedded with turbidites in Unit 3. Evidently, these two sandstones were affected by large storm waves and must have been located above storm wave base for those two storm events. The other sandstone beds in Unit 3 and those in Units 1 and 2, are assumed to be deposited below storm wave base as they exhibit no wave formed stratification.

A minor thickening and coarsening upward sequence of turbidites overlies Unit 3. This sequence terminates at the top of Unit 4 and was probably created by the same mechanisms responsible for the formation of the lower thickening upward sequence. Unit 4 is overlain by turbidites (Unit 5) which are thicker (15 cm - 55 cm) than any present in the underlying units. This feature may be related to the shallowing trend which has superimposed thick, relatively proximal turbidites over thinner distal turbidites.

The importance of turbidites in Cretaceous seas has been underemphasized in the past. Turbidites occur in lakes, delta fronts, continental shelfs, deep-sea trenches, abyssal plains and geosynclinal flysch deposits. This wide variety of environments results because turbidites can be produced by any sudden surge of sediment laden water. Turbidity currents can be produced by levee breaks in a river, rivers in flood entering deltas, storm currents and slope failure. The process responsible for generation of turbidity currents at Lundbreck Falls should be of environmental significance.

Turbidity currents in marine environments are commonly assumed to be the result of failure and acceleration on a slope. Failure may result from sediment overloading on a slope or be triggered by earthquakes (Hunter, 1980). Evidence of the slope is often preserved (Walker, 1966) but no evidence of slope deposits occur in the Fernie-Kootenay transition (Hamblin and Walker, 1979) or in the Wapiabi-Belly River transition (Hunter, 1980). An alternative mechanism for the generation of turbidity currents was proposed by Hamblin and Walker (1979) to account for turbidites in the Fernie-Kootenay transition, namely that water driven shoreward in storm surges returned seaward, carrying large amounts of sediment in suspension, thus producing a turbidity current (Fig. 5-1). Sediments deposited between fairweather wave base and storm

FIGURE 5-1: Mechanism proposed for creation of hummocky cross-stratification and turbidites, from Walker (1979).

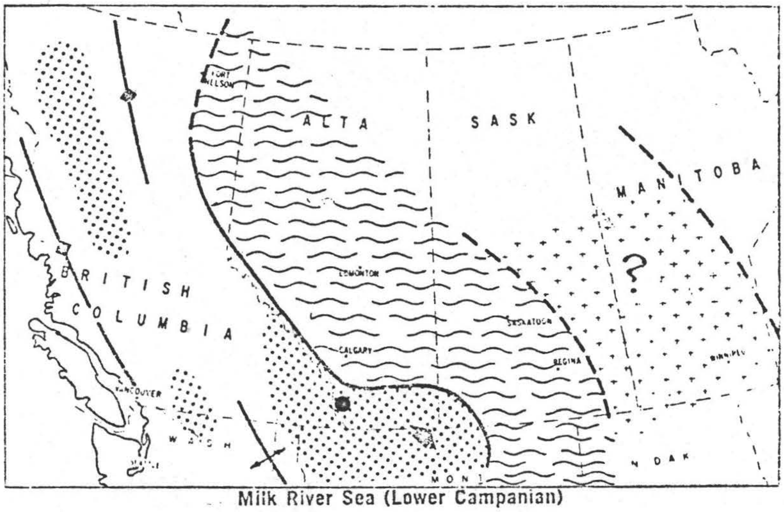

① MAJOR STORM
② STORM SURGE TIDE
6M+
③ WIND ABATES - STORM SURGE EBB ENTRAINS SAND ⟶ DENSITY CURRENT
FAIRWEATHER WAVE BASE
STORM WAVE BASE
TURBIDITE
H.C.S. SANDSTONE

wave base resulted in hummocky cross-stratified sandstones while sands deposited from suspension below storm wave base resulted in turbidites.

At Lundbreck Falls turbidite formation by the storm generation mechanism is favoured over slope failure as a mechanism because thick (15 m) storm generated sandstones (Unit 6) overlie the turbidites. No evidence of a slope or slope deposits is preserved.

The direction of flow of the turbidity currents in Units 1-5 is controlled by the regional paleoslope. Paleocurrent directions obtained from these turbidites (Chapter 3) consistently indicate that the turbidity currents flowed towards the north. A northerly paleoslope is unexpected in the Lower Campanian. The rising cordillera in the west would be expected to shed clastics which flowed to the east or northeast and into the northwest-southeast trending seaway. The Lower Campanian seaway as predicted by Williams and Burk (1966) possesses a lobe of continental deposits advancing towards the northeast (Fig. 5-2). The northerly shore of this lobe may have possessed a northward dipping paleoslope. In order for such a paleoslope to be recorded in the turbidites of Lundbreck Falls the section must be located near the north shore of this lobe. The turbidites of Lundbreck Falls were deposited during the Upper Santonian and Lower Campanian and it is impossible to reconstruct the shoreline position with any degree of

FIGURE 5-2: Proposed extent of Milk River Sea (Lower Campanian) and location of measured section (Lundbreck). Adapted from Williams and Burke (1966).



Milk River Sea (Lower Campanian)

LEGEND

- Direction of major coarse clastic supply
- Direction of minor coarse clastic supply
- ↔ Moderately to strongly positive area
- Weakly positive area
- Continental deposition
- + + + Erosion or non-deposition
- Marine deposition
- ● LUNDBRECK

accuracy. The position of the Lower Campanian shoreline of William and Burk (1966) is even questionable (Hunter, 1980).

A more feasible explanation for the northerly flow directions based on interpretations by Hamblin and Walker (1979) and Hunter (1980) may be applicable to the Lundbreck Falls section. Hamblin and Walker (1979) attributed northerly flow directions in the Passage Beds of the Fernie Formation to the existence of a trough between the emerging cordillera and the Aptian ridge which funnelled sediments to the north-northwest.

Hunter (1980) suggested that northwesterly flow directions in turbidites of the Wapiabi-Belly River transition resulted from density currents which were swept into the trough from the southwest, then swung around toward the northwest. A similar mechanism may have resulted in the northerly flow direction recorded in the turbidites of the Lundbreck Falls section. Northeasterly flow directions have been recorded in fluvial Belly River sandstones by Hunter (1980), Ogunyomi and Hills (1977) (N40^{o}E) and Dodson (1971). Density currents which were swept into the trough from the southwest probably swung around and flowed northward down the regional paleoslope, possibly parallel to the long axis of the trough.

The shallowing upward trend established in Units 1-5, continues in Units 6 to 8. These units are characterized by the presence of sharp based, H. C. S. sandstones deposited by turbidity currents and reworked by storm waves. The siltstones and shales interbedded with the hummocky cross-stratified beds are deposited by fairweather processes then bioturbated to varying degrees. Fairweather processes or waning storm waves may have formed symmetrical ripples on the top of a few H. C. S. beds. A few Bouma B and C type turbidites occur in Unit 7. These were probably deposited below the storm wave base of the storm responsible for generation of the turbidity current. Subsequent fairweather processes have produced symmetrical ripples on the top of the Bouma B turbidites and bioturbated horizons on the top of the Bouma C turbidites. Therefore, the sediments of Units 6-8 (30 m) have been deposited in a marine environment which is usually below normal fairweather wave base but above storm wave base and thus dominated by storm processes which produce sharp based, hummocky cross-stratified sandstones. This environment represents water depths of between approximately 10 m and 100 m, above relatively deep water turbidites and below lower shoreface deposits.

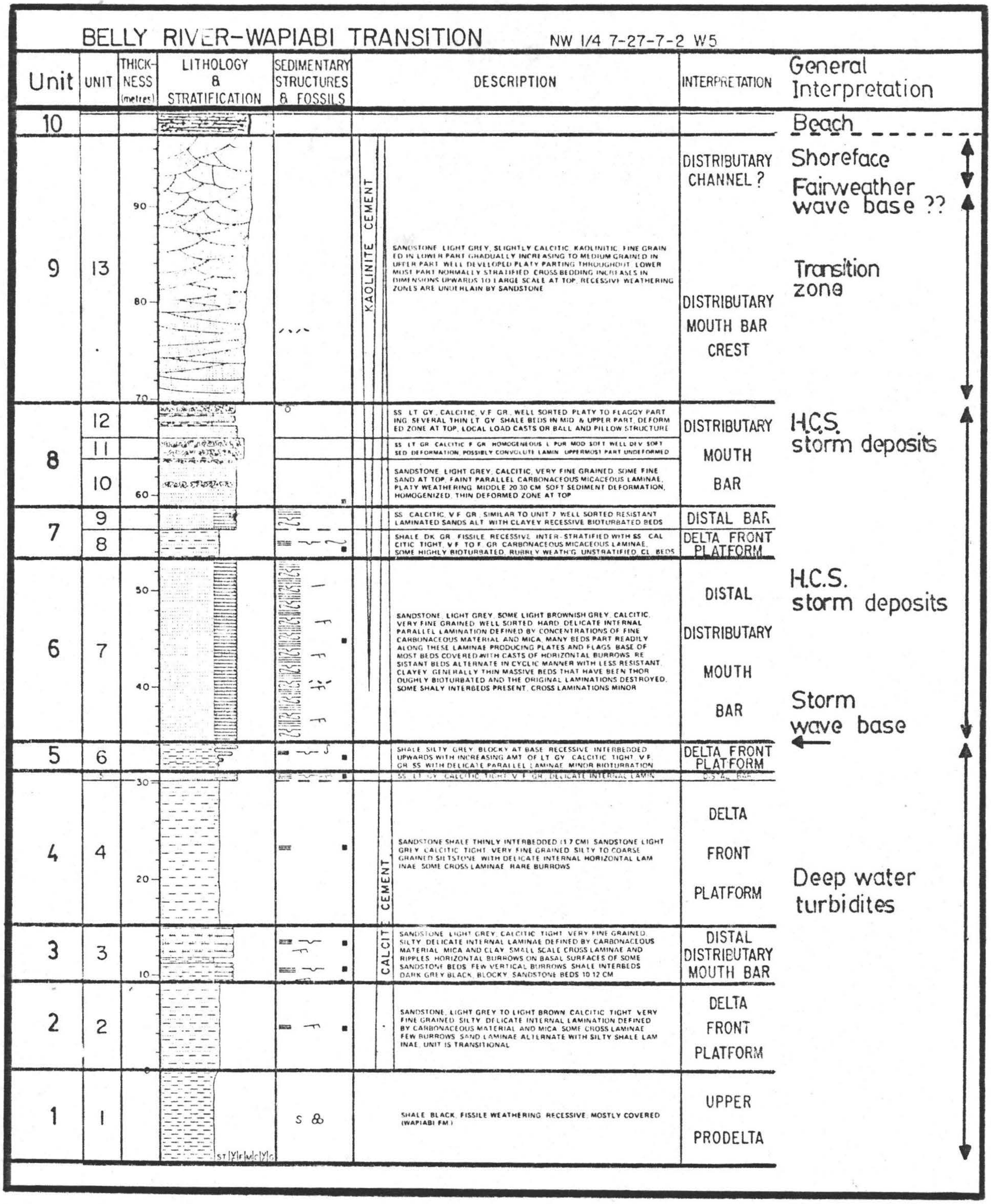
The sedimentary structures contained within Unit 9 are consistent with its stratigraphic position. The unit is situated between beach deposits (Unit 10) and storm deposits, and as a result should contain features indicative of a shallow marine environment influenced by storm processes. The observed association of parallel lamination, hummocky, swaley and trough cross-stratification has been described in Chapter Two. The unit as described represents the result of the interaction of storm generated density currents, waves and normal shallow marine processes. The top 4 m are dominated by trough cross-bedding which probably represents the shallowest water depths in the unit. Unit 9 probably represents an environment situated between a fluctuating storm wave base (10 m - 20 m) and the upper shoreface. The shallowing trend established in Units 1-8 therefore continues in Unit 9.

The shallowing trend is continued through the beach deposits of Unit 10 and into subaerially exposed sandstones and trough cross-bedded fluvial channel sands of Unit 11. The detailed measured section ends at the top of Unit 11 but evidence presented in Chapter Two and Appendix A indicates that the regression may be interrupted by a transgressive marine tongue, approximately 60 m above the top of the measured section.

Distributary Mouth Bars

The Wapiabi-Belly River transition at Lundbreck Falls and Trap Creek has been interpreted in terms of prograding delta front environments by Lerand and Oliver (1975; 1980) and Nelson and Glaister (1975; 1980), respectively (Figure 5-3). Recently, Walker *et al.* (1981)

FIGURE 5-3: Comparison of environmental interpretations from this study and that of Lerand and Oliver (1975; 1980).



BELLY RIVER–WAPIABI TRANSITION NW 1/4 7-27-7-2 W5

Unit	UNIT	DESCRIPTION	INTERPRETATION	General Interpretation
10				Beach
9	13	SANDSTONE LIGHT GREY, SLIGHTLY CALCITIC KAOLINITIC FINE GRAINED IN LOWER PART GRADUALLY INCREASING TO MEDIUM GRAINED IN UPPER PART WELL DEVELOPED PLATY PARTING THROUGHOUT LOWER MOST PART NORMALLY STRATIFIED CROSS BEDDING INCREASES IN DIMENSIONS UPWARDS TO LARGE SCALE AT TOP. RECESSIVE WEATHERING ZONES ARE UNDERLAIN BY SANDSTONE	DISTRIBUTARY CHANNEL ? DISTRIBUTARY MOUTH BAR CREST	Shoreface Fairweather wave base ?? Transition zone
8	12	SS LT GY, CALCITIC, V.F GR., WELL SORTED PLATY TO FLAGGY PARTING SEVERAL THIN LT GY SHALE BEDS IN MID & UPPER PART, DEFORMED ZONE AT TOP, LOCAL LOAD CASTS OR BALL AND PILLOW STRUCTURE	DISTRIBUTARY MOUTH BAR	H.C.S. storm deposits
	11	SS LT GR CALCITIC F GR HOMOGENEOUS L POR MOD SOFT WELL DEV SOFT SED DEFORMATION, POSSIBLY CONVOLUTE LAMIN UPPERMOST PART UNDEFORMED		
	10	SANDSTONE LIGHT GREY, CALCITIC, VERY FINE GRAINED SOME FINE SAND AT TOP, FAINT PARALLEL CARBONACEOUS MICACEOUS LAMINAE, PLATY WEATHERING MIDDLE 20 30 CM SOFT SEDIMENT DEFORMATION, HOMOGENIZED, THIN DEFORMED ZONE AT TOP		
7	9	SS CALCITIC, V.F GR., SIMILAR TO UNIT 7 WELL SORTED RESISTANT LAMINATED SANDS ALT WITH CLAYEY RECESSIVE BIOTURBATED BEDS	DISTAL BAR	
	8	SHALE DK GR FISSILE RECESSIVE INTER-STRATIFIED WITH SS CALCITIC TIGHT, V.F TO F GR CARBONACEOUS MICACEOUS LAMINAE, SOME HIGHLY BIOTURBATED, RUBBLY WEATH'G UNSTRATIFIED CL BEDS	DELTA FRONT PLATFORM	
6	7	SANDSTONE, LIGHT GREY, SOME LIGHT BROWNISH GREY, CALCITIC, VERY FINE GRAINED WELL SORTED HARD DELICATE INTERNAL PARALLEL LAMINATION DEFINED BY CONCENTRATIONS OF FINE CARBONACEOUS MATERIAL AND MICA, MANY BEDS PART READILY ALONG THESE LAMINAE PRODUCING PLATES AND FLAGS BASE OF MOST BEDS COVERED WITH CASTS OF HORIZONTAL BURROWS RESISTANT BEDS ALTERNATE IN CYCLIC MANNER WITH LESS RESISTANT, CLAYEY GENERALLY THIN MASSIVE BEDS THAT HAVE BEEN THOROUGHLY BIOTURBATED AND THE ORIGINAL LAMINATIONS DESTROYED, SOME SHALY INTERBEDS PRESENT, CROSS LAMINATIONS MINOR	DISTAL DISTRIBUTARY MOUTH BAR	H.C.S. storm deposits Storm wave base
5	6	SHALE SILTY GREY BLOCKY AT BASE RECESSIVE INTERBEDDED UPWARDS WITH INCREASING AMT OF LT GY CALCITIC TIGHT V.F GR SS WITH DELICATE PARALLEL LAMINAE MINOR BIOTURBATION	DELTA FRONT PLATFORM	
	5	SS LT GY CALCITIC TIGHT V F GR, DELICATE INTERNAL LAMIN	DISTAL BAR	
4	4	SANDSTONE SHALE THINLY INTERBEDDED (1 7 CM) SANDSTONE LIGHT GREY CALCITIC TIGHT VERY FINE GRAINED SILTY TO COARSE GRAINED SILTSTONE WITH DELICATE INTERNAL HORIZONTAL LAMINAE SOME CROSS LAMINAE RARE BURROWS	DELTA FRONT PLATFORM	Deep water turbidites
3	3	SANDSTONE LIGHT GREY, CALCITIC TIGHT VERY FINE GRAINED, SILTY DELICATE INTERNAL LAMINAE DEFINED BY CARBONACEOUS MATERIAL MICA AND CLAY SMALL SCALE CROSS LAMINAE AND RIPPLES HORIZONTAL BURROWS ON BASAL SURFACES OF SOME SANDSTONE BEDS FEW VERTICAL BURROWS SHALE INTERBEDS DARK GREY BLACK, BLOCKY SANDSTONE BEDS 10 12 CM	DISTAL DISTRIBUTARY MOUTH BAR	
2	2	SANDSTONE, LIGHT GREY TO LIGHT BROWN CALCITIC TIGHT VERY FINE GRAINED SILTY DELICATE INTERNAL LAMINATION DEFINED BY CARBONACEOUS MATERIAL AND MICA SOME CROSS LAMINAE FEW BURROWS SAND LAMINAE ALTERNATE WITH SILTY SHALE LAMINAE, UNIT IS TRANSITIONAL	DELTA FRONT PLATFORM	
1	1	SHALE BLACK, FISSILE WEATHERING RECESSIVE, MOSTLY COVERED (WAPIABI FM.)	UPPER PRODELTA	

and Hunter (1980) have re-interpreted the transition at Trap Creek and Highwood River, finding no evidence of distributary mouth bar deposits. Distributary mouth bars can be subdivided into four distinctive morphological zones namely, bar back, bar crest, bar front, and distal bar (Wright and Coleman, 1974). The deposits consist of interbedded sands, silts and clays in the bar front and distal bar. The bar crest is composed of well sorted sands. Thin, abundant, multidirectional trough cross-laminations, wave and current ripples and parallel laminations produced by wave and current processes are the dominant structures (Coleman, Gagliano and Webb, 1964).

The sharp based hummocky cross-stratified and turbidites have been interpreted as the deposits of storm surge generated turbidity currents. If these beds are deltaic in origin deposited by turbidity currents generated by floods or slope failure, then in shallow (1.5 m - 7.0 m) distal bar and distributary mouth bar environments they would be reworked by waves and tides. Ambient currents, landward return flow and convergent flows also contribute to reworking (Wright and Coleman, 1974). The sediments of Units 2-9 contain little evidence of reworking and cannot represent the deposits of the suggested deltaic environments (Figure 5-3). The H. C. S. beds and turbidites may have been deposited below fairweather wave base by density currents generated by slope failure but no evidence of a slope or slope deposits exists in the section.

Blairmore Group

The Blairmore Group outcrop at Daisy Creek has been divided into three descriptive facies which also have genetic significance. The mudstone facies is characteristic of overbank deposits in the floodplain or inter-channel areas of meandering fluvial systems. Overbank flooding inundates floodplain and inter-channel areas depositing sediments from suspension which fine away from the channel. Subaerial exposure may result in vegetation which produces the vertical roots. The grey colour may result from the maintenance of reducing conditions by a high water table. The interbedded thin (25 cm - 40 cm) ripple cross-laminated and cross-bedded sandstones may be created by episodic decelerating flows. These flows may be generated by distal sheet floods of a fan or crevasse splays. The fluvial origin of this facies has been supported by micropaleontology studies of a shale sample (R. Price pers. commun. Appendix A).

The cross-bedded sandstone facies (CS) can be interpreted as very thick crevasse splay deposits and/or channel deposits. Crevasse splays typically have erosive bases, and internal evidence of waning flow. The upward transition from trough cross-bedding to ripple cross-lamination and ripple drift cross-lamination in Units 4, 6, 10 and 14 is evidence of waning flow. Ripple cross-lamination may have been present on the tops of Unit 2, 8, 12 and 15 but colonization by plants could have obscured stratification. In order to interpret facies CS as crevasse splay deposits evidence of a large river capable of producing thick (1.75 m - 3.0 m) crevasses is essential.

Alternatively, facies CS can be interpreted as channel deposits. The trough cross-beds may have formed from sinuous crested dunes migrating down the channel floor. Planar, tabular sandstones would result from lateral accreting surfaces such as point bars. The ripples may be created by flows over the top of the point bar or low flow during abandonment (neck or chute cut-off). In general the preserved deposits of an active channel will consist of trough cross-bedded coarse sands overlain by ripple-cross-laminated fill sands (Units 4, 6, 10 and 14). Parallel lamination as observed in Unit 15 can occur in many places within a channel. It can be interbedded with trough cross-bedding or ripple cross-lamination. The coarse lag deposits commonly on the floor of channels are absent in this facies (CS).

The thick cross-bedded sandstone facies (TCS) probably represents the deposits of either one very thick channel or composite units comprised of many channels. The base is intensely scoured and casts of large logs are present indicating that flows of high velocity, possibly floods, periodically occurred. Only one thick scoured interval occurs thus suggesting that facies TCS represents only one channel. Large scale trough cross-stratification, large (1 m - 4 m) tabular sets and reactivation surfaces all indicative of in-channel processes are present. The crevasse splays of facies M and CS may have originated from this channel. Alternatively, the cross-bedded sandstones of facies CS may be tributaries of this main channel.

The mudstone facies is the dominant facies in the outcrop, the sandstone:mudstone ratio being 0.58. This situation is usually encountered on alluvial plains traversed by high-sinuosity (meandering) streams.

CONCLUSIONS

1) The vertical succession of sediments which constitute the Wapiabi-Belly River transition at Lundbreck Falls may be interpreted in terms of a shallowing trend produced by the progradation of the Belly River shoreline.

2) The shallowing trend is reflected in the vertical succession of deposits which is as follows: a) Bouma type classical turbidites deposited in relatively deep, quiet marine environments below storm wave base; b) sharp based hummocky cross-stratified sandstones deposited

between fairweather wave base and storm wave base; c) a heterogeneous sandstone (Unit 9) containing parallel lamination, hummocky, trough and swaley cross-stratification, representing an environment situated between the upper shoreface and the upper limits of storm wave base (10 m - 20 m depth); d) parallel laminated beach deposits; e) subaerially exposed sands and muds; f) trough cross-stratified fluvial channel sands.

3) The turbidites and hummocky cross-stratified sandstones have been deposited by storm-generated density currents.

4) These density currents swept into the Milk River Sea (Lower Campanian) (Figure 5-2) from the southwest and then swung around to flow northward down the regional paleoslope. The existence of a northerly paleoslope is suggested by paleoflow directions obtained from solemarks and current ripple cross-lamination.

5) The sandstones are composed of detrital quartz, chert, feldspar, carbonate and rock fragments surrounded by a matrix of carbonate, iron oxide and calcite. Authigenic cements consist of quartz, calcite and kaolinite.

Blairmore Group

The sediments of the Daisy Creek outcrop (Blairmore Group) have been deposited in a sandy, high sinuosity fluvial environment.

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APPENDIX A

APPENDIX A

Six shale samples were taken for micropalentology and palynology investigations performed by W. Brideaux and R. Price. The sedimentary environments as determined from these investigations are compared to the predicted environments of this study in Table A-1.

Four of the six samples (1, 4, 5, 6) are in general agreement with the predicted environments of this study. Samples 1, 4 and 6 are in direct agreement and it should be noted that sample 4 occurs 60 m above the top of the Lundbreck Falls section. This suggests that a marine tongue exists above the top of the measured section, in Unit 12. Sample 5 comes from shales interbedded with turbidites (Unit 2) suggesting a relatively deep, quiet environment below storm wave base. The presence of abundant forams in this sample is used to place it in a shallow marine environment. The type of forams recovered has not been recorded.

Samples 2 and 3 are in disagreement with the predicted environment. No microfauna was recovered in these samples. Only rare spores were found in sample 3. These spores may be allochthonous, transported by winds and currents. Spores and rare angiosperm pollen was found in sample 2. This assemblage may also be allochthonous. The absence of marine fauna may be a function of the high energy level of the environment. Palynology and micropaleontology studies have classified marine environments as fluvial in the past (Walker, pers. commun., 1981).

Lundbreck Falls Sample No. - Unit	Sedimentary Environment from Paleontology	Predicted Sedimentary Environments
1 - 11	Fluvial	Fluvial
2 - 8	Fluvial	Below fairweather wave base
3 - 9	Fluvial	Nearshore
4 - 12	Coastal subaqueous 10m-200m depth	Marine
5 - 2	Shallow marine	Below storm wave base
Daisy Creek		
6 - 1	Fluvial	Fluvial

Table A-1: Sedimentary environments predicted from micropaleontology and palynology <u>versus</u> predicted sedimentary environments from this study. Location of sample indicated by m on Figures 2-1 and 2-2.