CHANGING DEPOSITIONAL ENVIRONMENTS IN THE WAPIABI-BELLY RIVER TRANSITION (UPPER CRETACEOUS) NEAR LONGVIEW, ALBERTA

CHANGING DEPOSITIONAL ENVIRONMENTS IN THE WAPIABI-BELLY RIVER TRANSITION (UPPER CRETACEOUS) NEAR LONGVIEW, ALBERTA

By

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ABSTRACT

The transition from the Wapiabi Formation to the Belly River Formation was studied in two outcrops, Highwood 1 and 2, near Longview, Alberta. The lowest units in the stratigraphic sections consist of deep marine, storm-generated density flow deposits interbedded with shales. They are overlain by dominantly crossbedded sandstones deposited in a marine environment which was dominated by shallow water processes. At Highwood 1, the next deposits are those of a braided fluvial system, which consist of crossbedded sandstones and much conglomerate. There is no shale. At Highwood 2, the fluvial deposits consist of thick sandstone units separated by thick dominantly shale units, with some roots. The uppermost units are again marine sandstones and shales. This return to marine conditions has not been mentioned previously in the literature.

Paleoflow directions indicate that regional paleoslope dipped northwest at the base of the sections, but northeast in the fluvial parts. It is suggested that the slow rate of deposition in the Coniacian and Santonian, coupled with slow subsidence, permitted topographic expression of a northwest trending trough between the emerging Cordillera and the Aptian Ridge. In the Campanian, the trough was filled in with Belly River sediments, so that the paleoflow swung toward the northeast.

Petrographic studies show that these sediments are much like those in the Belly River in the Milk River area, studied by Ogunyomi and Hills (1977).

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CHAPTER 1

INTRODUCTION

OBJECTIVES

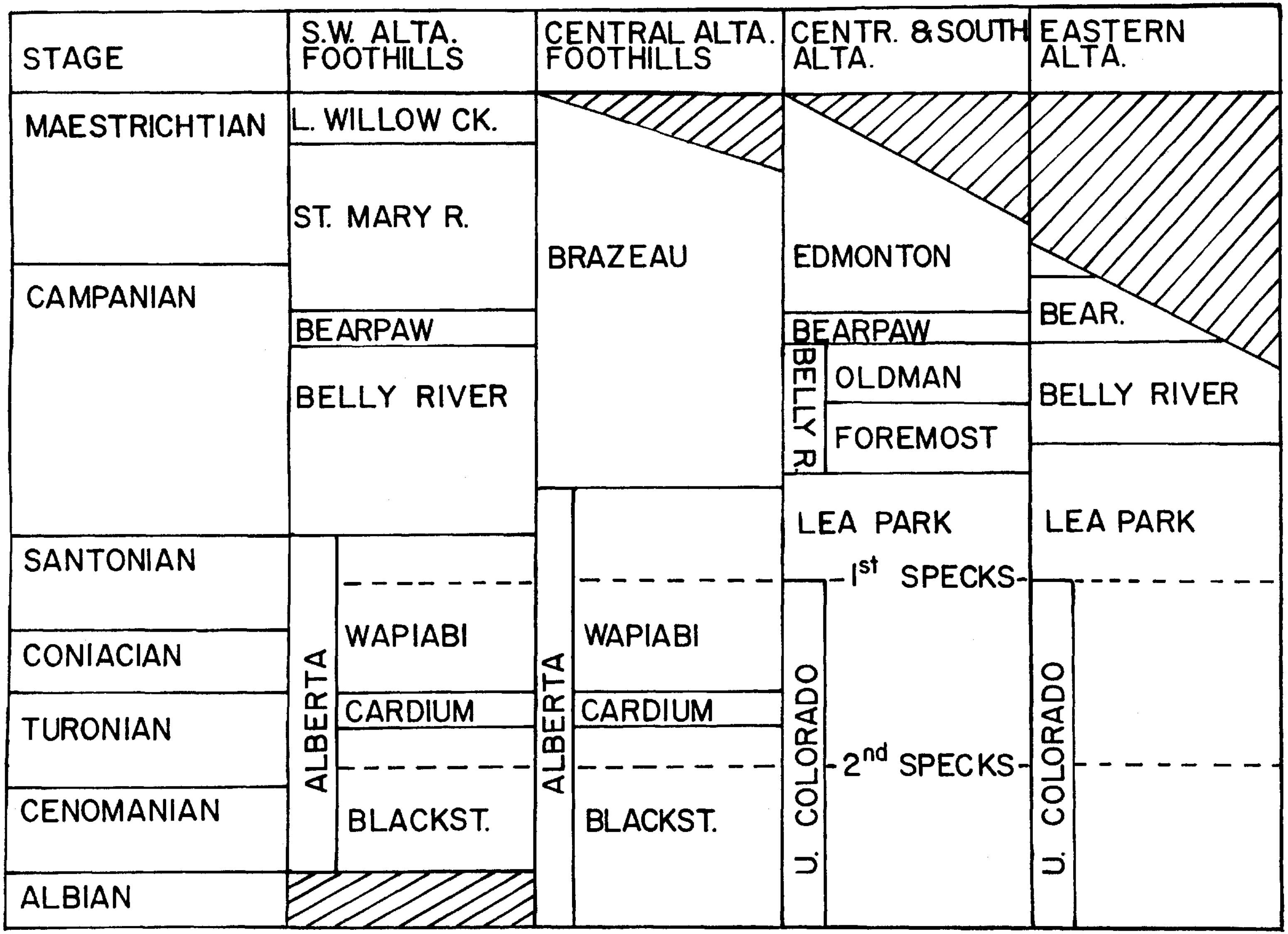
The Upper Cretaceous Belly River Formation consists of a series of sandstones, siltstones and shales (Figure 1-1). Those at the base were deposited in a marine environment, but above them, the rocks are dominantly fluvial in origin. The Belly River thins from an average of 380 m in the Alberta Foothills to about 275 m at 104° longitude in Saskatchewan, where it grades into shale (Williams and Burk, 1966).

The underlying Wapiabi Formation consists of about 500 m of dark, bioturbated shales and interbedded thin, fine-grained sandstones with sharp bases and tops. It has been interpreted as having been deposited in a quiet and relatively deep marine environment (Stott, 1963).

Overlying the Belly River is the Bearpaw Formation, which is a marine sequence very much like the Wapiabi. It is about 120 m thick, and extends only as far north as the present Bow River.

The basic objective of this study is to examine the depositional environments through the transition from the Wapiabi to the Belly River, with two major questions in mind. In eastern Alberta, several marine-nonmarine alternations have been recognized in the lower Belly River (Slipper and Hunter,

Figure 1-1: Stratigraphic timetable of the Upper Cretaceous in Alberta. Adapted from Williams and Burk (1966).

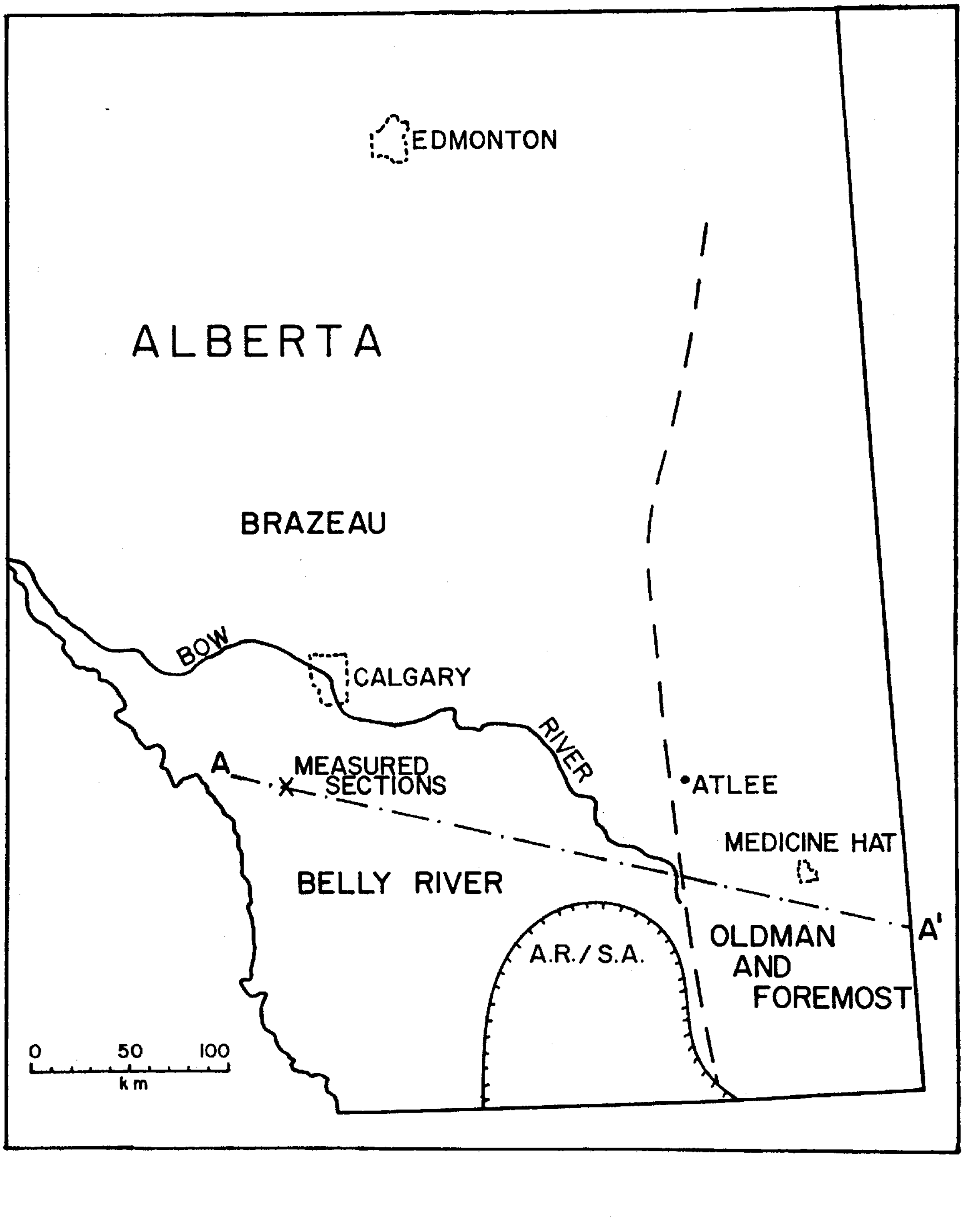

STAGE
S.W. ALTA. FOOTHILLS
CENTRAL ALTA. FOOTHILLS
CENTR. & SOUTH ALTA.
EASTERN ALTA.
MAESTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
L. WILLOW CK.
ST. MARY R.
BEARPAW
BELLY RIVER
ALBERTA
WAPIABI
CARDIUM
BLACKST.
BRAZEAU
ALBERTA
WAPIABI
CARDIUM
BLACKST.
EDMONTON
BEARPAW
BELLY R.
OLDMAN
FOREMOST
LEA PARK
1st SPECKS
U. COLORADO
2nd SPECKS
BEAR.
BELLY RIVER
LEA PARK
U. COLORADO

2

1931; Shaw and Harding, 1954; Ogunyomi and Hills, 1977; Shouldice, 1979). None of these alternations has been found west of about 111° ato 112° longitude, half way between Mėdicine Hat and Lethbridge, (Shaw and Harding, 1954; Shouldice, 1979), so that in the foothills, all of the Belly River above the basal transition from the Wapiabi is allegedly nonmarine (Figure 1-2). Therefore, the first question to ask is whether there are any marine tongues in the lower part of the Belly River in the Foothills region of Alberta.

The discovery of the recently-defined hummocky cross stratification (Harms et al., 1975) in both the Fernie-Kootenay transition (Hamblin and Walker, 1979) and the Cardium Formation (Ainsworth, Duke and Walker, personal communication) has resulted in the reinterpretation of their environments of deposition. They are now considered to have been deposited in storm-dominated, shallow marine environments, since hummocky cross stratification is apparently the result of reworking of sediments below fair-weather wave base by storms. The Fernie,Kootenay and Cardium Formations are all found in the same geographic region as the Belly River. The second question, then, is whether the shallow marine part of the Belly River Formation was indeed deposited in the quiet environment of a prograding delta as suggested by Nelson and Glaister (1975), Lerand and Oliver (1975) and Glaister and Nelson (1978), or if it

Figure 1-2: Map of southern Alberta, showing western extent of the Oldman and Foremost (dashed line). The Belly River Formation covers the area south of the Bow River; north of the Bow River, where the Bearpaw shales are not present, it is called Brazeau. The line AA' is the approximate position of the schematic cross section in Figure 1-3. It can be seen that the studied sections are about 175 km west of the supposed limit of marine members of the Foremost. "A.R./S.A." is Aptian Ridge/Sweetgrass Arch. Adapted from Shouldice (1979).


EDMONTON
ALBERTA
BRAZEAU
BOW
CALGARY
RIVER
A
MEASURED SECTIONS
ATLEE
MEDICINE HAT
BELLY RIVER
A.R./S.A.
OLDMAN AND FOREMOST
A'
0 50 100
km

too was storm dominated.

PREVIOUS WORK

Dawson (1883, 1884) was the first person to examine the Belly River Formation. He divided it into lower marine "yellow beds" and upper, dominantly freshwater "pale beds". Although he noted that the upper beds were influenced by strong currents or wave action, Dawson actually interpreted them as lake deposits. Tyrrell (1886) found that he could trace the upper and lower beds westward into central Alberta, where the distinction died out, and the fauna was nonmarine in origin. Dowling (1917) renamed the yellow beds "Foremost", and Slipper and Hunter (1931) interpreted them as being lagoonal, deltaic and beach sediments, interfingering with the deposits of a regressive Lea Park sea.

In eastern Alberta, the Belly River has been divided into ten members, with depositional environments alternating between continental and marine (Shaw and Harding, 1954). None of the marine members, as correlated primarily from electric logs and core data, extends westward of about 110° to 112° longitude south of Edmonton.

Lerbekmo (1963) studied the sedimentary structures in outcrop along the Drywood River, but focussed on the petrology of the Belly River deposits. He interpreted the deposits to be those of a low-lying coastal plain with channels and overbank deposits. There were rapid shoreline shifts. He suggested, from petrographic evidence, that the source of the sediments was in the south.

The Trap Creek section has been interpreted in terms of a prodelta, distributary mouth bar and delta plain (Nelson and Glaister, 1975; Glaister and Nelson, 1978). Further south, near Lundbreck Falls, Lerand and Oliver (1975) interpreted a section also as a prograding delta. Shawa and Lee (1975) considered a Chin Coulee section to be crevasse splay and marsh deposits overlain by a fluvial channel.

Ogunyomi and Hills (1977) based their interpretation of the transition from the Wapiabi to the Belly River on eighteen measured sections in the Milk River area. The lower (Foremost) part they considered to exhibit cycles of sedimentation, including barrier island, lagoon and marsh deposits. The upper (Oldman) part was deposited in a fluvial environment.

In Shouldice's (1979) study of the Belly River in the subsurface, its log characteristics and reservoir characteristics were defined, but depositional environments were not discussed.

In summary, in eastern Alberta, the Belly River Formation consists of alternating marine and nonmarine units overlain by nonmarine, dominantly fluvial deposits. The transition at the base consists of the deposits of a prograding shoreline. In central and western Alberta, however, there are supposedly no marine tongues once the shoreline has been crossed.

The economic significance of the Belly River Formation has been the main reason for the many studies of its characteristics. The early studies by Dawson (1883, 1884), Tyrrell (1886) and Dowling (1917) were undertaken to estimate its coal deposits, which are extensive, particularly in eastern Alberta. Mellon (1961) studied the magnetite deposits in various Belly River sandstone units near Crowsnest Pass. More recently, it has been the Belly River's oil and gas which have prompted studies, particularly in the subsurface (Shouldice, 1979).

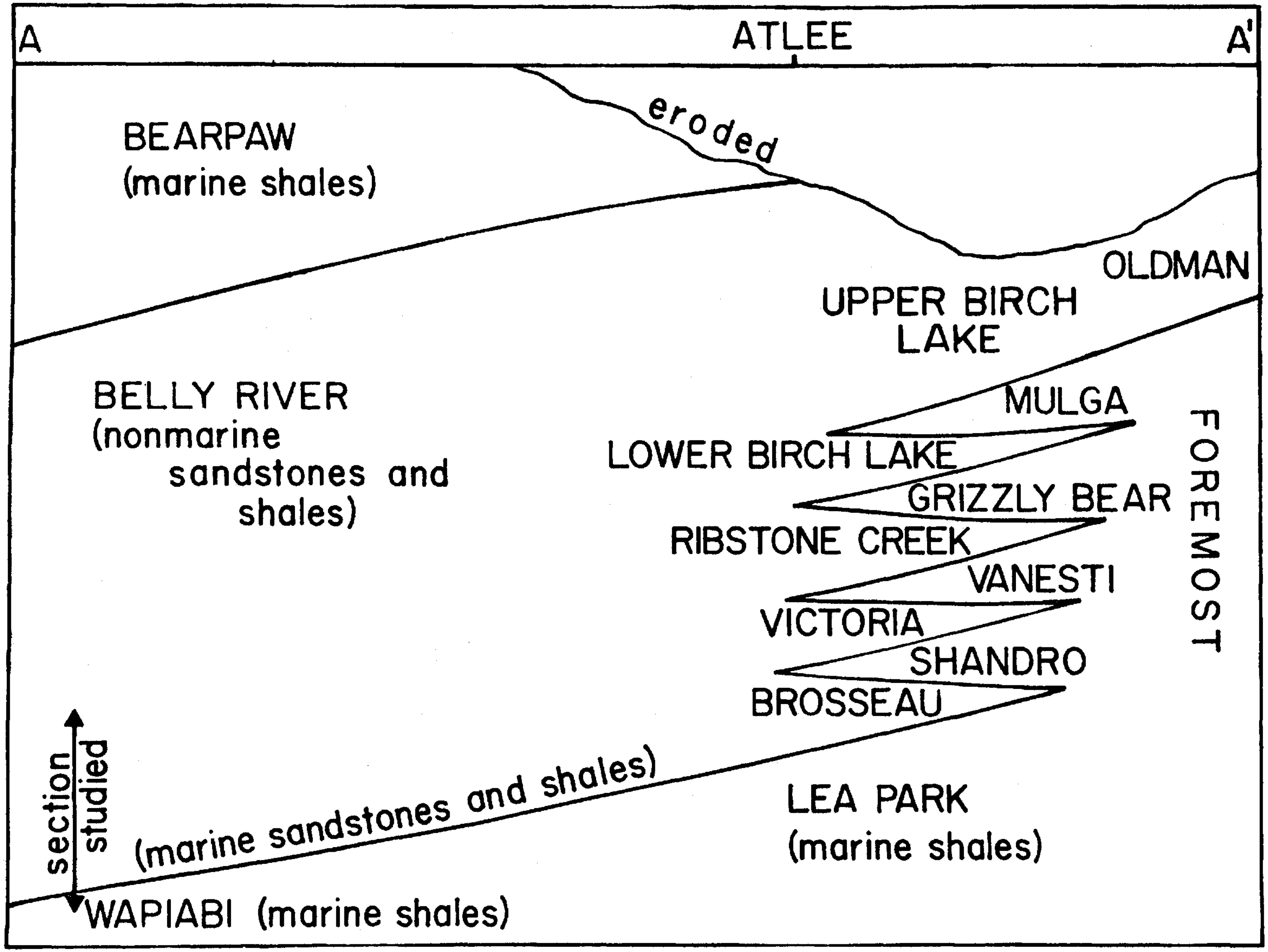
STRATIGRAPHY AND STRUCTURE

In the Upper Cretaceous, there was a series of worldwide transgressions and regressions which has been revealed through seismic stratigraphy (Vail et al., 1977). At the same time, there was a shallow epeiric sea which covered a considerable portion of North America, and at various times was linked with the oceans in the north and south (Williams and Burk, 1966). Although the worldwide changes in sea level would have been present in the Cretaceous seaway, it is probable that periodic uplift in the Cordillera in western North America was the dominant control for the shoreline in the seaway. Erosion of the Cordillera would also have provided the major source of clastic sediments deposited in the sea.

Early in the Campanian, changes in sea level (probably due to uplift of the Cordillera) resulted in alternating marine and nonmarine environments in the area which is now central and southern Alberta. The Belly River sediments deposited in these fluctuating environments have been collectively called Foremost, and have individually been given member status (Figure 1-3). Subsequent uplift and erosion resulted in the deposition of continental sediments for the rest of Belly River time, and these sediments were called Oldman in eastern Alberta. A relative rise in sea level then covered the area of Alberta up to the region of the present Bow River, depositing the marine shales of the Bearpaw Formation. After more uplift and erosion in the Cordillera, the continental clastics of the Edmonton Formation were deposited in central and southern Alberta, and equivalent St. Mary River clastics in the southwest Alberta foothills (Figure 1-2).

Two recent attempts to clear up this confusion in nomenclature have been made by McLean (1971, 1977), primarily from cores. He suggests that the names "Belly River", "Oldman" and "Foremost" be dropped in east and central Alberta and "Judith River", which is older and is used in Montana, U.S.A. be adopted. McLean's reasoning is that the Oldman and Foremost cannot always be distinguished in eastern Alberta, and therefore should not have different names. He points out that the distinction between Oldman and Foremost has never been made in western Alberta since the marine units of the Foremost do not reach that far, and therefore there has been no problem. However, evidence will be presented

Figure 1-3: Schematic cross section along line AA' of Figure 1-2 (not to scale), showing alternating marine and nonmarine members of the Foremost Formation, Belly River Group, Central and Southern Alberta. The relative position of the studied sections, 175 km west of the apparent limit of the marine Foremost members, is also shown. Adapted from Shouldice (1979).


A
ATLEE
A'
eroded
BEARPAW
(marine shales)
OLDMAN
UPPER BIRCH
LAKE
BELLY RIVER
(nonmarine
sandstones and
shales)
MULGA
LOWER BIRCH LAKE
GRIZZLY BEAR
RIBSTONE CREEK
VANESTI
VICTORIA
SHANDRO
BROSSEAU
FOREMOST
section
studied
(marine sandstones and shales)
LEA PARK
(marine shales)
WAPIABI (marine shales)

here for a marine tongue in the dominantly fluvial part of the Belly River in western Alberta. It is unknown whether this marine tongue can be traced to eastern Alberta, but considering this new information, it seems impractical to abolish the nomenclature currently used in eastern Alberta.

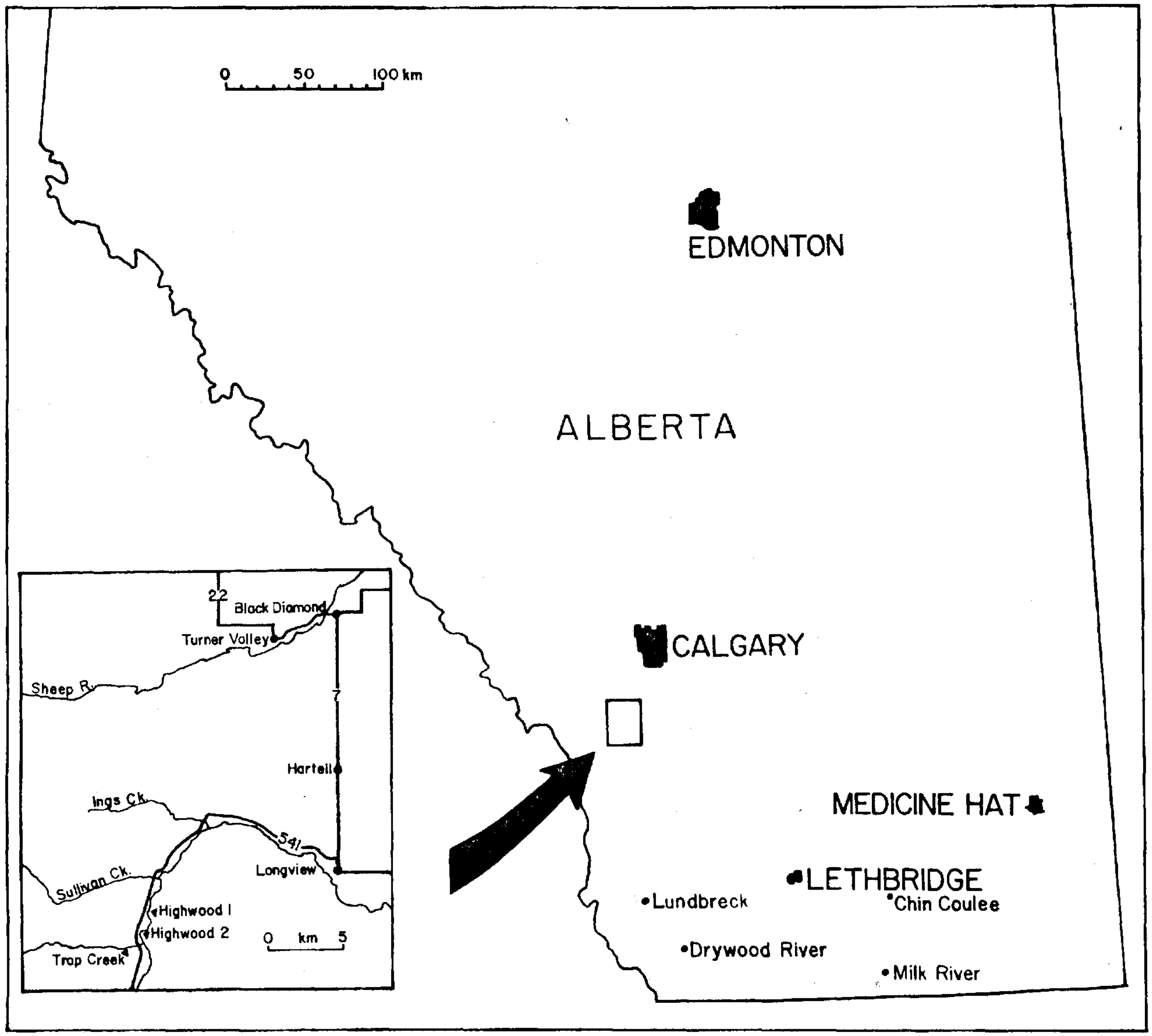
LOCATION

Two Belly River outcrops, which will be referred to as Highwood 1 and Highwood 2, were studied in the field in the summer of 1979 (Figure 1-4). Both are well exposed along the Highwood River, to the south of Highway 541 at 17.9 and 21 km respectively, west of Longview Alberta. The outcrops cannot be seen from the highway.

Since this area is in the Foothills District of Alberta, there are repeated thrust faults which cause the beds to dip steeply westward, and make exact correlations of stratigraphic units difficult.

These Belly River outcrops are mostly two dimensional. The measured sections at Highwood 1 and 2 are 105.7 and 131.2 m thick respectively -- about one-third of the total thickness of the Belly River Formation in this area. Although the rocks are exposed on both sides of the river at both outcrops, high flow conditions prevented crossing to observe the sedimentary structures on the south side at Highwood 1, and restricted observations at Highwood 2.

Figure 1-4: Map of southern Alberta, showing the location of the measured sections, Highwood 1 and 2. Also shown are the locations of the Drywood (Lerbekmo, 1963), Trap Creek (Nelson and Glaister, 1975; Glaister and Nelson, 1978), Chin Coulee (Shawa and Lee, 1975), Lundbreck Falls (Lerand and Oliver, 1975) and Milk River (Ogunyomi and Hills, 1977) sections.


0 50 100 km
EDMONTON
ALBERTA
CALGARY
MEDICINE HAT
LETHBRIDGE
Lundbreck
Chin Coulee
Drywood River
Milk River
22
Black Diamond
Turner Valley
Sheep R.
7
Hartell
Ings Ck.
541
Longview
Sullivan Ck.
Highwood 1
Highwood 2
Trap Creek
0 km 5

CHAPTER 2

FACIES DESCRIPTIONS

In the field, each of the Highwood sections was divided into over thirty "units" on the basis of such features as lithology, internal and sedimentary structures and grain size. Later, it became evident that these field "units" could be greatly reduced in number, and condensed into descriptive units, or facies (Figure 2-1). Certain facies at Highwood 1 are virtually the same as those at Highwood 2, and they will be described together. Therefore, Units 1A and 2A, for example, represent the same facies at Highwood 1 and 2 respectively.

UNITS 1A AND 2A

Units 1A and 2A contain the lowest part of the transition from the Wapiabi Formation to the Belly River Formation at Highwood 1 and 2 respectively (Plate 2-1). They consist of marine shales interbedded with thin, fine-grained sandstones and siltstones. The sandstones are generally less than 40 cm thick, averaging about 20 cm. The shales occur both in packets about 1 m thick, and in thinner zones between similar sandstone beds, where they may be 1 to 25 cm thick. The siltstones are often shaly and are 1 to 28 cm thick, averaging around 10 cm.

Plate 2-1: Upper Wapiabi and Unit 1A (at right) on the south side at Highwood 1. The rocks are marine shales and thin, fine-grained sandstones and siltstones.

The sandstones have sharp bases, and tops which are bioturbated or have symmetrical ripples with wavelengths of about 10 cm. There are three main sandstone types. The first type has small scale hummocky cross stratification of wavelength 50 to 65 cm and amplitude 3 to 4 cm (Plate 2-2). Second, there are sandstone beds with undulating parallel laminations that lack the regular periodicity which characterizes hummocky cross stratification. Third are those sandstone beds with parallel horizontal laminations. The undulating and horizontal laminations do not occur in the same sandstone beds as hummocky cross stratification, and are generally above it in the unit. The fourth type of sandstone bed, about 50 to 60 cm thick, is that with cross stratifications with maximum apparent dips of 10 to 18 degrees. They occur in the upper part of the unit.

There are inorganic sole markings on most of the sandstone beds, in the form of tool marks (mostly grooves), and fluted burrow tubes or current crescents. Organic markings such as trails and burrows were found on the tops and on the soles of the beds. The siltstones and shales also have a bioturbated or mottled appearance.

As a preliminary interpretation, the sandstones in this unit may be the deposits of largely storm-induced density flows in an otherwise quiet, relatively deep marine environment below fair weather wave base. This interpretation is based on a comparison with "Facies C" of the Fernie-

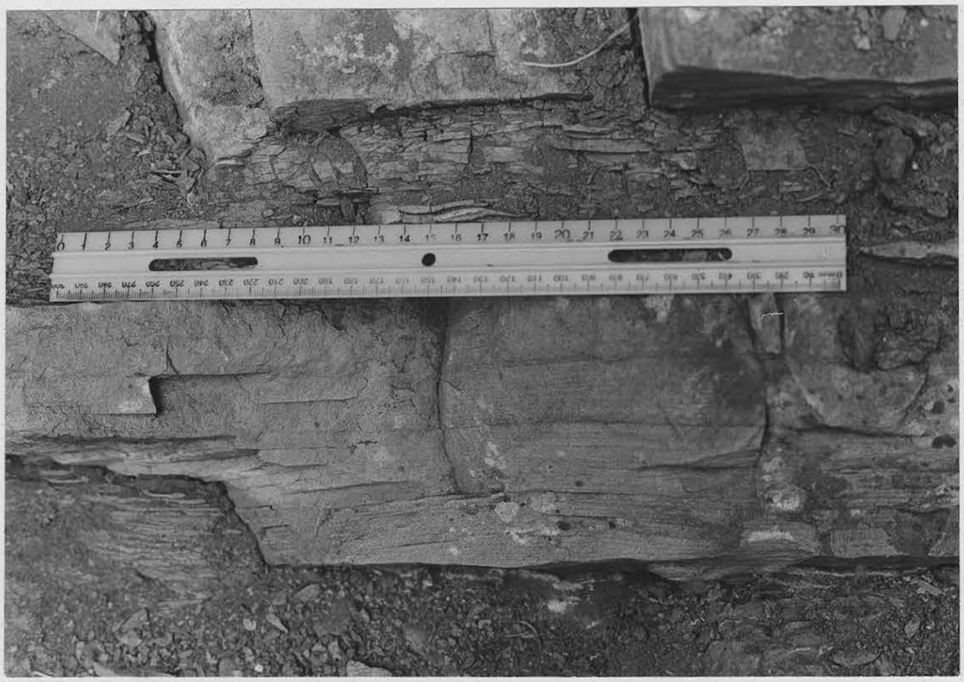


Plate 2-2: Upward dome of a small scale hummocky cross stratification set in Unit 1A. Scale is in centimetres.

Kootenay transition (Hamblin and Walker, 1979).

UNITS 1B AND 2B

Units 1B and 2B are also made up of interbedded sandstones and shales, but the sandstone to shale ratio is much greater, at about 2:1.

The sandstones range in thickness from 0.1 to 1.6 m, averaging about 0.6 m. They have sharp bases but the tops may be either sharp or grade into shale. At Highwood 2, two of these beds contain possible hummocky cross stratification. Complete hummocks were not observed, but wavelengths were estimated to be about 1 m, and amplitude 3 to 4 cm.

In a few other sandstone beds there is trough cross stratification in sets about 15 cm thick. However, some of it was distorted by a large slump or scour which cut down into these beds. There are also a few beds, about 10 to 25 cm thick, with horizontal parallel laminations throughout.

Ripple cross laminations are common on the tops of the sandstone beds. The ripple form is generally symmetrical. On beds where the form is asymmetrical, the internal laminations usually have apparent dips in different directions. There are also interference ripple marks on the tops of some beds. The wavelengths for the ripples are about 10 to 12 cm. Ripple marks may be found on sandstone beds with any of the other internal sedimentary structures.

Most of the bases of the sandstone beds seen have organic and/or inorganic sole markings. The organic markings (also seen on the tops of beds) were casts of horizontal trails (Planolites) and vertical tubes (Skolithos). The inorganic sole markings were grooves, and casts of fluted-out burrows on the underlying beds. Some of the bases also had casts of small scours into the underlying beds, usually 20 to 25 cm long and 3 to 4 cm deep. There may be rip up shale or mud clasts in the casts. There are carbonaceous flecks through many of the sandstone beds.

The shales are 30 cm or less in thickness, and are usually dark grey. They appear to contain a lot of carbonaceous material, and commonly have a churned, bioturbated appearance.

The basic interpretation of these units is much the same as that of Units 1A and 2A. In this case, however, the water may have been shallower because there is a larger sandstone to shale ratio, and a small amount of medium-scale crossbedding.

UNITS 1C and 2C

Unit 1C is a sharp-based, 9 m sandstone. The base has tool marks (grooves, flutes) and organic trails and burrows. There are no shale breaks whatsoever, and internally it is mostly apparently structureless, but does contain a few parallel laminations with subtle changes of apparent dip of about 8° (Plate 2-3a). These laminations are seen only on the joint surfaces in the lowest 1.5 m of the unit, and

Plate 2-3: Units 1C and 2C. a) Parallel laminations with subtle changes of dip on joint surfaces in Unit 1C. b) Fracture surfaces on Unit 2C.

a)

b)

occur in packets less than 10 cm thick. There is no curvature in the laminations.

Grain sizes in Unit 1C are quite consistent at about 0.1 mm, except at the top of the unit, where it coarsens to about 0.3 mm. Also, the rock is more calcareous where the grain size is finer.

Near the top, there are a few shale clasts. The top of the unit may be amalgamated with the base of the overlying unit, 1D, which is also considered marine.

At Highwood 2, Unit 2C is very similar to Unit 1C, and is an 8.6 m sandstone (Plate 2-3b). The base is sharp, with a few scours containing shale clasts. The basal 5 m part is mostly massive but contains some internal parallel laminations like those of Unit 1C. However, there are 3 thin shale partings about 2 cm thick in the upper 3.6 m, and the internal laminations change to crossbeds with set thicknesses of 20 to 30 cm. The top is sharp and is overlain by Unit 2F, which again is interpreted as marine.

In the field, Units 1C and 2C appeared enigmatic, so any interpretations will be left until later.

UNIT 1D

The beds that make up Unit 1D are sandstones. Above the base of the lowest sandstone, which may be amalgamated with the top of Unit 1C, there may be some hummocky cross stratification, but complete hummocks were not seen. This 1.04 m sandstone becomes massive upward.

Overlying that subunit is a 0.5 m thick subunit of thinly-weathering micaceous sandstone with parallel to undulating stratification, which is cut by a broad, flat trough over 2 m wide and 0.46 m deep. The trough fill consists of thin sandstone beds which generally follow the contours of the base of the trough, but become parallel at the top. The fill grades up into 0.2 m of very weathered, coarse, sandstone which reacts strongly with hydrochloric acid.

The next sandstone subunit is 8 m thick, sharp-based, and has no shale partings. Within the lower 7 m are a few low-angle, upward doming intersections of stratification (possibly partial views of hummocky cross stratification), overlain by 3 or 4 more continuously exposed possible sets of hummocky cross stratification. The top metre of the subunit contains a well exposed hummocky cross stratification set in which 1 hummocks and 2 troughs can be seen (Plate 2-4). The wavelength is 5 m and the amplitude 0.2 m.

The top of the unit is draped by the overlying Unit 1E.

The basic interpretation of Unit 1D is that it was deposited just below fair weather wave base in a storm dominated shallow sea. This interpretation is based on the presence of large scale hummocky cross stratification, the absence of crossbeds and any shale, and the position of the unit in the total section.

Plate 2-4: Large scale hummocky cross stratification set (wavelength 5 m, amplitude 0.2 m) at the top of unit 1D. Hammers are approximately at the positions of troughs.

UNIT 1E

The shallow marine unit at Highwood 1 is at least 12.1 m thick. Subunit A is a 0.18 m upward-fining zone of sandstone laminations and carbonaceous material. It is quite weathered and recessive. The subunit has a planar top, and the laminations drape the hummocky cross stratifications of the underlying unit at the base. There are a few trace fossil burrows, possibly Diplocraterion.

Subunit B is a sharp based, 8 m thick sandstone. In the lower half are abundant trough crossbeds with set thicknesses of about 0.5 m and a few ripple cross laminations. Grain sizes fine from 0.3 mm at the base of the subunit to 0.25 mm at the top of the crossbeds. The next 0.85 m is essentially horizontally stratified, and is overlain by more crossbeds for half a metre, 0.75 m of massive sandstone, and a 1.1 m thick infilled trough. The exact width of the trough is not known, but it is over 4 m. The grain size here is 0.2 mm. There are several Skolithos burrows.

Subunit C, gradational from the top of subunit B, is a 0.6 m limestone bed, which is blocky and is weathered brown. Its upper surface is scoured.

The sandstones which make up subunit D scour through subunit C down to subunit B. There are large mud clasts in the base, the largest being 9 cm by 5 cm in two dimensions. A sequence of trough crossbeds, 15 to 40 cm per set, horizontal bedding and/or sinuous crested ripples repeats 3 times in a thickness of about 3 m. There are a few subparallel wood fragments in the base of one scour. The top has a few limy concentrations, where there are some burrows. From a study of the palynology in this section, the large amount of terrestrially-derived organic material is indicative of a very shallow marine environment (Dr. S. Pocock, personal communication).

Subunit E, 0.45 m thick, is covered.

Next is subunit F, which is 7 cm of very thin sandstone and shale interbeds. The sandstone to shale ratio is 1:1.

Subunit G is a 0.2 m thick, slightly lenticular sandstone. The base has grooves, prod marks, rib and furrow, and a few shale clasts.

The preliminary interpretation of unit 1E, based on the large-scale crossbeds with Skolithos burrows, the palynology, and the position of the unit in the sequence, is that it was deposited in a shallow marine environment. More detailed interpretations will be left until later.

UNIT 1G

Unit 1G overlies a 7 m interval which is largely covered with debris. The uncovered patches mostly reveal black, carbonaceous shale interbedded with a few thin siltstone beds. These siltstones are about 5 cm thick, contain a few coal fragments, and have some iron stains. Internally, they are massive.

The nonmarine beds which make up Unit 1G are a total of

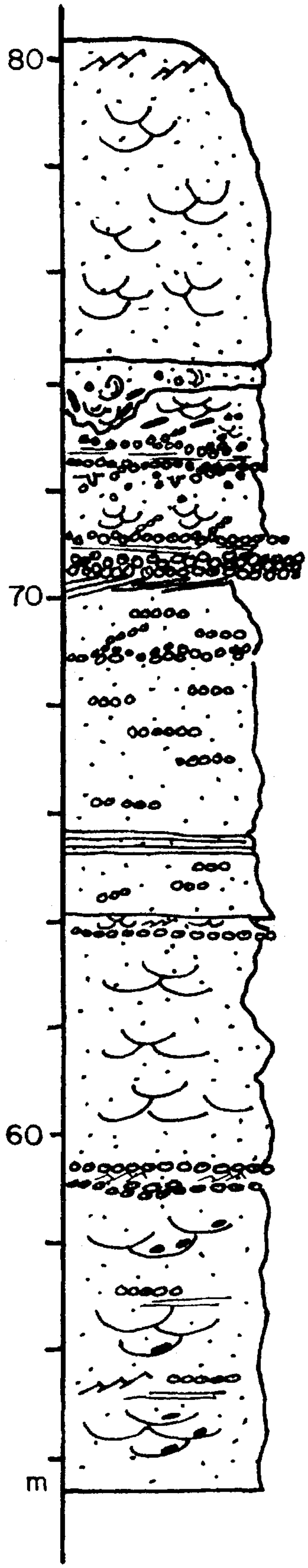
27 m of resistant sandstone and conglomerate with no shale breaks (Figure 2-2). In the 5.7 m above the sharp base are many large-scale (0.5 m per set) trough crossbeds, some of which are truncated by horizontal beds. These troughs have irregular bases with rip-up clasts. In some places complete laminae can be followed over the crest of the crossbeds. Pebbles 1 cm or less in diameter are found in a few discontinuous stringers. There are also coaly flecks and climbing ripples.

The uppermost of these crossbeds are scoured by conglomerate which fines upward to sandstone, and thins laterally. There are crossbeds in the sandstone, each set being about 0.2 m thick.

The next 12 m is made up of sandstone with discontinuous chert pebble stringers, and conglomerate (Plate 2-5). The conglomerates vary from a few pebbles thick to 0.4 m. The smaller pebbles are almost round to oval in shape, the longest dimension being 1.0 cm. Larger pebbles are usually oval, and may be up to 7 cm in length. A couple of conglomerate beds have flat bases but undulatory tops, as though worked into dunes.

Interbedded with these conglomerates are sandstones 0.18 to 3.2 m thick, with trough crossbeds which are 0.3 to 0.5 m thick per set. The crossbeds may be truncated by plane beds. Pebbles occur along the foresets of trough crossbeds, in horizontal stringers, or, to a lesser extent, scattered throughout the beds. These pebbles are essentially the

Figure 2-2: Detailed drawing of Unit 1G, the nonmarine unit at Highwood 1. Refer to text for further explanation.



HIGHWOOD I
DETAILED DRAWING
OF UNIT IG
BRAIDED FLUVIAL

LEGEND
- TROUGH CROSSBEDS
- CLIMBING RIPPLE CROSS LAMINATIONS
- LOW ANGLE INCLINED LAMINATIONS
- TRACE FOSSIL
- SLUMP, DISTORTED BEDDING
- PEBBLES, CONGLOMERATE
- RIP-UP CLASTS

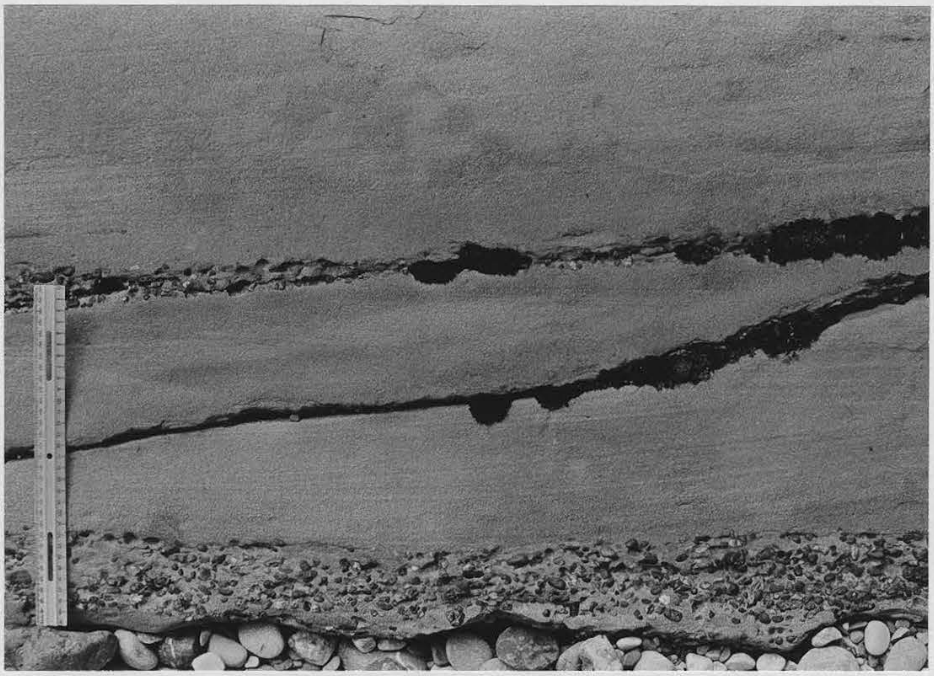


Plate 2-5: Pebble horizon in nonmarine Unit 1G. Scale is in centimetres.

same as those in the underlying conglomerate, and may, in fact, have been derived from the conglomerate. In addition, these sandstones may have a few asymmetrical ripples, carbonaceous flecks, and a bit of iron staining.

Next is a 0.2 m conglomerate which grades up into 0.75 m of sandstone with 0.4-m per set crossbeds and pebble stringers. It is essentially the same as the underlying sequences until this level. However, then the sandstones become bioturbated in appearance, and there are a few trace fossils. Chert pebbles are scattered throughout this upper 0.53 m.

Then the sandstone is scoured into by a 1.36 m sequence of conglomerate and pebbly, crossbedded sandstone repetitions. It contains many coal fragments.

A 1 m thick slump feature cuts into underlying sandstones and conglomerates next. The slump is a churned mixture of sandstone, pebbles, mud clasts and coal lenses.

Finally, there is a 6 m grey sandstone with almost continuous crossbeds of 0.3 to 0.4 m thickness per set. The uppermost 0.45 m has climbing ripple cross laminations. There are no pebbles in this sandstone.

The basic interpretation of Unit 1G is that it consists of fluvial deposits, probably braided.

UNITS 1J and 2J

The uppermost units at Highwood 1 and 2 indicate a return to a marine environment. At Highwood 1, Unit 1J overlies a 13.6-m covered interval, which is probably black shale (from comparison with the south side of the river). Unit 1J consists of 3 parts: 1) a basal 3-m sandstone, 2) a 7.6 m interval of resistant shales and thin, silty sandstones, and 3) a sandstone 1 m thick with many ironstone concretions.

The basal sandstone has a fairly sharp base. There are trough crossbeds in sets 30 cm thick near the base, but they decrease in number towards the top. There are a few trace fossils. The upper contact is gradational.

The resistant shales and silty sandstones appear very bioturbated, and have many iron stains. They contain marine dinoflagellates (Dr. S. Pocock, personal communication) and arenaceous foraminifera Verneuilinoides bearpawensis Wickenden and Haplofragmoides c.f. H. rota Nauss (Mr. J.C. Hanna, personal communication). The sandstones are a maximum of 10 cm thick, and have thin, parallel, horizontal laminations and a few ripple cross laminations. It is overlain by an extremely resistant sandstone 1 m thick which contains many ironstone concretions (Plate 2-6a).

The uppermost unit at Highwood 2, Unit 2J, also consists of 3 parts: 1) a basal sandstone of 6.5 m thickness, 2) 1 m shale and 3) sandstone 2 m thick, pebbles scattered throughout, and ironstone concretions (Plate 2-6b).

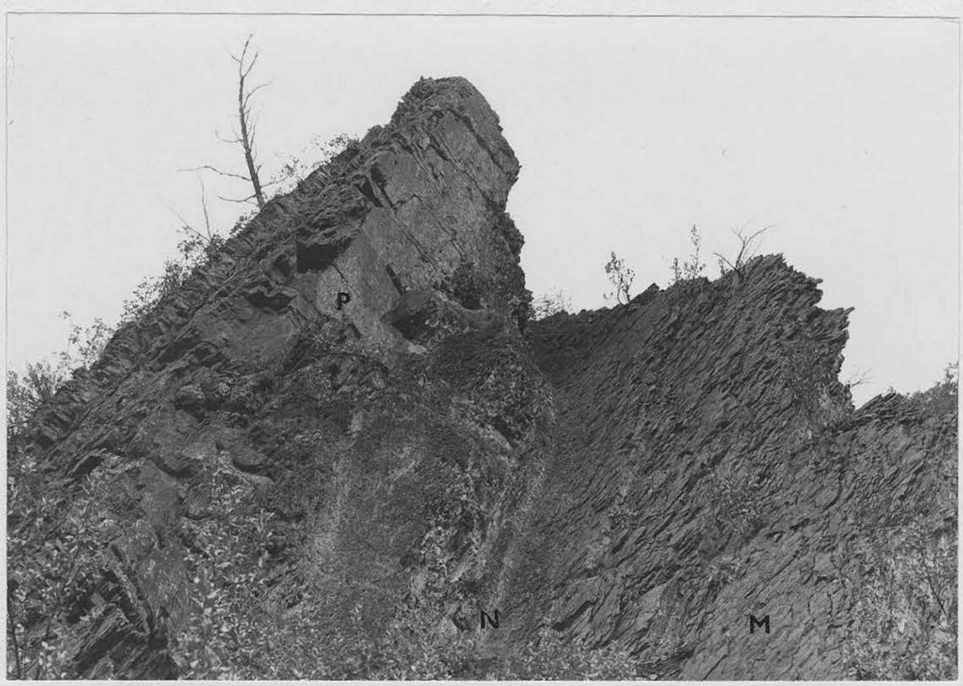
The basal sandstone has a fairly sharp base, but it is somewhat friable. It is extremely bioturbated, and no sedimentary structures remain. There are many trace fossils, including Thalassinoides, Chondrites and Planolites. Palynological studies show that there are marine dinoflagellates

Plate 2-6: a) Uppermost marine unit at Highwood 1, 1J. X is top of interbedded shales and silty sandstones; Y is top, resistant sandstone with ironstone concretions.

b) Uppermost marine unit at Highwood 2, 2J; M is basal sandstone, N is shale, P is top sandstone with pebbles and ironstone concretions.

a)

b)



(Dr. S. Pocock, personal communication). The arenaceous tests of foraminifera Haplofragmoides cf. H. rota Nauss were also found (Mr. J. C. Hanna, personal communication). There are iron stains all over this sandstone. The upper contact is not particularly well defined.

Extremely fine, fissile shales overlie the lower sandstone. They, too, appear bioturbated. They grade upward into the top sandstone, which is hard but bioturbated, thinly bedded and fissile. There are rounded chert pebbles, about 1 cm in diameter, scattered throughout this sandstone. Ironstone concretions are found all through it as well, but particularly in the top 0.3 m. The top is very sharp.

UNIT 2F

Unit 2F consists of about 9.7 m of sandstone and shale (Plate 2-7). Lowermost in this unit is a crossbed set, about 0.3 m thick with rip-up clasts in the base, overlain by a sandstone 2.8 m thick with almost paper-thin, carbonaceous parallel laminations. The parallel laminated part is over-all concave up and may be part of a very, very broad trough of width greater than 4 m. There are a few burrows in the parallel laminations.

Above the thin-bedded sandstone is a crossbedded sandstone, 4.64 m thick, with sets about 15 cm. Some of the crossbeds are planar tabular with apparent dips in opposite directions, the angle between the foresets being about 21°. These crossbeds are cut by large scours, 0.5 to 1.0 m deep.

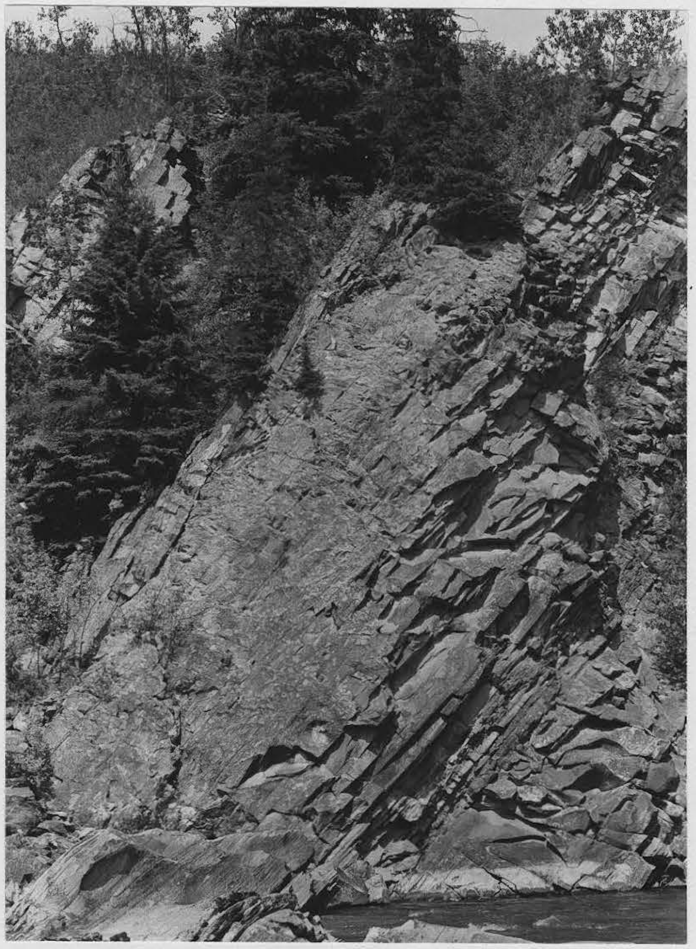


Plate 2-7: General view of the shallow marine at Highwood 2 (Unit 2F). Top is to the left.

The scour fill consists of sandstone laminations which follow the contours of the scour at its base, and become more horizontal near the tops. The fill is iron stained. Above that is 0.2 m of carbonaceous shale, and then 0.7 m of sandstone with abundant iron concretions and carbonaceous material. Within this upper sandstone was found one carbonaceous streak suggestive of a root, but no definite roots were found.

Because of the absence of characteristics definitive of any particular environment, interpretation of this unit will be left until it can be examined in context with the rest of the sequence.

UNITS 2H and 2I

The nonmarine beds of Highwood 2, a total of 60.58 m thick, consist of a 2-part sequence. The lower unit of the sequence consists of a shale with thin sandstones and siltstones. The upper unit is made up of thick resistant sandstone.

Nonmarine shale units, 2H

The four shale units with thin interbedded silty sandstones are from 6 to 16 m thick. The interbedded sandstones and siltstones, which make up approximately 15 percent of the total thickness of each interval, are a maximum of 0.45 m thick (Plate 2-8). These beds have sharp, scouring bases with woody fragments, and sharp tops. Internal parallel hori-

Plate 2-8: Interbedded sandstones, siltstones and shales in nonmarine Unit 2H. Note the fractured pinch and swell in the silty sandstones. Some of the sandstones contain roots and other plant debris. Scale is in both centimetres and inches.

zontal laminations are emphasized by coaly and carbonaceous fragments. The beds also seem to pinch and swell, or even lense out in places. A couple of roots were found in one of these beds.

The shales themselves are dark grey to black, weathering to light grey, with abundant carbonaceous material and a few thin coaly lenses (about 1 cm thick). In some places they appear churned.

Nonmarine sandstone units, 2I

The three major sandstone units are 6.65, 3.5 and 6.0 m thick. They all have sharp scouring contacts with the underlying shales. There are flutes and grooves on sandy parts of the base, while in other places the base has pebbles or shale clasts or is actually conglomeratic. Pebbles are generally chert and are one cm or less in diameter. There are many large pieces of wood in the base of the uppermost of these sandstones. The ends of burrows protrude on the bases of two of these units. The tops of all the units are sharp.

Above the bases of these sandstones, the sedimentary structures are large and medium-sized cross stratification, ripple cross laminations, planar tabular cross stratification and horizontal parallel laminations. However, there are variations in the order and occurrence of these sedimentary structures in the sandstones. Above the base of the lowermost sandstone unit there are parallel horizontal laminations, followed by 0.5 m sets of trough cross strata. Above that, the bedding is convolute or distorted and the rock is argillaceous for 0.35 m. Then there are again large scale cross strata with fairly straight foresets and small toesets, followed by ripple cross laminations scoured by a trough about 1 m deep and 6 m wide. There are climbing ripples within the trough.

The sequence in the middle sandstone unit, where the most conglomerate is found (lenses maximum 15 to 20 cm thick), starts with large scale, 0.5 m trough crossbeds, with or without pebble stringers along the foresets. Above that, the crossbeds have set thicknesses of 0.3 m and have no pebble stringers.

The uppermost sandstone unit has an essentially lensoidal or channelled shape when viewed from a distance, the base being convex and the top almost flat (Plate 2-9). Above the base are very large scale trough crossbeds, sets being 0.5 to 1.0 m thick. Next there are a couple of 0.5 m thick sets of planar tabular cross strata and above them, troughs greater than 4 m wide, lined with laminae that follow the shape of the basal scour surface, but flatten upward into parallel laminations. Following these huge troughs are medium-sized trough crossbeds (approximately 0.22 m thick per set). At the top there are poorly defined ripple cross laminations.

The grain size changes from 0.5 mm at the base to 0.3 mm at the top in the uppermost unit. The other units showed the same upward-fining trend, but the grain size was smaller, between 0.1 and 0.2 mm.

The basic interpretation of this part of the Highwood

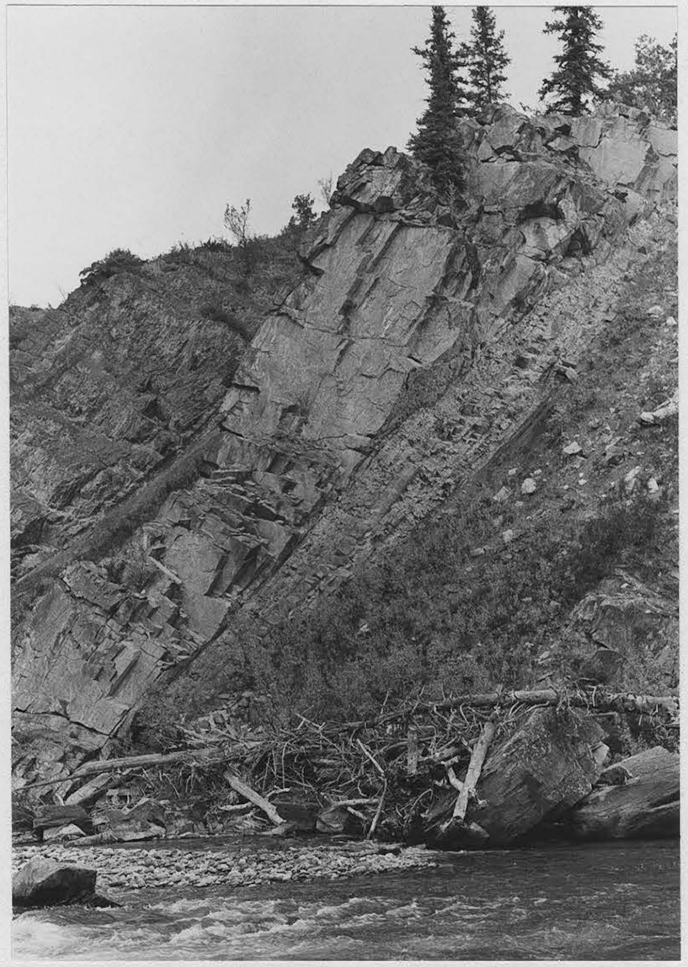


Plate 2-9: Uppermost resistant nonmarine sandstone (Unit 2I) at Highwood 2. The overall shape is somewhat lensoidal. Top is to the left.

2 section as the deposits created by a meandering fluvial system is based on the alternation of thick sandstone units and thick shale units, the lensoidal shape of the upper sandstone unit, internal structures of all the sandstone units, and the roots in one of the shale units.

CHAPTER THREE

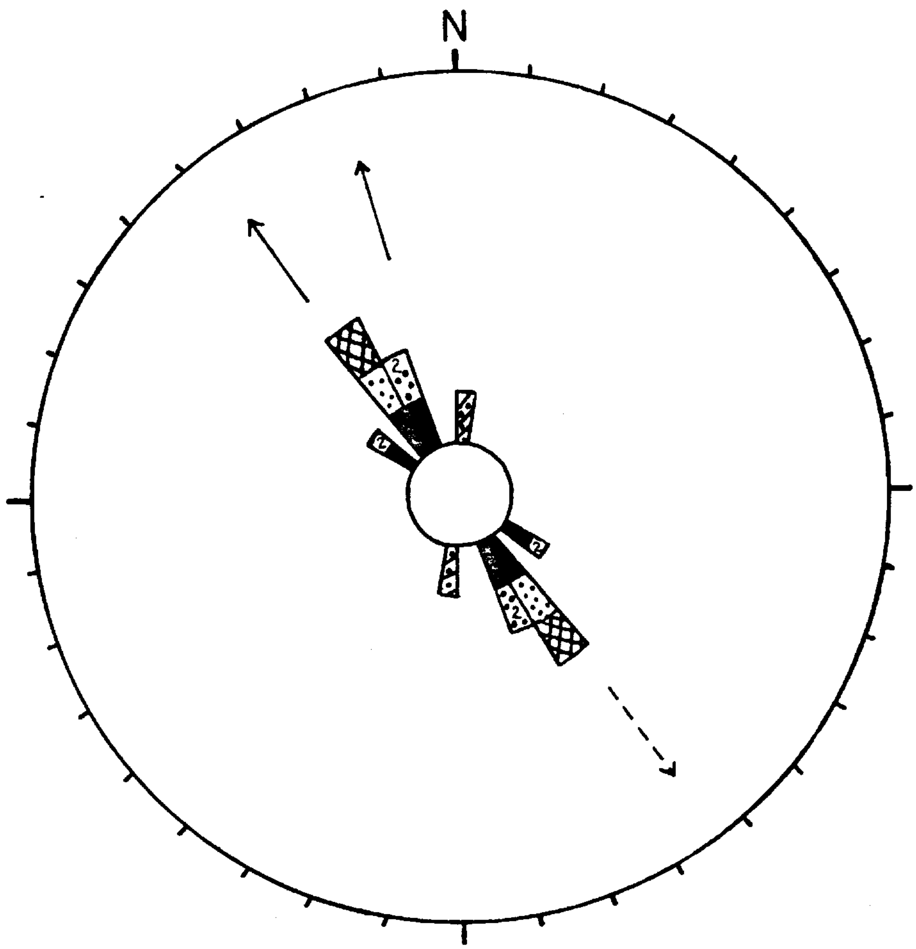
PALEOCURRENTS

Data for paleocurrent analyses were collected through both field and laboratory work. In the field, measurements were taken of the orientation of random portions of foreset planes of crossbeds, as permitted by exposure, as well as of rib and furrow, sole marks (grooves, prod marks, fluted burrows), and parting lineations (See Appendix 1a). Oriented samples were taken to determine grain orientations by the method discussed in Appendix 2, and results are tabulated in Appendix 1b. Both field and grain orientation data were reoriented back to a horizontal bedding position by simple rotation about strike. All data were analyzed using a computer program by Martini (1965).

A) Units 1A, 1B, 2A and 2B

Data for the lowest units of the Highwood sections consist of seven readings (parting lineations, grooves and the orientation of a channel wall), which have a 147° - 327° trend, but the exact flow direction is not apparent in the field (Figure 3-1). Three other samples were analyzed for grain orientations, but only two yielded statistically significant results, which were 160° - 340° with a standard deviation of 87°, and 140° - 320° with a standard deviation of 84°. In ad-

Figure 3-1: Paleocurrent data in Units 1A, 1B, 2A and 2B, the partly hummocky cross stratified part of the transition. The overall trend is 147°-327°. The sample with the flute mark indicating northwest flow (toward 344°) was also studied for grain imbrications, which supported the northwest paleoflow direction. Individual readings are tabulated in Appendix 1a.



LEGEND

- GROOVE
- LINEATION
- GROOVE & LINEATION
- CHANNEL WALL
- FLUTED BURROW
- POORLY DEFINED FLUTED BURROW
- 2 DATA FROM HIGHWOOD 2

dition, three beds had fluted burrows on the base; two gave a suspicion of flow toward the northwest and one, which was poorly defined, suggested a southeasterly flow direction (Plates 3-1 and 3-2). The specimen figured in Plate 3-2 was cut perpendicular to bedding and approximately parallel to the fluted burrows (as shown in the Plate). An oriented thin section was made and the imbrication of 200 grains measured. The vector mean (11.26°) and standard deviation (13°) were computed (Martini, 1965), and the z-statistic used to test the hypothesis H_o: $\bar{X} = 0$, where $\bar{X}$ is the sample vector mean imbrication. Calculation showed the z value to be 14.14, well outside the range -2.58 to +2.58 required to accept the hypothesis that $\bar{X} = 0$; in other words, the 11° imbrication is a true imbrication. The grains dip to the southeast, and hence the imbrication supports the preliminary interpretation of the fluted burrows, namely, that flow was toward the northwest.

The sandstones in these units are sharp based, sharp topped, parallel laminated or hummocky cross stratified beds which are interbedded with friable, bioturbated shales. They resemble closely, both sedimentologically and stratigraphically, the sandstones in the "Facies C", or hummocky cross stratified part, of the Fernie-Kootenay transition (Hamblin and Walker, 1979), which were convincingly shown to be the deposits of density flows. By analogy, then, the Belly River sandstone beds in Units 1A, 1B, 2A and 2B may have been deposited by density

Plate 3-1: Sole markings from a sandstone bed in Unit 1A. Direction of flow was toward northwest.

Plate 3-2: Sole markings from a sandstone bed in Unit 2A, suggesting northwest flow. The sample was cut along solid line, an oriented thin section made, and the imbrication of 200 grains measured. The southeast-dipping grains supported the northwest flow direction.

flows. Since density flows respond to regional paleoslope, and there are indications of flow to the northwest both in sole marks and in grain imbrications, the paleoslope at this time in the Campanian may have dipped to the northwest.

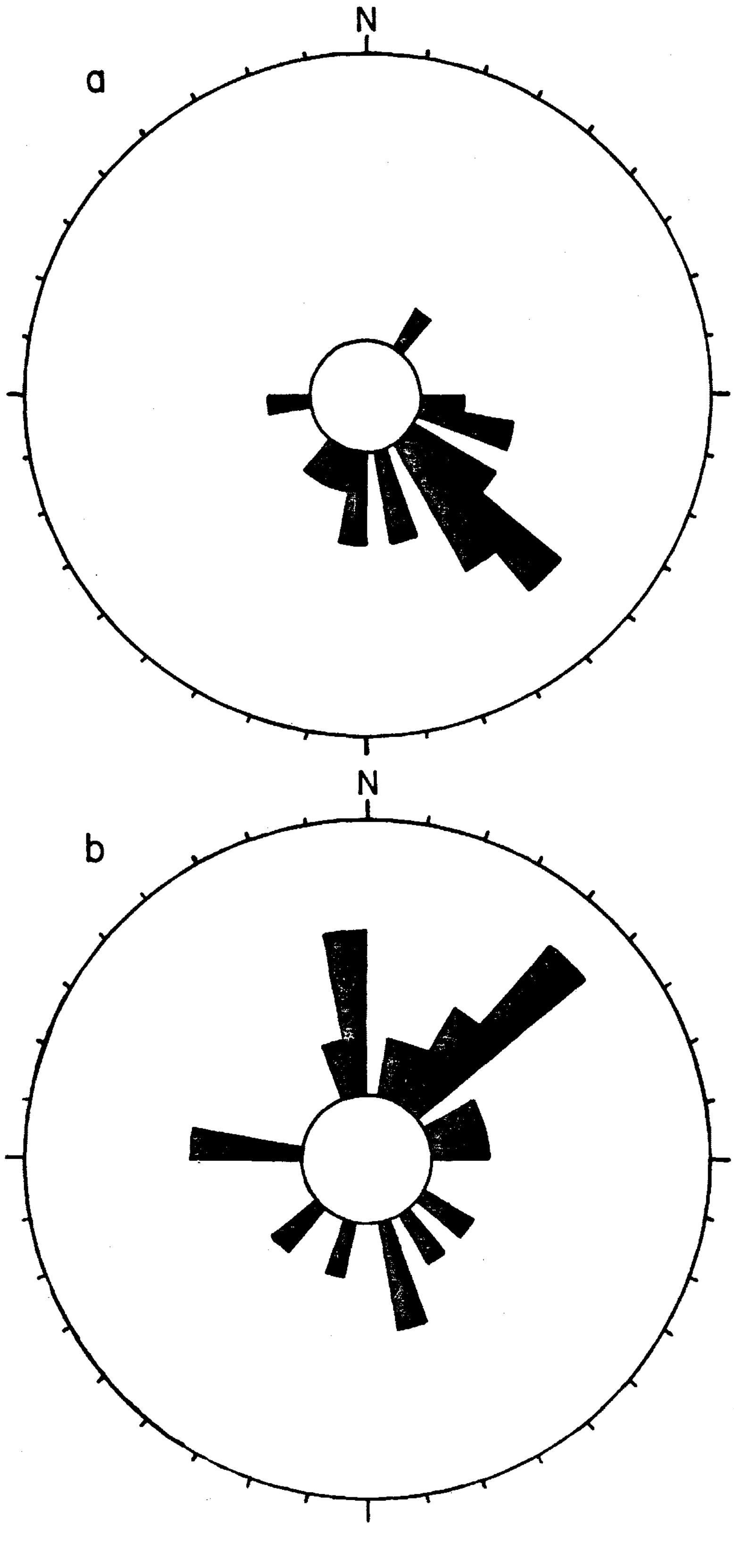
B) Unit 1D

A sample taken from a broad, flat trough over 2 m wide and 0.46 m deep yielded a mean grain orientation of 146° - 326° with a standard deviation of 88°. The trough fill consists of thin sandstone beds which generally follow the contours of the base of the trough, but become parallel at the top. Therefore, the beds appear not to have been reworked by storms, and the grain trend found here may actually be that of the flow in the trough. There is a strong similarity between the orientation of the grains in this sample and the 147° - 327°, 140° - 320°, and 160° - 340° trends from various sources in Units 1A, 1B, 2A and 2B.

C) Units 1E and 2F

The paleocurrent direction obtained by measuring the direction of dip or crossbed foresets in the shallow marine unit at Highwood 1 was about 148° with a standard deviation of only 24°. At Highwood 2, twenty-three data points from the stratigraphically equivalent part of the section were found to give results not statistically significantly different from random (Figure 3-2). The grain orientations for two samples

Figure 3-2: Paleocurrent data from direction of dip of crossbed foresets. Individual readings are tabulated in Appendix 1a. a) Data for Unit 1E. Vector mean obtained statistically is toward 148°. b) Data for Unit 2F. Orientations are not statistically significantly different from random.


N
a
N
b

were found to be 157° - 337° with a standard deviation of 85° and 024° - 204° with a standard deviation of 90° from Highwood 1 and 2 respectively.

An interpretation of the paleocurrents in a shallow marine environment above storm wave base is difficult, as this environment is affected by wave action, tides, longshore currents and storms, and actually encompasses many sub-environments. There can therefore be great variability in the paleocurrents obtained. In addition, there may be some variability in the direction due to the small number of data (23 readings for Highwood 2).

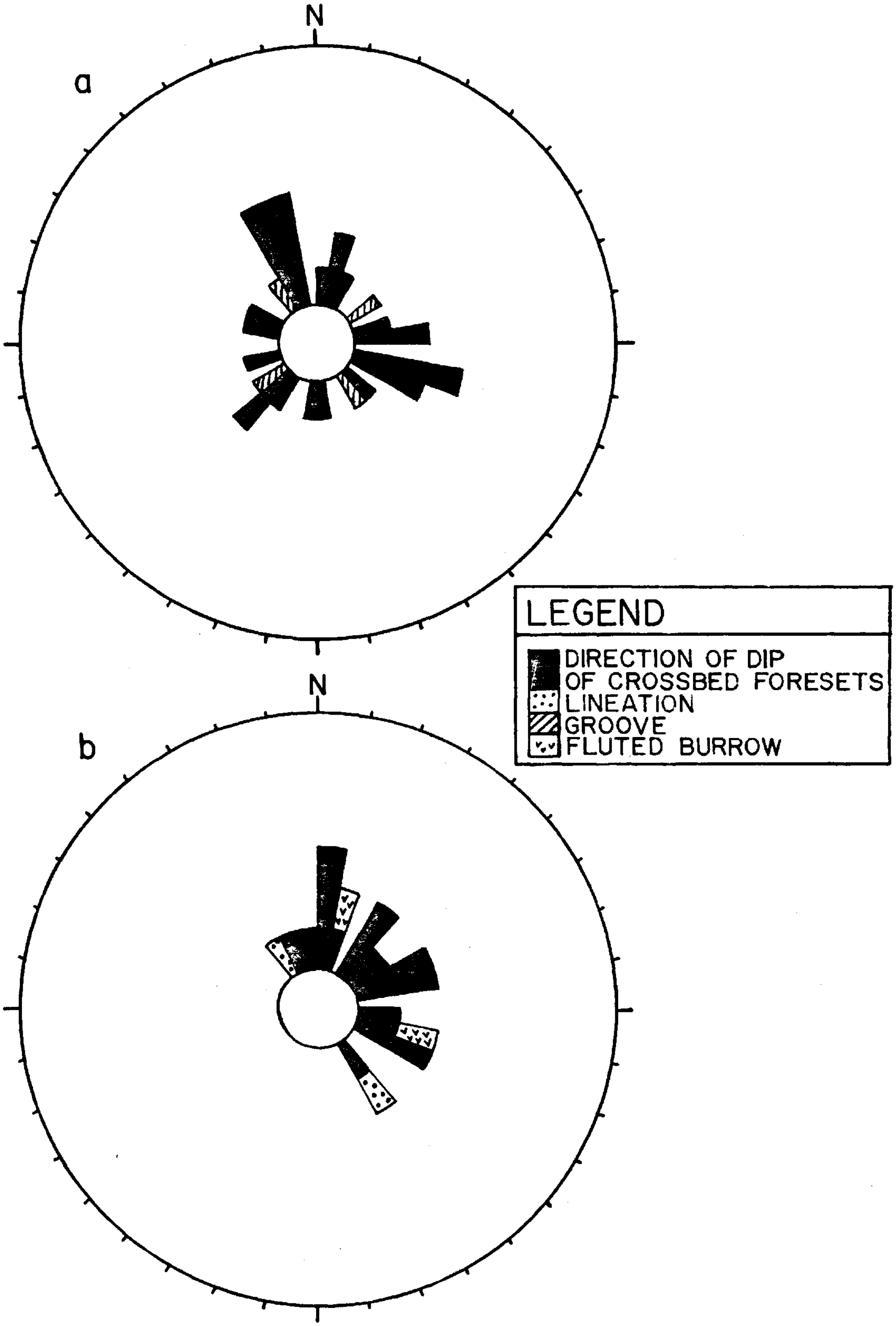
D) Units 1G, 2H and 2I

For the nonmarine part of the section, the mean flow direction obtained from 22 measurements of direction of dip foreset planes of medium and large scale crossbeds in the large sandstones at Highwood 2 was toward 049° (standard deviation 25°), but the data for Highwood 1 are not statistically significantly different from random (Figure 3-3).

Grain orientations for individual beds, each higher in the Highwood 1 section than the one before it, yielded trends of 002° - 182°, 001° - 181°, 145° - 325° and 153° - 333°. At the top of the nonmarine beds at Highwood 2, the long axes of the grains trend 144° - 324°.

The flow direction of a fluvial system reflects the regional paleoslope on a large scale, but locally, there is

Figure 3-3: Paleocurrent data for the nonmarine units. Individual readings are tabulated in Appendix 1a. a) Unit 1G, Highwood 1. The data are not statistically significantly different from random. b) Units 2H and 2I, Highwood 2. The vector mean is toward 049°.


N
a
N
b
LEGEND
DIRECTION OF DIP
OF CROSSBED FORESETS
LINEATION
GROOVE
FLUTED BURROW

variation due to meandering, overbank deposits and small scale topographical features. An interpretation of the data presented here is that the regional paleoslope at this time in the Campanian dipped to the northeast. The variations in the grain orientations would then be due to such processes as meandering, overbank deposition, or local variations in the river's course.

CHAPTER 4

PETROGRAPHY

METHOD

Samples were collected in the field for petrographic work and to estimate grain size when it was too small to determine with a hand lens. Twelve field units were sampled at Highwood 1 and seven at Highwood 2.

Thin sections were made from the samples, which had been impregnated with blue plastic to fill pore spaces. The petrographic composition and porosity of each was then determined by microscopic identification of at least 400 points using a stage point counter.

The results are listed in Table 4-1, along with summaries of the findings of Lerbekmo (1963) and Ogunyomi and Hills (1977).

GENERAL DESCRIPTION

The rock is made up of quartz, feldspar, detrital chert, carbonate and volcanic rock fragments, and carbonate/iron oxide/clay matrix, plus other minor constituents. Grain size increases upward in the measured sections until the return to marine conditions at the top, but is still in the fine sand range. Overall, the grains are subrounded to subangular. Although the thin sections were made in random orientations, in almost all of the thin sections, there was a very conspicuous parallel alignment of elongate grains and platy minerals. The rocks in the hummocky cross stratified unit and top marine unit have more of a matrix of carbonate, iron oxides and clay, while the rest have less matrix and more carbonate cement. There was virtually no porosity in any of the thin sections. All of the thin sections show some replacement of detrital grains by carbonate, but it is especially prevalent in 6-1 and 18-1. An opaque mineral, probably magnetite, occurs in most of the thin sections, but is most evident in 25-1 and 26E-2, where it is in bands parallel to the alignment of elongate grains. These two samples also have the most porosity. The upper marine sands are unusual in having mostly large rock fragments and quartz clasts set in a matrix of combined clay, iron oxides and carbonate.

COMPARISONS

Lerbekmo (1963) and Ogunyomi and Hills (1977) have studied the petrography of the Belly River Formation. In the Drywood River area "the proportions of essential components in Belly River sandstones are one-half quartz (and quartzite), one-third rock fragments and one-sixth feldspars" (Lerbekmo, 1963). These rocks also have minor carbonates, chlorite, biotite, glauconite and heavy minerals. The grain sizes in the sandstones are near the boundary between fine and medium sand. There are bentonite beds and magnetite-rich sands in the Drywood section which do not occur in the Highwood sections.

Lerbekmo (1963) suggests that the source of these clastics is to the south and west of the Drywood section. He bases this idea on the presence of bentonite beds with grains which he believes could have travelled no more than 100 miles (160 km), an abundance of plutonic quartz and feldspar grains, comparisons of K/Ar age dating from feldspars with those from nearby plutons, and on field observations of paleocurrent indicators. The source of plutonic grains would be the Nelson and Idaho batholiths, and that of the volcanic grains, a volcano not now evident because of overthrusting of Paleozoic rocks from the west toward the east.

The sections studied by Ogunyomi and Hills (1977) are far to the east in the Milk River area. The Belly River there is about 32 - 42% quartz, 3 - 4% chert, 14 - 41% feldspar and 1 - 7% volcanic rock fragments, plus muscovite, biotite, sedimentary and metamorphic rock fragments and glauconite. The matrix is a mixture of fine quartz, clays, and iron oxide. As clay increases, carbonate cement decreases. Quartz and feldspar grains are angular to subangular, and less frequently subrounded to rounded, much as in the Highwood sections. Grains are disk-shaped, usually elongate parallel to bedding, and there is little porosity, also similar to the findings of this study.

The composition of the sediments in this study is more like that of the sediments of the Milk River area. There are apparently many more rock fragments and magnetite grains in the thin section, and more bentonite beds in the Drywood section.

Sample	Quartz	Plagioclase Feldspar	Alkali feldspar	Chert	Carbonate grains	Carbonate cement	Siliceous Cement	Clay	Iron oxides	Biotite	Muscovite	Rock fragments	Other	Porosity
5-1	38	2	8	11	17	20		1	1	2				
6-1	19	2	2	2	4	65*		.5	.5	5		1	2	
10-1	45	3	5	11	9	15			4	4				
11-1-4	48	5	5	14	12	9		4		3				
17-1	37	4	8	20	13	2		4	1	10		1		
18-1	10	1	3	2	5	77*			.6	.3	.3	.8		
19-1-2	51	8	6	11	2	1	7	2	2	4	.5	.5	4	1
25-1	56	1	5	10	2		6	3	8	1			5	3
29E-1	54	3	3	10	1	.2	16		1	9	.5	.2	.7	1.4
30-1	26		5	7	9	48*	1		1	3				
31-1	34	1		32	14			10		1	1	1	1	1
33-1	10			7	9			70				4		

Table 4-1: Rock composition in percent, based on at least 400 grains, * indicates matrix. Sample locations are indicated on Figure 2-1.

Sample	Quartz	Plagioclase feldspar	Alkali feldspar	Chert	Carbonate grains	Carbonate cement	Siliceous Cement	Clay	Iron oxides	Biotite	Muscovite	Rock fragments	Other	Porosity
9-2	41	3	8	9	10	11		9	2	7				
17-2	42	5	9	7	14	13		1	3	6				
24-2-1	46	2	7	6	9	15	3	2	1	6			2	1
26-2	45	8	8	5	7	2	8		2	9		2	2	2
28-2	50	3	3	17	17	2		1	2	2	.8	1	1.2	
30-2	41	5	2.5	13	15	3.5	9	1	1	3	.5	2	2.5	1
32B-2	42	3	5	5	16	4	9	3	4	5		.5	3	.5
Lerbekmo (1963)	50	13	9		1-3					1-4		28	1-3	
Ogunyomi & Hills (1977)	32-42	14 - 41		3-24	X	X	X	X	X	X	X	1-7		

Table 4-1 continued: In Lerbekmo's (1963) study, chert was included in rock fragments. "X" indicates that substance was present, but not measured.

CHAPTER FIVE

INTERPRETATIONS AND DISCUSSION

A) General

The Belly River Formation in the two sections studied is confined below by the marine shapes of the Wapiabi Formation. It passes upward through a few, largely sandy facies, and is confined at the top by dominantly fluvial deposits.

The lowest sandstones in the measured sections are sharp based, sharp topped and parallel laminated or hummocky cross stratified, and are interbedded with fissile, bioturbated shales. By analogy with similar beds in the Fernie-Kootenay transition (Hamblin and Walker, 1979), these sandstones are considered to be the deposits of density currents. Usually density currents are associated with failure and acceleration on a slope, and deposition of sediments at the base of the slope. Failure may result from sediment overloading, or it may be triggered by earthquakes. In many cases, evidence of the slope is preserved (Walker, 1966; 1971). However, there is no indication of these slope deposits in the Fernie-Kootenay transition (Hamblin and Walker, 1979) or in the Wapiabi-Belly River transition. Hamblin and Walker (1979) propose an alternative mechanism for the generation of the density currents which deposited "Facies C" of the Fernie-

Kootenay transition, namely that water driven shoreward in storm surges eventually returned seaward, carrying large amounts of sediment with it in suspension and producing a density current.

To determine what sort of velocities would be required to suspend grains of sizes found in the lowest part of the Wapiabi-Belly River transition, a few calculations were made. For a maximum grain size of 0.03 cm, the settling velocity, w, is about 3 cm/sec (Blatt et al., 1980). For suspension, w/U_* is less than 1, so U_* must be greater than 3 cm/sec. Relating the shear velocity U_*, to the mean velocity, $\bar{U}$, $\bar{U} = U_*\sqrt{8/f}$. For a value of f = 0.15 to 0.04 (Simons et al., 1961), $\bar{U}$ is in the range 20 to 40 cm/sec. These velocities are very reasonable, and if anything low. They are compatible both with the idea of a density current and with suspension.

Therefore, since some of the sandstones in this part of the Highwood sections are hummocky cross stratified, and hummocky cross stratification is apparently formed by storm waves (Harms et al., 1975), and because a storm-generated density current could suspend grains of these sizes, the storm-generation of density currents is preferred over slope failure as a mechanism.

The direction of flow of density currents is controlled by regional paleoslope. The paleocurrent directions for this part of the measured sections indicate that flow was either to the northwest or to the southeast. The few sole markings and the grain imbrication of the one studied sample suggest that flow was actually toward the northwest. This flow direction is somewhat surprising, because it would be expected that the flow would be from the cordillera in the west toward the sea in the east.

Hamblin and Walker (1979) found that the flow direction in the Passage Beds of the Fernie Formation also was toward the north-northwest. They suggest that this flow direction was due to the existence of a trough between the emerging cordillera and the Aptian Ridge. Early in the Upper Cretaceous, the flow which deposited the Cardium Formation may have been toward the southeast but the rate of deposition of the sands was great enough to fill in the trough faster than it subsided (Walker, Ainsworth and Duke, personal communication). If there were continuous slow subsidence between the emerging cordillera and with the Aptian Ridge, then the very slow rate of deposition of the Wapiabi shales would not have filled in the trough as it subsided, and may have given it topographic expression.

The indications of flow toward the northwest in this part of the Highwood sections have already been discussed. In addition, Lerbekmo (1963), who studied the Belly River further south along the Drywood River, suggested from petrographic evidence that the source of sediments was in the south. Therefore, it is possible that the density currents of the lowest part of the Wapiabi-Belly River transition swept into the trough from the southwest, then swung around toward the northwest, and it is this paleocurrent direction that is recorded in the rocks of the lowermost Highwood sections.

Above the interbedded sandstones and shales are several sandstones separated by a few centimetres of shale at most. These beds were probably deposited in a dominantly sandy, shallow marine environment worked by waves, longshore currents, tidal currents, and storms. Because of the variability of these processes, paleocurrent directions are difficult to determine. Within these shallow water sandstones, hummocky cross stratification is present in one or two places, suggesting that it was not always erased by the fairweather processes.

There is no definite indication of a shoreline, such as a beach deposit. However, in each of the Highwood sections, there is a thick, shallow marine sandstone with burrows, overlain by dark, carbonaceous shale. The shale contains a flora typical of a very shallow marine or delta plain environment (Dr. S. Pocock, personal communication). As the shales are overlain by the fluvial part of the sequence, the shoreline must be somewhere in this zone.

The fluvial parts of the measured sections consist of several fining-upward sequences. At Highwood 1, there is much more gravel than at Highwood 2. In addition, there are no thick shales between the upward-fining sandstones at Highwood 1, and the deposits are those of a braided stream.

At Highwood 2, where there is very little gravel in the fining-upward sequences, and where the fluvial part of the section consists of thick sandstone units alternating with thick shale units, the deposits are more likely those of a meandering stream system.

The determination of a paleoflow direction in the fluvial part of the sections is hampered to an extent by the small number of readings. Although it would be expected that there would be a greater variance in the data for meandering streams than for braided streams, in this study the opposite occurred. From the data for the meandering stream deposits at Highwood 2, it was found that the regional paleoslope dipped toward the northeast. This change from a dip toward the northwest at the base of the sections suggests perhaps that as the shoreline prograded eastward, the rate of deposition of coarser sediments was greater than the rate of subsidence between the emerging cordillera and the Aptian Ridge, such that the topography of a trough was no longer apparent. The paleoflow for the bulk of the Belly River then is toward the northeast.

The uppermost units at Highwood 1 and 2 are very bioturbated, silty sandstones, shales and ironstones. There are pebbles scattered through the sandstone at Highwood 2. The rocks contain marine dinoflagellates (Dr. S. Pocock, personal communication) and arenaceous foraminifera (J. C. Hanna, personal communication). Although there is no indication of the thin, bioturbated sandstones commonly associated with a shoreline in a transgressive sequence, these rocks undoubtedly represent a marine transgression. The existence of marine tongues in this part of the Belly River Formation in western Alberta has not been noted before.

B) Distributary Mouth Bars

The transition from the Wapiabi to the Belly River has been interpreted at Trap Creek (Nelson and Glaister, 1975; Glaister and Nelson, 1978) and near Lundbreck Falls (Lerand and Oliver, 1975), in terms of prograding deltas with distributary mouth bars. It cannot really be ascertained if there is a distributary channel in the shallow marine parts of the Highwood sections. The deposits expected in that situation would be those of a very wide channel which gradually filled, possibly with fines. The dimensions of such a channel are too great to be seen in either of the measured sections, but the grain size is about fine to medium sand. A distributary mouth bar, being in fairly shallow water, is constantly reworked by waves, and many ripple marks might be expected. There are very few in the shallow marine part of the Highwood sections. Rather, there are trough crossbeds of a scale of tens of centimetres, and strata with low angle intersections, which are not as common in distributary mouth bars. Therefore, the sedimentary structures in the shallow marine parts of the Highwood sections do not seem to be those of a distributary mouth bar.

C) Transgressive Marine Tongue

The uppermost units in Highwood 1 and 2 include well developed, coarsening-upward, marine sandstones. At Highwood 2, the sandstone contains scattered pebbles. There are, then, two problems concerning these units which are left to be discussed.

First is the presence of the scattered pebbles. In the Cardium Formation, there are bioturbated sandstone units which pass upward into beds with scattered pebbles, which are very similar to this Belly River unit (Walker, Duke, Ainsworth and Wright, a personal communication). It is postulated for the Cardium that the conglomerate was transported offshore by storm-generated density currents or large scale rips. As there are many conglomeratic beds in the fluvial part of Highwood 1, in which the pebbles are of about the same size as those in the marine unit (1 cm or less in diameter), it is likely that there was a source of pebbles which could be transported offshore, to be eventually incorporated in deposits such as those at Highwood 2.

The second problem is the extent of the marine tongue, and its correlation with the marine members of the Foremost of Eastern Alberta. It is most likely that these marine units are present in many other Belly River outcrops, but until more of them are located and described, it is impossible to correlate them with any specific member of the Foremost.

CONCLUSIONS

1. The sharp based, sharp topped parallel laminated to hummocky cross stratified sandstones interbedded with marine shales were deposited largely by storm-generated density currents, into an otherwise quiet, deep marine environment.
2. The regional paleoslope at the time of deposition of the density current deposits dipped northwest. This direction of dip is supported by the paleoflow direction obtained from sole markings and the imbrication of sand grains in one sample.
3. There may have been a persistent tectonic and topographic low between the emerging cordillera and the Aptian Ridge. The sediments, carried by density currents entered the trough from the southwest, then swung toward the northwest and flowed down the paleoslope.
4. As the rate of sedimentation increased with the progradation of the Belly River shoreline, the topographic low was infilled and the dip of the regional paleoslope shifted to the northeast. This change is supported by the northeasterly direction of dip of crossbed foresets in the fluvial part of Highwood 2.
5. The shallow marine part of the Highwood sections consists of sandstones with very little shale. There is hummocky cross stratification in a couple of places, but for the most part, the dominant sedimentary structures are trough

crossbeds. Because of the variability in the processes which operate in a shallow marine environment (waves, tides, longshore currents, storms) one particular paleocurrent direction cannot often be found, as at Highwood 2. Although a direction was obtained for Highwood 1, its meaning is debatable, again because of the variability of the processes.

6. The fluvial part of the measured section at Highwood 1 consists of braided stream deposits. At Highwood 2, the stratigraphically equivalent deposits are those of a meandering fluvial system. Regional paleoslope, as determined from the direction of dip of crossbed foresets in the meandering stream deposits, was toward the northeast.

7. There was a rapid marine transgression after the initial deposition of continental sediments. This marine unit has not been recognized elsewhere in western Alberta, and cannot yet be correlated with any of the members of the Foremost.

8. These rocks are made up mostly of quartz, with plagioclase and alkali feldspars, chert and carbonate grains, rock fragments, iron oxides, biotite, muscovite, siliceous and carbonate cements, and clays. As at the Milk River section (Ogunyomi and Hills, 1977), there is more clay where there is less carbonate cement.

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APPENDICES

TABLE OF APPENDICES

APPENDIX 1a: Paleocurrent directions from field data.

Unit	Height (a)	Type of Data	Measurement (degrees)		Orientation (Degrees)	Standard Deviation	Significance level (%)
1A	0.96	3 grooves	153-335		147-327	40	> 97.5
	3.26	groove	140-320				
	6.26	2 lineations	007-187				
		2 grooves					
	8.72	2 lineations	143-323				
2A	0	groove	116-296				
	34.25	3 channel walls	143-323				
	35.53	lineation	153-333				
1E	42.36	direction of dip of foreset planes	192	137	toward 148	23	> 99.5
			139	107			
			130	160			
			180	137			
			095	141			
			213	209			
			269	183			
			129	140			
			032	161			
			126	104			
			149				
2F	60.43	direction of dip of forest planes	277	277	toward 043	37	> 83
			168	047			
			191	062			
			345	350			
			046	220			
			121	013			
			145	161			
			359	031			
			081	358			
			023	033			
			080	044			
			042				

Unit	Height (m)	Type of Data	Measurement (degrees)		Orientation (Degrees)	Standard Deviation	Significance level (%)
1G	53.28	direction of dip of foresets	286	330	toward 064	47	< 75
			079	210			
			336	170			
			019	015			
			107	088			
			344	224			
			179	005			
			102	340			
			339	119			
			108	223			
			188	117			
			136	088			
			348	025			
2H	68.37	direction of dip foresets	039	001	toward 049	25	> 99.5
			063	342			
			115	006			
			062	117			
			010	098			
			107	031			
			336	070			
			009	148			
			076	049			
			356	051			

APPENDIX 1b: Orientation of long axes of grains

Highwood 1

Unit	Sample	Height (m)	Orientation (degrees)	Standard Deviation	Significance (percent)
1A	10-1-2	12.62	126-306	100	< 75
1D	13-1	25.02	146-326	88	> 99
1E	19-1	42.96	157-337	85	> 99.5
1G	24-1	53.03	002-182	95	> 88
	25-1-2	58.73	001-181	70	> 99.5
	26-1	70.13	145-325	97	< 75
	27-1	70.53	153-333	67	> 99.5

Highwood 2

2A	11-2	34.49	160-340	87	> 99.5
2B	17-2-2	37.58	140-320	84	> 99.5
2F	26-2	55.79	024-204	90	> 99.5
2I	31-2-2	90.02	144-324	80	> 99.5

APPENDIX 2

Grain Orientation Measurement Using Acetate Peels

A) Preparation of acetate peels.

1. Orientation, including top or base and strike must be marked on the sample in the field prior to removal of the sample.
2. Cut the sample parallel to bedding, making sure the orientation markings are maintained.
3. The cut surface of the slab to be used is coarse-ground, then fine-ground until all saw marks are removed and the surface is smooth.
4. Wash off the sample and dry it in open air or in an oven. Avoid touching it on the cut surface.
5. Making sure that proper safety measures are taken (face mask, rubber apron, thick rubber gloves), in a fume hood, pour 40% HF into a shallow plastic container over which the samples will fit, until it is about 3 cm from the top.
6. Place a trial sample over the container, cut face down, and let it etch in the fumes for about 3 minutes. If it has etched, that area will appear dark; if not leave it longer in the fumes. If the grains fall out, the etching time is too long.
7. Rinse the sample in distilled water and place it in a solution of methylene blue (1 g/l water) for 1 minute. Dry it in an oven.

8. Cut thin acetate sheets into pieces just larger than the sample. Put the straightest edge of the sample towards you, cut face up.
9. From a squeeze bottle, pour acetone all over the cut surface of the sample, and before it dries, starting from the straight side, roll the acetate over the surface. Be sure not to trap air bubbles.
10. Leave the sample at least 2 hours to dry in open air.
11. Transfer orientation markings to the acetate. Make sure top and bottom are correct.
12. Carefully peel the acetate off the sample.

B) Measuring grain orientations

1. The peel can be used directly as a "negative" in a photo enlarger to make a print. Make sure it is enlarged enough to make grains easily visible, and that again, orientation markings are maintained.
2. Select grains to be measured using a grid. Of those grains where grid intersections lie, use only those which are at least twice as long ("a" axis) as they are wide ("b" axis).
3. Measure the orientation of the long grain dimension ("a" axis) of 100 grains relative to some known orientation.

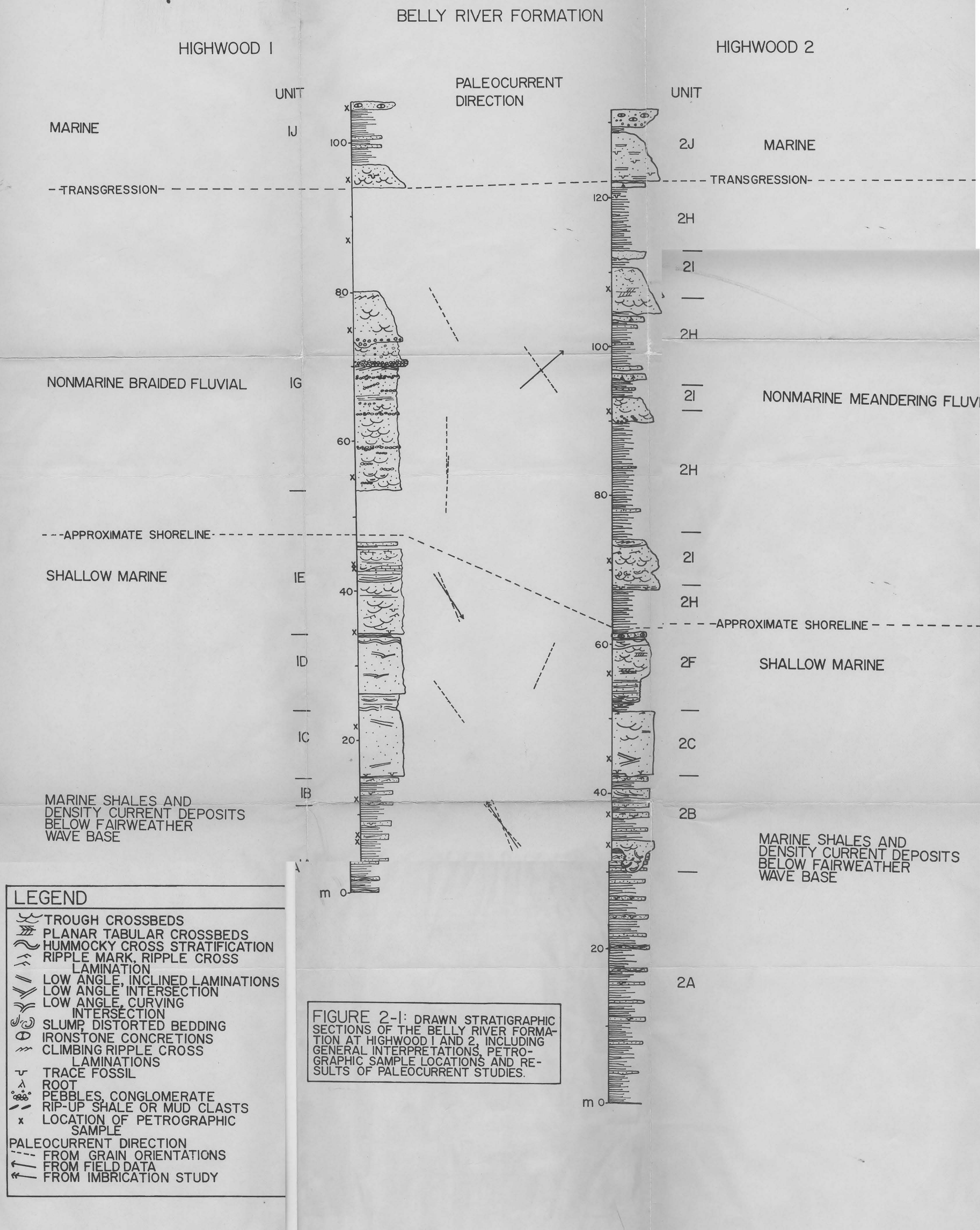

FIGURE 2-1: DRAWN STRATIGRAPHIC SECTIONS OF THE BELLY RIVER FORMATION AT HIGHWOOD I AND 2, INCLUDING GENERAL INTERPRETATIONS, PETROGRAPHIC SAMPLE LOCATIONS AND RESULTS OF PALEOCURRENT STUDIES.