SEDIMENTOLOGY OF THE MOOSEBAR TONGUE AND BOUNDING STRATA, LOWER CRETACEOUS BLAIRMORE GROUP, SOUTH-CENTRAL FOOTHILLS, ALBERTA

By

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A Thesis

Submitted to the School of Graduate Studies

in partial fulfilment of the Requirements

for the Degree

Master of Science

McMaster University

December, 1981

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SEDIMENTOLOGY OF THE MOOSEBAR TONGUE, CRETACEOUS BLAIRMORE GROUP, ALBERTA

MASTER OF SCIENCE (1981)
(Geology)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Sedimentology of the Moosebar Tongue and Bounding Strata, Lower Cretaceous Blairmore Group, South-Central Foothills, Alberta

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NUMBER OF PAGES: xv, 239

ABSTRACT

This thesis provides detailed sedimentological descriptions and generalized interpretations of depositional environments within the Lower Cretaceous Blairmore Group of Alberta. In earliest Blairmore time (Hauterivian - Barremian ?), uplift to the west resulted in a period of extensive pedimentation and deposition of coarse clastics of the Cadomin Formation. Paleogeographic reconstructions indicate that a series of humid-climate alluvial fans to the west fed a NW flowing trunk stream to the east that occupied the Spirit River Channel. In the Spirit River Channel, a series of lenticular channels filled with conglomerate and coarse-grained sandstone suggest that deposition was in pebbly braided and low sinuosity sandy fluvial environments.

Subsequent to deposition of the Cadomin Formation (Aptian time), finer grained sandstones and shales of the Gladstone Formation were deposited. Thicker sandstones commonly contain lateral accretion surfaces and are rooted in their uppermost parts indicating deposition in a high sinuosity meandering fluvial environment. Paleocurrent

data suggest that the ancient rivers flowed NNW, debouching into a boreal sea to the north. The uppermost part of the Gladstone Formation contains nonmarine to brackish fauna and is interpreted as having been deposited in a large brackish lake analagous to modern Lake Maracaibo of Venezuela.

In early Albian time, a boreal sea (Clearwater Sea) transgressed southward and covered most of central Alberta and northeastern British Columbia. Marine sandstones and shales of the Moosebar Tongue were deposited at this time. In the study area, the shoreline of the Clearwater Sea was oriented ENE-WSW and coarsening-upward sequences within the Moosebar Tongue indicate that the shoreline advanced by the progradation of nearshore bars. Deposition was in a high energy, storm-dominated system. Bordering the Clearwater Sea to the south was the large brackish lake in which sediments of the uppermost part of the Gladstone Formation were deposited.

Following regression of the boreal sea from the Foothills region in early to middle Albian time, a coastal plain environment prevailed within the depositional basin. As regression continued, the coastal plain sequence was overlain by a fluvial sequence deposited by large-scale meandering rivers. Paleocurrent data indicate that the rivers flowed generally northwards, subparallel to the foreland basin, and debouched into an Arctic embayment.

ACKNOWLEDGEMENTS

I would like to thank Dr. Roger Walker for his help and encouragement throughout the writing of this thesis. I would also like to thank my fellow graduate students for their helpful discussions of sedimentological problems encountered in this study.

Technical assistance for this thesis was provided by Jack Whorwood and Len Zwicker. Roger J. Price (Amoco Canada) identified the microfossils used to aid sedimentological interpretations. Bill Duke helped measure the Crescent Falls section (Section 1). Amoco Canada provided logistic support in the field.

Finally I would like to thank Chris (C.F.T.B.L.) Anderson for more than capable assistance in the field. Funding for this project was provided by a Natural Science and Engineering Council Grant to Dr. Walker.

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CHAPTER 1

Introduction

1.1 Purpose of Study

This thesis involves a sedimentological study of the Lower Cretaceous Blairmore Group exposed in the south-central Foothills of Alberta. The Blairmore Group is a thick (up to 2000 m) sequence of largely nonmarine strata. A marine tongue (herein the Moosebar Tongue) has previously been reported near the middle of the Blairmore Group in the south-central Foothills. It can be correlated with the Moosebar Formation of northeastern British Columbia which is a sequence of marine shales, siltstones, and sandstones with an overall coarsening-upward trend (Leckie and Walker, in press).

No detailed sedimentological study of the Moosebar Tongue in the south-central Foothills exists in the literature at the present time, and its extent is not known other than in general terms. Sedimentological studies of the formations bounding the Moosebar Tongue in the south-central Foothills (i.e. the underlying Gladstone

Formation and overlying Beaver Mines Formation) are also currently lacking in the literature.

The main purpose of this study therefore, is to provide detailed sedimentological descriptions and generalized interpretations of depositional environments within the Moosebar Tongue. This study also serves to better define the thickness of the marine tongue in the south-central Foothills and place a limit on its southernmost extent. Description and interpretation of marine deposits presented in this thesis contributes to the understanding of processes ongoing in shallow marine environments.

A second purpose of this study is to provide detailed descriptions, interpretations, and paleocurrent data for formations bounding the Moosebar Tongue. Previous work has focussed mainly on age, correlation, and nomenclature, not the sedimentology.

1.2 Location

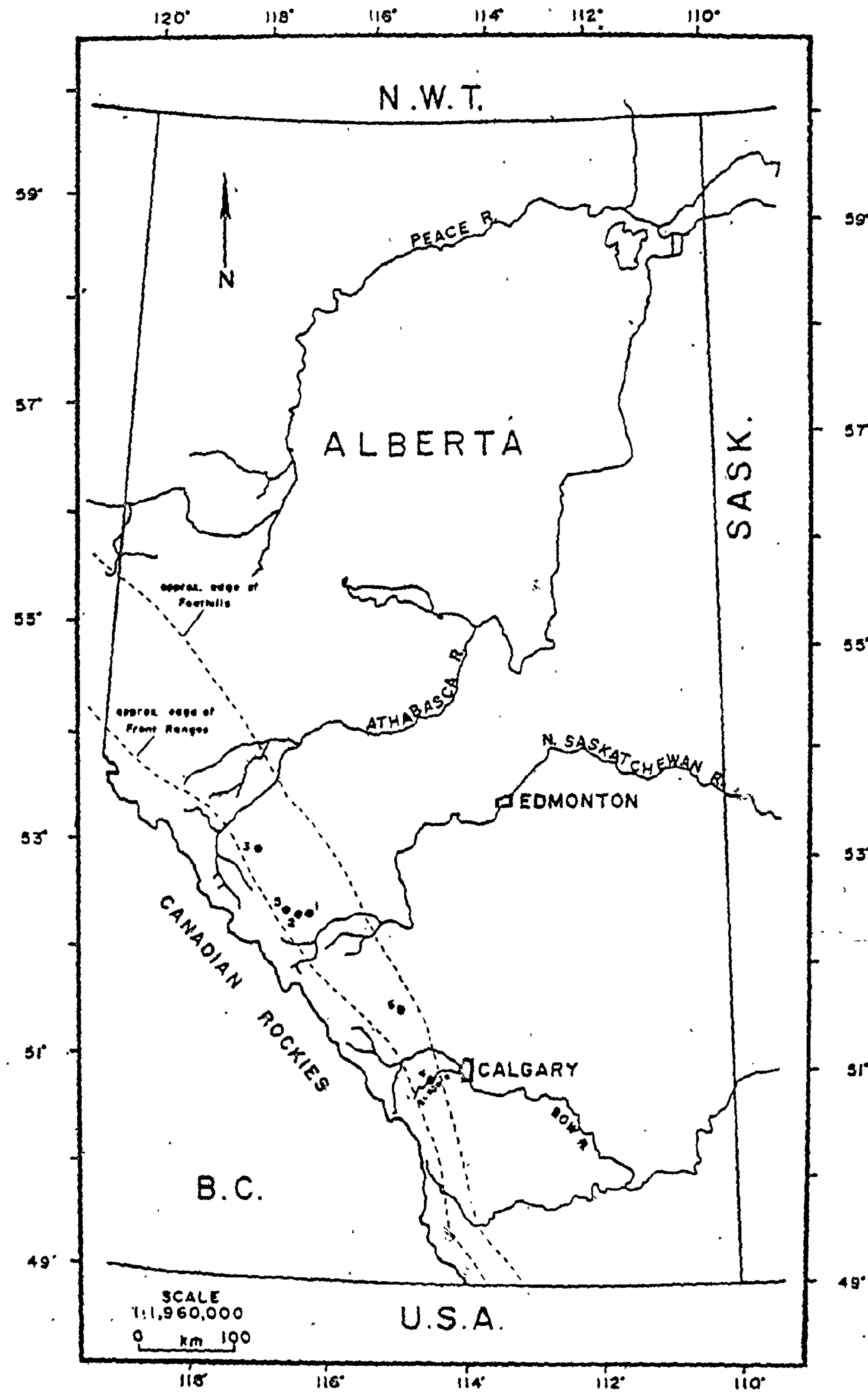
Strata of the Lower Cretaceous Blairmore Group crop out along strike of the south-central Foothills of Alberta. Only six well exposed sections occur in the region between the Elbow River and just south of the

Athabasca River (i.e. between latitudes 50° 45' and 53° 10') and these were measured in detail for this study. Sections measured range from 70 to 240 m in thickness and their approximate locations are shown on Figure 1.1.

1.3 Format of Thesis

The geologic setting, structural setting, stratigraphy, and regional paleogeography of the Blairmore Group are discussed in Chapter 2. Detailed sedimentological descriptions and generalized interpretations of measured sections are found in Chapter 3, arranged section by section. Chapter 4 is a discussion of the generalized interpretations arrived at in Chapter 3 and their implications in terms of paleogeography and tectonic setting. Chapter 5 lists the conclusions reached in this thesis. Detailed measured sections can be found in the back pocket and are briefly discussed in Appendix 1. Petrographic data for examined thin sections are found in Appendix 2. Special methods utilized in this thesis (i.e. treatment of paleocurrent data; picking of microfossils) are described in Appendix 3. Detailed locations maps for measured sections

Figure 1.1. Location map for measured sections.


120°
118°
116°
114°
112°
110°
N.W.T.
N
PEACE R.
59°
57°
ALBERTA
SASK.
55°
approx. edge of Foothills
approx. edge of Front Ranges
ATHABASCA R.
N. SASKATCHEWAN R.
EDMONTON
53°
CANADIAN ROCKIES
CALGARY
51°
BOW R.
B.C.
49°
SCALE
1:1,960,000
0 km 100
U.S.A.

and raw paleocurrent data are given in Appendices 4 and 5, respectively.

CHAPTER 2

Setting and Stratigraphy

2.1 Geologic Setting

Two main sequences of rock comprise the southeastern Canadian Cordillera: 1) a Middle Proterozoic to Mid-Jurassic sequence of carbonates and clastics, with regional unconformities between many of the units; and 2) a Late Jurassic to Early Tertiary clastic wedge.

Middle Proterozoic to Mid-Jurassic carbonates and clastics form a southwest thickening wedge of miogeoclinal-platform sediments that were deposited on the westward edge of the North American craton (Monger and Price, 1979; Price et al., 1972). This miogeoclinal-platform wedge is greater than 13,000 m thick at its southwesterly limit and consists of a series of overlapping lenticular sedimentary bodies separated by unconformities (Price et al., 1972; Wheeler et al., 1972a). Unconformities mark transgressions of the bordering ocean and suggest tectonic instability along the ancient continental margin (Price et al., 1972).

The Late Jurassic to Early Tertiary clastic wedge has a maximum preserved thickness of about 6,600 m and thins towards the northeast. It comprises two major clastic megacycles: the Kootenay-Blairmore Assemblage, and the Belly River-Paskapoo Assemblage (Eisbacher et al., 1974). The Kootenay-Blairmore Assemblage was deposited in an elongate foreland basin created in Mid-Jurassic to Middle Cretaceous time (150-100 Ma) when miogeoclinal-platform carbonates and clastics were thrust northeastwards over the edge of the North American craton during the Columbian Orogeny. Early deposition in the foreland basin is represented by the Fernie Group and the Kootenay Formation which prograded northward in Late Jurassic time (Hamblin and Walker, 1979). This northward progradation was halted in Hauterivian-Barremian (?) time by major uplift and a resulting period of extensive pedimentation (i.e. the Cadomin Formation of the Alberta and British Columbia Foothills: Eisbacher, in press; Schultheis and Mountjoy, 1978, p. 331; McLean, 1977, p. 810). Subsequent to this, coarse clastics of the Blairmore Group were deposited. The timing of the Kootenay-Blairmore Assemblage can be related to the emplacement of gneissic and granitic rock in the Omineca Crystalline Belt (represented by the Shuswap metamorphic complex: Wheeler et al., 1972b; Price and Mountjoy, 1970). This caused northeastwardly progressing deformation mainly in the form of major thrust sheets. Deformation and uplift continued in the southeast Canadian Cordillera throughout Late Cretaceous-Early Tertiary time resulting in the deposition of the second clastic megacycle (Belly River-Paskapoo Assemblage) in the foreland basin.

Deposition in the foreland basin from Late Jurassic through Early Tertiary time was influenced by the isostatic maintenance of Precambrian basement arches. These include the east-west trending Peace River arch to the north and the northeast-southwest trending Sweet Grass arch to the southeast (Stelck, 1975; Stelck *et al.*, 1972).

2.2 Structural Setting

The Foothills subprovince is the northeasternmost subprovince of the Rocky Mountains. It is bounded on the northeast by the Interior Plains of Alberta and on the southwest by the Front Ranges (Bally *et al.*, 1966; Campbell, 1973). Rocks exposed in the Foothills are part of the Late Jurassic to Early Tertiary clastic wedge.

The structure of the Foothills comprises a series of subparallel, southwest dipping, major thrust sheets involving Paleozoic carbonates that form a framework which is draped with Late Jurassic to Early Tertiary clastics (Bally et al., 1966). Late Jurassic and Early Tertiary strata are arranged in a series of southwest dipping stacked imbricate thrust sheets and closely spaced concentric folds (Price et al., 1977), and have been rotated around nearly horizontal axes due to translation along major listric thrust faults (Price and Mountjoy, 1970). The deformed clastic wedge is entirely detached from the underlying, relatively undisturbed westward continuation of the Canadian Shield (Bally et al., 1966).

The Front Ranges subprovince comprises predominantly Middle Proterozoic to Mid-Jurassic carbonate and clastic rocks. It is structurally similar to the Foothills subprovince consisting of subparallel, southwest dipping stacked imbricate thrust sheets dominated by Paleozoic carbonates that are entirely detached from a relatively undisturbed basement (Bally et al., 1966).

Sections measured for this thesis occur on the following Foothills thrust sheets:

Section 1 - Bighorn Thrust Sheet
Section 2 - Bighorn Thrust Sheet
Section 3 - Bighorn Thrust Sheet
Section 4 - Outwest Thrust Sheet
Section 5 - Bighorn Thrust Sheet
Section 6 - Burnt Timber Thrust Sheet

All strata are folded, dipping northeast and southwest (range 0° to 128°) and striking northwest (310° to 345°). Sections 1, 4, and 6 are gently folded and relatively undisturbed. Section 3 is highly folded and has a minor fault near the top. Major faults occur above and below the measured section. At Section 5 strata are overturned, dipping 128° NE. Section 2 is folded and cut by a minor thrust fault; however, a distinct marker bed can be located along the exposure and a composite section is easily obtained.

2.3 Stratigraphy of the Blairmore Group

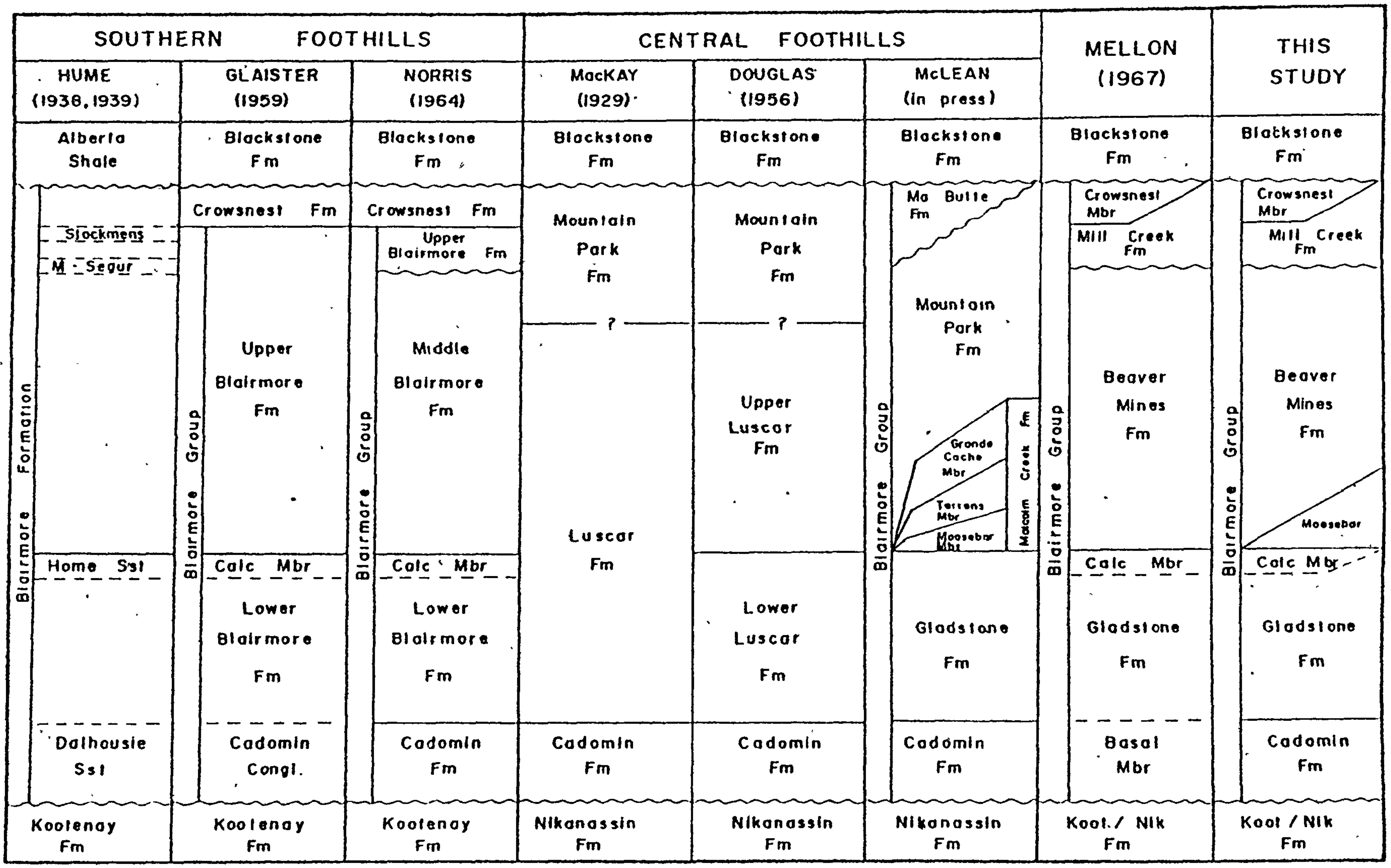
2.3.1 Historical Review

The term "Blairmore Formation" was first proposed by Leach (1914) for a sequence of dark sandstones and sandy shales exposed in the southern Foothills. As originally defined, the Blairmore Formation stratigraphically overlay a conglomerate at the top of the Kootenay Formation and underlay a series of tuffs and agglomerates that Leach (1912) had previously named the "Crowsnest Volcanics". Rose (1917) later recognized an unconformity at the base of the uppermost Kootenay conglomerate and included it in the Blairmore Formation.

Various stratigraphic schemes have been applied to the Blairmore Group in the southern and central Foothills of Alberta in recent years. These are shown in Figure 2.1. In the southern Foothills, Hume (1930, 1938, 1939) and Douglas (1950) used drillers terms to distinguish the major sand bodies within the Blairmore. They divided the Blairmore into an upper and lower part separated by the "Home Sandstone", a locally developed sandstone in the Turner Valley area of Alberta. The base of the Blairmore was defined by the quartzose "Dalhousie Sandstone". Glaister (1959) also divided the Blairmore Group into two parts separated by a "Calcareous Member". The Calcareous Member was correlated throughout the southern Foothills and Plains and it closely coincided with the "Ostracod Zone" of Hunt (1950) and Loranger (1951). Tripartite divisions of the Blairmore Group in the southern Foothills were proposed by Mellon and Wall (1961, 1963) and Norris (1964). Mellon and Wall (1961, 1963) gave member status to the basal conglomerate and upper volcanic sequence of the Blairmore Group whereas Norris (1964) gave the basal conglomerate formational status and did not include the volcanics in the Blairmore Group.

In the central Foothills, Lower Cretaceous rocks were first described by Malloch (1911) and were later

Figure 2.1. Comparison of stratigraphic schemes for the Blairmore Group (compiled from Mellon, 1967; McLean, in press).


SOUTHERN FOOTHILLS
CENTRAL FOOTHILLS
HUME (1938, 1939)
GLAISTER (1959)
NORRIS (1964)
MacKAY (1929)
DOUGLAS (1956)
McLEAN (in press)
MELLON (1967)
THIS STUDY
Alberta Shale
Blackstone Fm
Slockmens
M. Segur
Home Ssl
Dalhousie Ssl
Blairmore Formation
Kootenay Fm
Crowsnest Fm
Upper Blairmore Fm
Calc Mbr
Lower Blairmore Fm
Cadomin Congl.
Blairmore Group
Upper Blairmore Fm
Middle Blairmore Fm
Cadomin Fm
Mountain Park Fm
?
Luscar Fm
Nikanassin Fm
Upper Luscar Fm
Lower Luscar Fm
Ma Butte Fm
Grande Cache Mbr
Torrens Mbr
Moosebar Mbr
Malcolm Creek Fm
Gladstone Fm
Crowsnest Mbr
Mill Creek Fm
Beaver Mines Fm
Basal Mbr
Koot./ Nik Fm
Moosebar
Koot / Nik Fm

divided by MacKay (1929a, 1929b, 1930) into formational units. MacKay's (1929a, 1929b, 1930) division of the Blairmore included the Cadomin, Luscar, and Mountain Park Formations. Douglas (1956, 1958) subsequently divided the Luscar Formation into upper and lower parts. A revised nomenclature for the Blairmore Group in the central Foothills region has recently been proposed by McLean (in press) and is shown in Figure 2.1, Column 6.

A stratigraphic scheme for the Blairmore Group to encompass strata in both the southern and central Foothills has been proposed by Mellon (1967). In this scheme the Blairmore Group is divided into three formations; the Gladstone, Beaver Mines, and Mill Creek Formations. Mellon's (1967) nomenclature is generally adhered to in this study (with some minor revisions) and is discussed below.

2.3.2 Stratigraphic Scheme Utilized in this Thesis

The stratigraphic scheme utilized in this thesis is shown in Figure 2.1, Column 8. All formations of the Blairmore Group are described and interpreted in Chapter 3, with the exception of the Mill Creek Formation. The base of the Blackstone Formation is also described and interpreted to determine its relationship to the underlying Blairmore Group.

Cadomin Formation. The Cadomin Formation was previously included as a member of the Gladstone Formation by Mellon (1967). This procedure is rejected in this study because it removes the widely used term "Cadomin" from the Blairmore Group nomenclature.

The Cadomin Formation unconformably overlies the Kootenay Formation in the southern Foothills and the Nikanassin Formation in the central Foothills. It is characterized by chert pebble conglomerate although pebbly sandstone and medium- to coarse-grained sandstone occur in some outcrops. In the study area of this thesis, the formation has a maximum thickness of about 78 m at Wind Ridge, west of Calgary. It generally thins eastward; however, local variations in thickness and composition occur throughout the Foothills (see McLean, 1977, Figures 2 and 3).

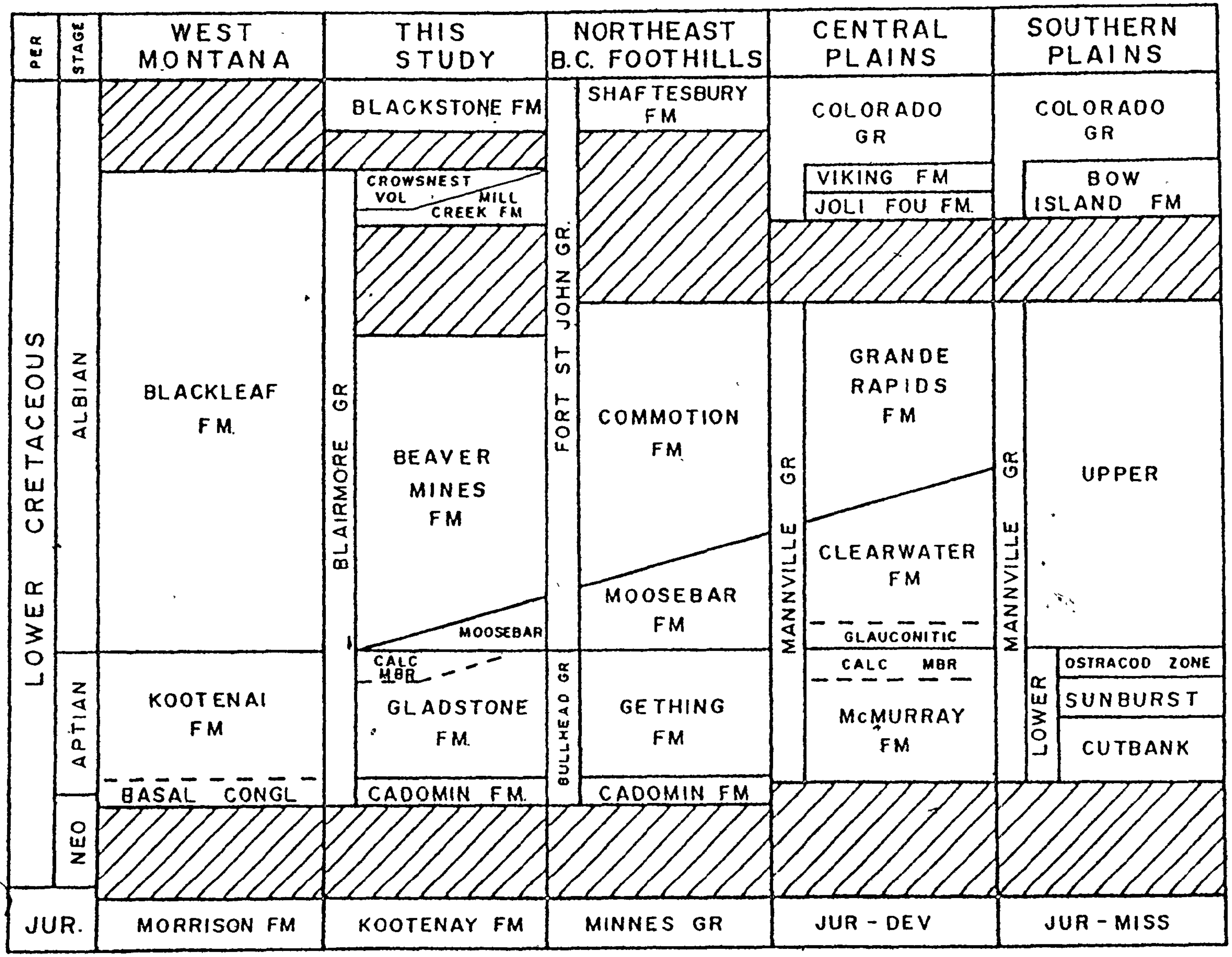
The exact age of the Cadomin Formation is questionable due to a paucity of good faunal evidence. Stott (1973, p. 71) suggests that the unconformity at the base of the formation represents Hauterivian and part of Barremian time. McLean (1977, p. 801) states that the Cadomin Formation may be of Late Jurassic to Albian age. The Cadomin Formation can be correlated throughout the

British Columbia and Alberta Foothills, and it can be correlated with the basal conglomerate of the Kootenai Formation of western Montana (Figure 2.2).

Gladstone Formation. In the study area of this thesis the Gladstone Formation varies in thickness from approximately 95 m at the Elbow River to greater than 170 m at Cadomin townsite. In general, the formation thickens westward and is divisible into two parts: 1) a sequence of interbedded grey, quartzose sandstone and varicoloured shale; and 2) an overlying Calcareous Member consisting of silty limestone and interbedded calcareous mudstone, siltstone, and sandstone. The Calcareous Member thins northward, disappearing north of the Clearwater River at latitude 52° 00' (Mellon, 1967, p. 46-50); however, an equivalent sequence of ostracod-bearing calcareous sandstones and shales can be found at the top of the Gladstone Formation north of the Clearwater River.

The age of the Gladstone Formation has been determined from floral evidence to be Aptian (Bell, 1956, p. 11). It is laterally equivalent to the Gething Formation of northeastern British Columbia, the McMurray Formation and Lower Mannville Group of the Alberta Plains, and the Kootenai Formation of western Montana (Suttner, 1969; Figure 2.2).

Figure 2.2. Correlation chart for Lower Cretaceous strata of Alberta, British Columbia, and Montana (modified from McLean, 1977).


PER
STAGE
WEST MONTANA
THIS STUDY
NORTHEAST B.C. FOOTHILLS
CENTRAL PLAINS
SOUTHERN PLAINS
LOWER CRETACEOUS
ALBIAN
APTIAN
NEO
JUR.
BLACKLEAF FM.
KOOTENAI FM
BASAL CONGL
MORRISON FM
BLACKSTONE FM
CROWSNEST VOL
MILL CREEK FM
BEAVER MINES FM
MOOSEBAR
CALC MBR
GLADSTONE FM.
CADOMIN FM.
BLAIRMORE GR
KOOTENAY FM
FORT ST JOHN GR.
BULLHEAD GR
SHAFTESBURY FM
COMMOTION FM
MOOSEBAR FM
GETHING FM
CADOMIN FM
MINNES GR
COLORADO GR
VIKING FM
JOLI FOU FM.
GRANDE RAPIDS FM
CLEARWATER FM
GLAUCONITIC
CALC MBR
McMURRAY FM
MANNVILLE GR
JUR - DEV
COLORADO GR
BOW ISLAND FM
UPPER
LOWER
OSTRACOD ZONE
SUNBURST
CUTBANK
MANNVILLE GR
JUR - MISS

Moosebar Tongue. The Moosebar Tongue was previously recognized in the Cadomin area by Mellon and Wall (1961, 1963) and Mellon (1967). Mellon (1967) included it in the lowermost part of the Beaver Mines Formation, however, in this study it is considered separately.

The Moosebar Tongue consists of dark grey marine shales and fine- to medium-grained sandstones. It thins southward in the study area of this thesis, disappearing near the latitude of Calgary.

The age of the Moosebar Tongue in the southern and central Foothills has been determined from microfossils to be early Albian (R.J. Price, pers. comm., 1981). It can be correlated with the Moosebar Formation of northeastern British Columbia (Stott, 1968) and the Clearwater Formation of the central Alberta Plains (Figure 2.2).

Beaver Mines Formation. The Beaver Mines Formation varies in thickness from about 200 m to 350 m within the study area, thickening westward. In the southern Foothills the formation consists solely of dark green feldspathic sandstones and varicoloured shales. The dark green colour of the sandstones is due to the presence of chlorite. In the vicinity of the Clearwater River (latitude 52° 00') the lowermost part of the formation consists of greenish-grey to grey feldspathic sandstone and contains commercially mineable coal seams. These are overlain by dark green sandstones similar to those comprising the Beaver Mines Formation in the southern Foothills. The uppermost part of the formation (dark green feldspathic sandstones and varicoloured shales) thins northward and grades laterally into greenish-grey and grey coal bearing strata of the lowermost Beaver Mines Formation. North of Cadomin townsite the uppermost part of the formation can no longer be recognized.

The Beaver Mines Formation is believed to be middle Albian in age based on floral evidence and its stratigraphic position (Mellon, 1967, p. 83). It can be correlated with parts of the Commotion Formation of northeastern British Columbia, parts of the Clearwater and Grande Rapids Formations of the central Alberta Plains, the lower part of the Upper Mannville Group of the southern Alberta Plains, and with part of the Blackleaf Formation of western Montana (Figure 2.2).

Mill Creek Formation. The Mill Creek Formation of Mellon (1967) is present only in the southern Foothills, disappearing between the Ghost River and Burnt Timber Creek. It unconformably overlies the Beaver Mines Formation and obtains a maximum thickness of greater than 700 m in the Crowsnest Pass area of British Columbia. The

Mill Creek Formation contains a lower member that consists of interbedded quartzose sandstone and varicoloured shale, and grades up into a volcanic member. The volcanic member (Crowsnest Member) consists of crudely bedded agglomerates and tuffs.

North of Burnt Timber Creek the Mill Creek Formation is absent and the Beaver Mines Formation is sharply overlain by marine shales of the Blackstone Formation.

The Mill Creek Formation has been assigned a late Albian age by Mellon (1967, p. 74). It is laterally equivalent to the Viking and Joli Fou Formations of the central Alberta Plains and to the Bow Island Formation of the southern Alberta Plains (Figure 2.2). No part of the Mill Creek Formation was examined in this study.

Blackstone Formation. The Blackstone Formation is the lowermost formation of the Alberta Group. It consists of dark grey marine shales that disconformably overlie the Mill Creek Formation south of Burnt Timber Creek and disconformably overlie the Beaver Mines Formation north of Burnt Timber Creek (Mellon, 1967, p. 83). The disconformity is most likely the result of erosion during transgression prior to deposition of the marine Blackstone shales.

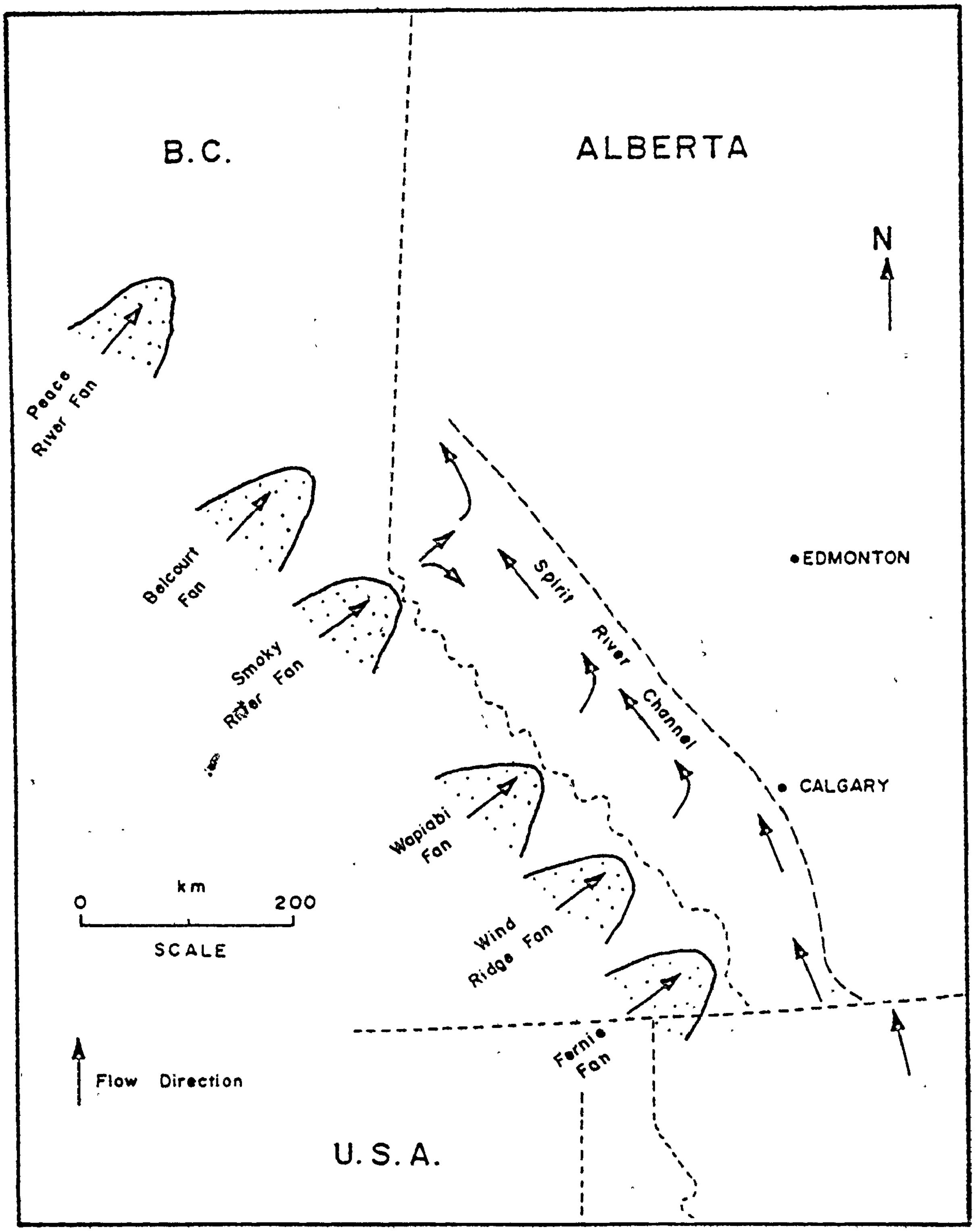
The base of the Blackstone Formation is of late Albian to Cenomanian age based on faunal evidence (Mellon, 1967, p. 83). It can be correlated with the Shaftesbury Formation of northeastern British Columbia and with part of the Colorado Group of the southern and central Alberta Plains (Figure 2.2).

2.4 Regional Paleogeography and Present Gross Interpretation of the Blairmore Group

The Cadomin Formation has previously been interpreted as a pediment lag and combined fluvial-alluvial fan deposit (McLean, 1977). In McLean's (1977) interpretation, a series of humid-climate alluvial fans to the west fed a NNW flowing trunk stream that occupied an eastern "Spirit River Channel" (Figure 2.3). McLean (1977, p. 812) suggested that both braided and meandering fluvial deposits could be recognized within the Cadomin Formation.

The overlying Gladstone Formation was previously interpreted by Mellon (1967) as a fluvial-floodplain and lacustrine deposit. During deposition of the Gladstone Formation (Aptian time) rivers flowed northward out of the United States (McGookey *et al.*, 1972) and southern Alberta emptying into a boreal sea to the north. The boreal sea

Figure 2.3. Regional paleogeography and paleodrainage pattern during deposition of the Cadomin Formation (modified from McLean, 1977).

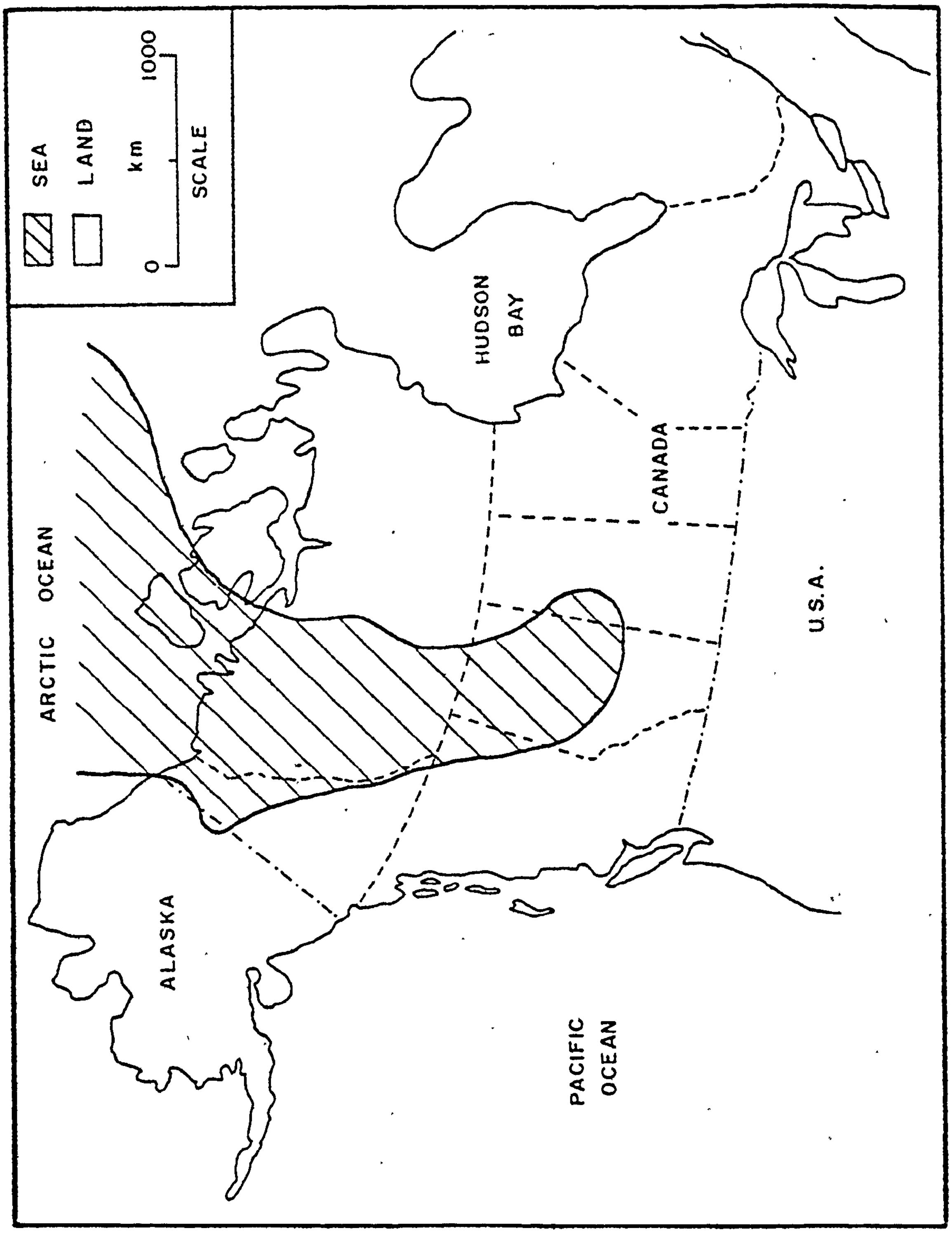

B.C.
ALBERTA
N
Peace River Fan
Belcourt Fan
Smoky River Fan
Spirit River Channel
EDMONTON
CALGARY
Wapiabi Fan
Wind Ridge Fan
Fernie Fan
0
km
200
SCALE
Flow Direction
U.S.A.

("Clearwater Sea") slowly transgressed southward in early Albian time and occupied parts of northeastern British Columbia and central Alberta (Figure 2.4; McLearn, 1944; Jeletzky, 1971; Williams and Stelck, 1975). Deposition of the marine Moosebar Tongue occurred at this time.

As the Clearwater Sea withdrew during middle to late Albian time, a major regressive sequence was deposited. In this sequence marine deposits of the Moosebar Tongue were overlain north of the Clearwater River by coastal plain deposits of the lower Beaver Mines Formation and fluvial deposits of the upper Beaver Mines Formation (Holter and Mellon, 1972; McLean, 1979). South of the Clearwater River the Beaver Mines Formation consists entirely of fluvial channel-floodplain deposits (Mellon, 1967).

The Mill Creek Formation of the southern Foothills is largely fluvial in origin; however, much of the volcanic member is comprised of pyroclastic beds (Mellon, 1967).

Figure 2.4. Regional paleogeography during deposition of the Moosebar Tongue (modified from Jeletzky, 1971).


SEA
LAND
0
km
1000
SCALE
ARCTIC OCEAN
HUDSON BAY
CANADA
U.S.A.
ALASKA
PACIFIC OCEAN

CHAPTER 3

Description and Interpretation of Units

3.1 Organization of Descriptions and Interpretations

In Chapter 3 descriptions and interpretations of individual measured sections have been organized into "units". A unit as defined in this thesis is a body of rock whose descriptive sedimentological characteristics may vary internally yet are distinct from overlying and underlying units. In the strictest sense, units are large-scale facies. Units were recognized in the field but were not formally defined until after field work was completed and all sedimentological criteria (i.e. lithology, primary sedimentary structures, bioturbation, and paleocurrent data) were considered.

In Chapter 3 each measured section is first described in detail (measured sections are located in the back pocket). Following each description is a table (Tables 3.1-3.6) that lists the salient characteristics of each unit of the particular measured section and gives it a basic interpretation. Basic interpretations are discussed and expanded upon following each table.

3.2 Unit Descriptions, Section 1 (Bighorn River at Crescent Falls)

3.2.1 Introduction

At Section 1, Units 1 through 4 are nonmarine and represent the uppermost 97.6 m of the Gladstone Formation. Units 5 through 8 represent the marine Moosebar Tongue.

3.2.2 Unit 1 (0-14 m)

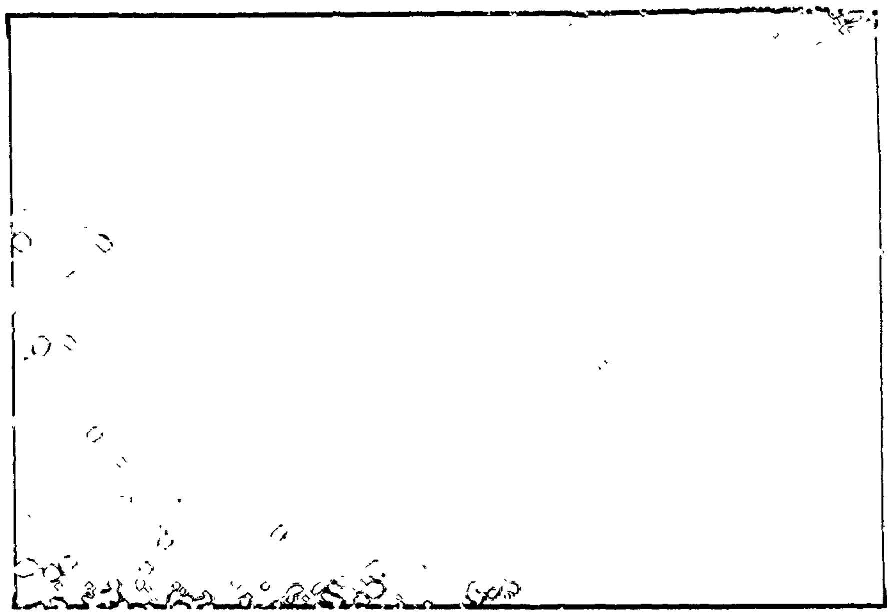
Unit 1 consists of medium greyish-brown sandstone that has a sharp, flat base. It is underlain by black fissile shale containing an abundance of partially intact plant fragments (4.0 cm long and 1.0 cm wide) and roots. The shale is capped by approximately 5-10 cm of coal that may be absent locally due to erosion by the overlying sandstone of Unit 1.

Unit 1 contains at least two sets of multi-storied lateral accretion surfaces (epsilon cross-bedding of Allen, 1963) that average 7.0 m in thickness (range 5.0-8.0 m). Individual lateral accretion surfaces average 1.0 m in thickness and have an average dip of 19° (range 10°-31°). The lateral accretion surfaces contain trough cross-beds near the base (sets average 30 cm), ripple cross-laminations at the top (sets average 2-3 cm), and parallel laminations in some places. Also present are small mudclasts 1-2 cm diameter near the base of the unit, and partially intact plant fragments (average 5.2 cm long and 0.7 cm wide) throughout. Sandstones comprising lateral accretion surfaces fine upward from medium-grained near the base to fine-grained at the top of the unit. Lateral accretion surfaces are commonly draped with 5-6 cm of mudstone or very fine-grained siltstone. The upper contact of Unit 1 is sharp and contains roots.

Within Unit 1, two distinct superimposed channels are exposed. They are approximately 5-8 m deep and greater than 20 m across, but are largely inaccessible. The base of one channel was examined closely and consists of 0.5 m of conglomerate containing abundant large coaly "logs" (10-20 cm diameter). The conglomerate is clast-supported and is composed of chert pebbles up to 5 cm in long dimension (average 2 cm in long dimension). Overlying the conglomerate are lateral accretion surfaces composed of trough cross-bedded sandstone, however, no detailed observations could be made due to inaccessibility. The second channel (Figure 3.1) also could not be examined closely but appeared to be filled with greyish-brown medium-grained sandstone containing

Figure 3.1. Superimposed channel within Unit 1. Channel is about 5-6 m deep.

Figure 3.2. Small shallow channel within Unit 2 (23.7-25.6 m).



trough cross-beds. Small partially intact plant fragments (1-2 cm long and 0.5 cm wide) are present in both superimposed channels.

3.2.3 Unit 2 (14.0-48.5 m)

Unit 2 consists largely of interbedded sandstone and shale with minor siltstone and coal. Within Unit 2, two thicker sandstones occur between 23.7-25.6 m and 34.0-36.2 m.

The sandstones present in the 23.7-25.6 m and 34.0-36.2 m intervals are dark greyish-brown and fine-grained. They have sharp, erosive bases and are composed of two or three superimposed channels that average about 1 m deep and 5-8 m across (Figure 3.2). In the lowermost interval, channel-fill is parallel laminated throughout and contains roots. In the uppermost interval, channel-fill is parallel laminated at the base, ripple cross-laminated at the top (sets average 1-2 cm), and lacks roots. Both intervals contain large partially intact plant fragments up to 49 cm long and 22 cm wide.

The remainder of Unit 2 is interbedded brownish-grey sandstone, siltstone, and greyish-black shale that has a sandstone:siltstone plus shale ratio of about 1:2. Individual sandstone beds are very fine- to medium-grained and undulate and pinch and swell slightly. They average 0.35 m in thickness (range 0.1-1.0 m) and commonly have gradational upper and lower contacts. Sandstone beds contain ripple cross-laminations (sets average 1-2 cm) and in some places are parallel laminated. One sandstone (37.1-38.2 m) has planar cross-beds with a set thickness of 0.2 m. The interbedded sandstone and shale of Unit 2 contains abundant partially intact plant fragments (about 4-5 cm long and 1-2 cm wide) and roots (Figure 3.3). Also, four coal beds are present within Unit 2 and average 0.23 m in thickness (range 0.1-0.5 m).

3.2.4 Unit 3 (48.5-64.0 m)

Unit 3 consists of light grey sandstone and is very similar in character to Unit 1. Lateral accretion surfaces are found throughout the unit (Figure 3.4). They average 2.0 m in thickness (range 0.8-2.9 m) and have an average dip of 11° (range 4°-19°). Within the lateral accretion surfaces, a similar succession of sedimentary structures to those of Unit 1 was observed. Abundant mudclasts are also present, averaging 2.0 cm diameter and 0.6 cm thick. A distinct but inaccessible channel is exposed in the cliff on the south side of the river. It is approximately 5-7 m deep and greater than 30 m across.

Figure 3.3. Rooted sandstone within Unit 2.

Figure 3.5. Thin shell hash layers within Unit 5.

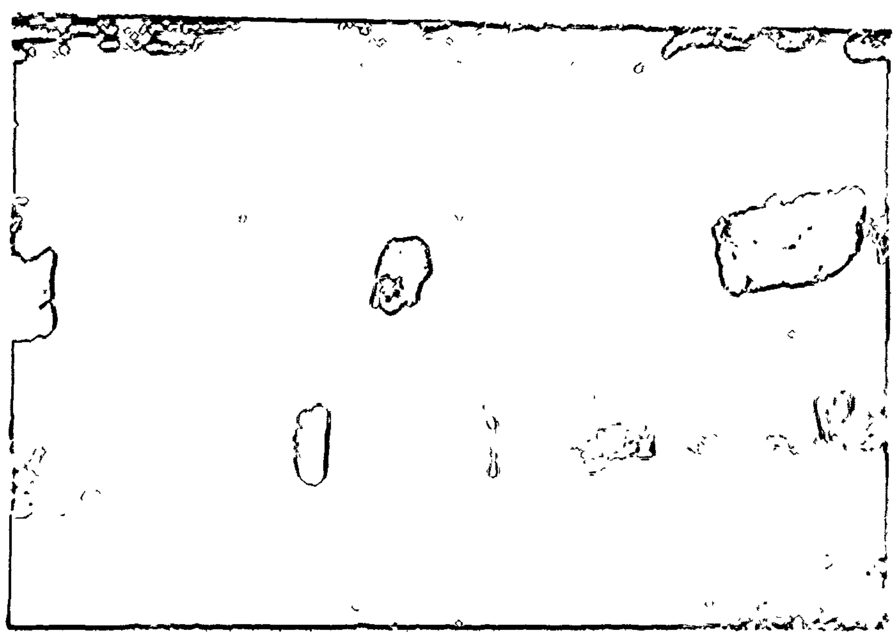


Figure 3.4. Photomosaic of lateral accretion surfaces within Unit 3. Individual lateral accretion surfaces average about 1 m in thickness. Sandstone is approximately 15 m thick.

3.2.5 Unit 4 (64.0-97.6 m)

Unit 4 contains four distinct sandstone intervals; between them are interbedded sandstone and shale with minor siltstone and coal. The four sandstone intervals occur between 70.2-72.0 m, 73.2-74.1 m, 89.5-91.5 m, and 92.3-95.5 m.

The lowermost three intervals contain medium grey, fine- to medium-grained sandstone and have sharp erosive bases. They occupy channels 0.4-1.0 m deep and approximately 5-12 m wide. Channel-fill is parallel laminated, ripple cross-laminated (sets average 2 cm), and in the 89.5-91.5 m interval it is trough cross-bedded in places (sets average 15 cm). Plant fragments 2.5 cm long and 1.0 cm wide, and roots are present within these sandstones.

The 92.3-95.5 m interval has a gradational base and coarsens upward from siltstone to medium-grained sandstone in the lowermost 1.0 m. The sandstone contains a series of small scours that average 5-6 cm deep and 56 cm across. A few larger scours up to 1 m deep and 3-4 m across are also exposed, but are rare. Parallel laminations, ripple cross-laminations (sets average 1 cm), and macerated plant fragments are present throughout this interval. A 3.5 cm thick shale break occurs approximately

1.5 m from the base of the sandstone, and it appears to be continuous along the full lateral extent of the outcrop. The upper contact of the interval is rooted.

The remainder of Unit 4 is interbedded greyish-brown sandstone and brownish-black shale, with minor siltstone. The sandstone:shale plus siltstone ratio is 1:2. Individual sandstone beds are fine- to coarse-grained and average 0.5 m in thickness (range 0.1-1.5 m). They commonly undulate, pinch and swell, and have sharp upper and lower contacts. The most common sedimentary structure observed was ripple cross-laminations (sets average 1-4 cm); however, parallel laminations are present in two beds. A layer of iron-stained spherical concretions 14 cm thick occurs at 83.6 m. Macerated carbonaceous material, small partially intact plant fragments, and roots are present throughout the interbedded sandstone and shale of Unit 4. Three coal beds are also present, averaging 0.4 m in thickness.

Within the shales of the uppermost part of Unit 4, the following species of nonmarine to brackish fauna were identified by R.J. Price (Amoco Canada):

1) <u>87.1 m</u>

Ostracods

Metacypris persulcata

Gastropods

Viviparus sp.

Liaplacoides ? sp.

2) <u>96.0 m</u>

Ostracods

Metacypris persulcata

Limnocypridea ? sp.

Cypridea ? cf. *wyomingensis*

Limnocythere calmontensis

Cooneyella cf. *quadrispina*

3.2.6 Unit 5 (97.6-148.4 m)

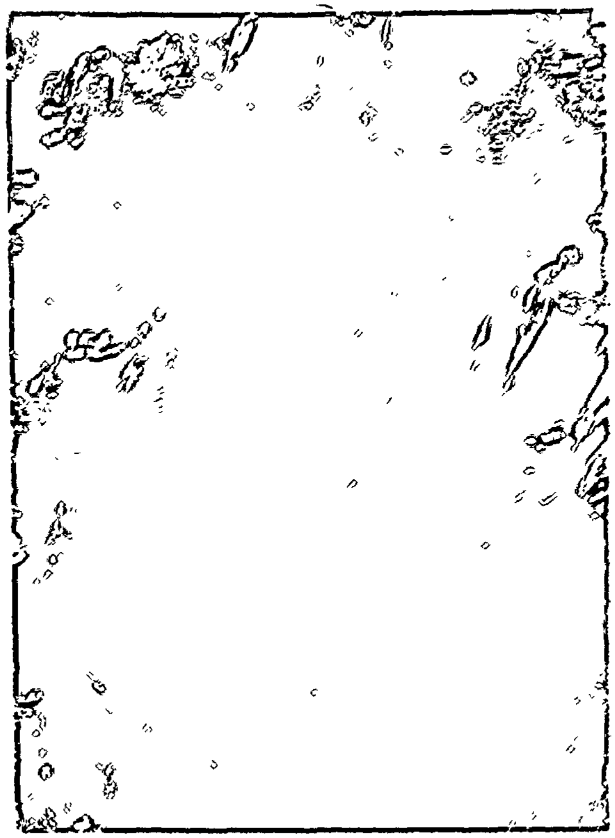
Unit 5 sharply overlies nonmarine deposits of Unit 4 and consists largely of dark grey, calcareous, fissile shale containing interbeds of iron-stained shell hash and oval concretions. Shell hash layers are silty and have scours 1.5-4.0 cm deep on their bases (Figure 3.5). They average 4.5 cm in thickness (range 1.5-10.0 cm) and contain randomly oriented disarticulate pelecypod shells as well as gastropod shells.

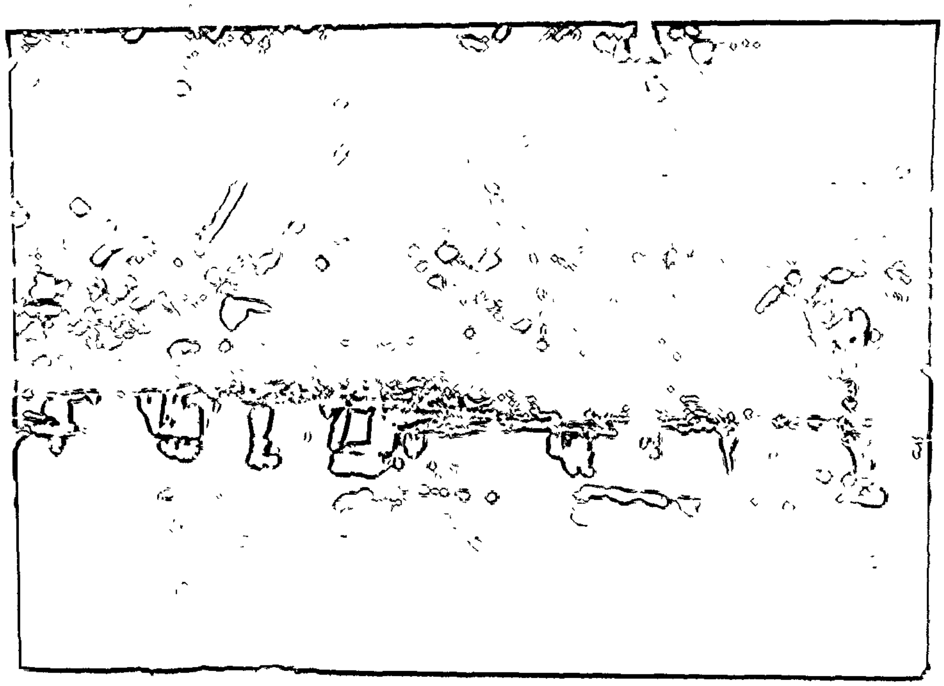
Concretionary layers are also silty and average 18 cm in thickness (range 4-50 cm). Between 142.9-147.1 m, a few lenticular calcareous sandstones are present that average 6-7 cm thick and 70 cm across.

Within Unit 5, three distinct sandstone intervals occur between 116.5-124.0 m, 141.2-142.9 m, and 147.1-148.4 m. The 116.5-124.0 m interval contains two thickening- and coarsening-upward sequences (Figure 3.6). The base of each sequence consists of fine-grained lenticular bioturbated sandstones. Upwards in each sequence these beds are slightly thicker (averaging 10 cm), more continuous, and less bioturbated. The sandstone:shale ratio increases from about 1:2 at the base of each sequence to 7:1 near the middle. The upper part of each sequence is thickly bedded, averaging 30 cm, and lacks shale partings. Individual sandstone beds in the middle and upper part of each sequence are medium-grained, parallel laminated, and have horizontal burrows on upper bedding planes. Sandstone beds in the lower sequence are planar, but in the upper sequence they tend to undulate and pinch and swell. Also, the upper contact of the upper sequence has straight-crested symmetrical ripples (amplitude 1-3 cm and wavelength 10-15 cm) and sub-angular to sub-rounded disk-shaped chert pebbles. These average 1.4 cm in long dimension (range 1.0-2.5 cm) and are sparsely scattered along the upper contact.

Figure 3.6. Two thickening- and coarsening - upward sequences within Unit 5 (116.5-124.0 m). Hammer for scale.

Figure 3.7. H.C.S. bed within Unit 5 (141.2-142.9 m). Hummocks average 8-16 cm high and 100-150 cm across. Scale is 1.7 m.



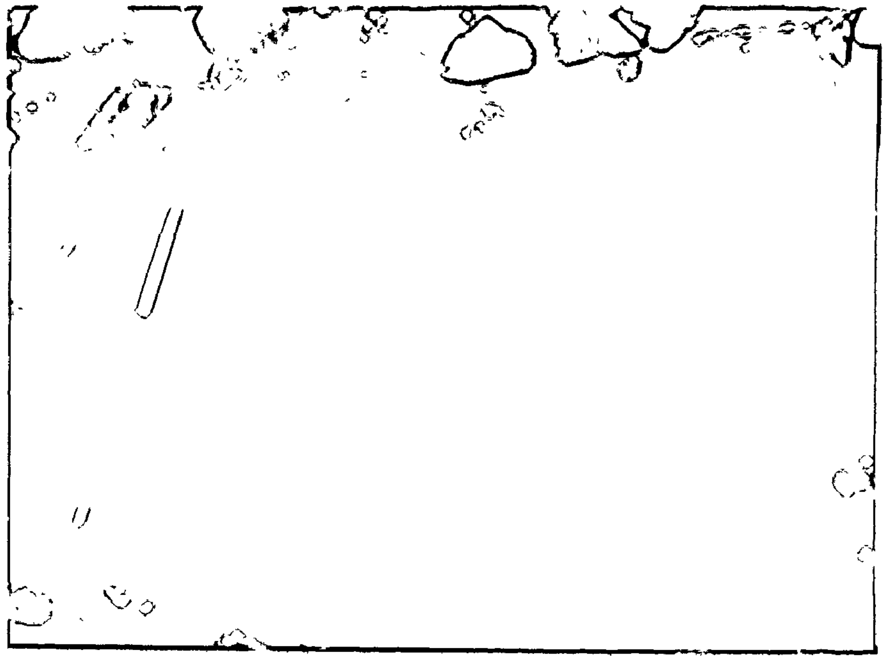


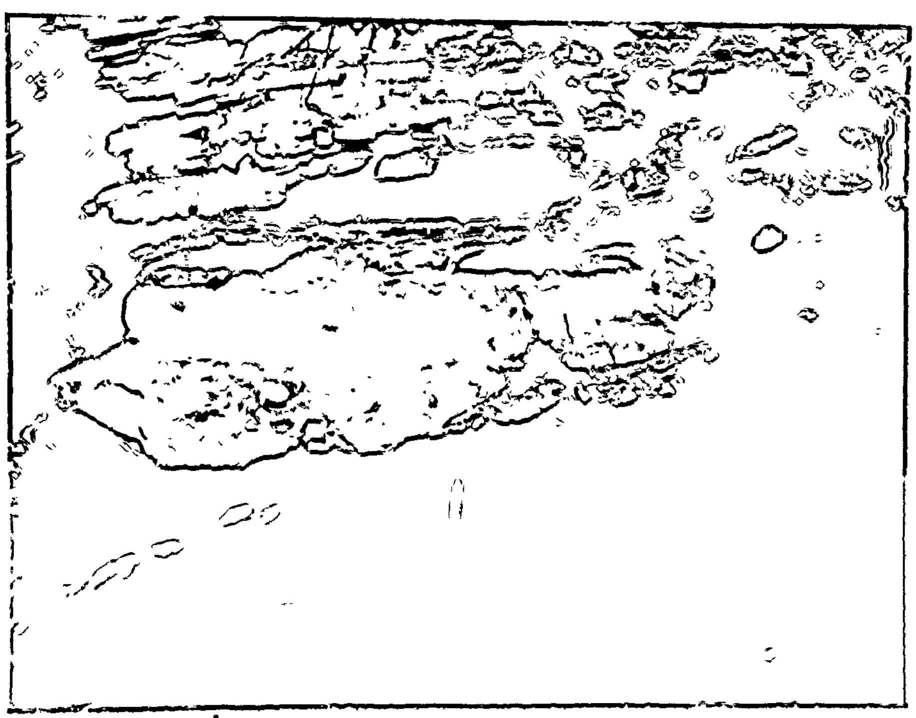
The 141.2-142.9 m interval begins with very fine-grained, thoroughly bioturbated lenticular sandstone and shale. Sandstone lenticles average 5-6 cm thick and 130-140 cm across. They become laterally continuous beds and thicken upwards in the lowermost 0.7-1.0 m of the interval into a sharp-based, hummocky cross-stratified sandstone (H.C.S.; Figure 3.7; Harms et al., 1975, p. 87). The H.C.S. is fine-grained and contains convex-up and convex-down laminations that intersect each other at less than 15°. Individual hummocks (convex-up laminations) are 8-16 cm high and 100-150 cm across. The upper contact of the interval is sharp and has straight-crested symmetrical ripples with an average amplitude of 5 cm and wavelength of 15-20 cm. Preserved near the base and on the upper contact of the interval are abundant horizontal Rhizocorallium traces (Figure 3.8).

The 147.1-148.4 m interval is dark greyish-brown bioturbated siltstone that has gutter casts (Whitaker, 1973) and larger channels eroding through it. Gutter casts consist of very fine-grained, parallel laminated sandstone. They average 5 cm deep, 10 cm across and may be several metres in length. Larger channels average 1.3 m deep and 5.2 m across and are filled with light grey, fine-grained, parallel laminated sandstone (Figure 3.9).

Figure 3.8. Horizontal *Rhizocorallium* traces near the base of the 141.2-142.9 m interval of Unit 5.

Figure 3.9. Channel eroding through bioturbated siltstones of Unit 5.





Within Unit 5, the following species of fauna were found and were identified by R.J. Price (Amoco Canada):

1) 103.0 m

Ostracods

Metacypris persulcata

Limnocypridea? sp.

Cypridea? cf. wyomingensis

Limnocythere calmontensis

Cooneyella cf. quadrispina

Pelecypods genus and species indet.

2) 133.0 m

Foraminifera

Ammomarginulina? sp.

Ostracods

Cytherida brevisspinosa

Gastropods genus and species indet.

Pelecypods genus and species indet.

3) 145.0 m

Foraminifera

Ammobaculites? sp.

The fauna found at 103.0 m are of freshwater to brackish origin while those found at 133.0 m and 145.0 m are of marine origin (R.J. Price, pers. comm., 1981).

3.2.7 Unit 6 (148.4-168.0 m)

A covered interval occurs at the base of Unit 6. Above the covered interval, 1.9 m of dark greyish-black, bioturbated mudstone is exposed. The remainder of Unit 6 consists of four sandstone intervals that occur between 155.1-155.8 m, 155.8-157.3 m, 157.3-161.1 m, and 162.2-168.0 m).

The 155.1-155.8 m interval has sharp upper and lower contacts and consists of dark grey, very fine-grained sandstone. It is medium bedded, averaging 17 cm (range 10-25 cm), and has 1-2 cm thick shale breaks between beds. Individual beds undulate slightly and have small scours at the base (average 6 cm deep and 37 cm across). Parallel laminations and minor bioturbation were noted throughout the interval.

The 155.8-157.3 m interval is interbedded sandstone and grey, fissile shale. Sandstone beds are medium grey, very fine-grained, parallel laminated, and thicken upward. Thicknesses increase from 0.5 cm near the base to 3-4 cm at the top of the interval.

The 157.3-161.1 m interval is a thickening- and coarsening-upward sequence of medium grey sandstones and greyish-brown shales (Figure 3.10). The base of the sequence consists of 1-5 cm thick sandstone beds which are very fine-grained and contain symmetrical ripple cross-laminations (sets average 2-4 cm). The sandstone:shale ratio at the base is approximately 1:8 and increases to 20:1 near the middle and upper part of the sequence. In the upper part of the sequence, sandstones are fine-grained, sharp-based, and contain poorly developed H.C.S. (hummocks average 15-20 cm high and 200-400 cm across). Bed thicknesses also increase upward, averaging 20 cm (range 14-30 cm), and individual beds have 1-2 cm thick shale breaks between them. The upper contact of this interval has symmetrical ripples with an average wavelength of 25 cm and amplitude of 2-3 cm.

Interbedded dark greyish-brown sandstone and brown shale occurs between the 157.3-161.1 m and 162.2-168.0 m intervals. The sandstone:shale ratio is 1:2.5. Sandstones are lenticular, very fine-grained, bioturbated, and contain symmetrical ripple cross-laminations. Lenticles average 2-3 cm thick and 50-100 cm across.

The 162.2-168.0 m interval consists of calcareous, light grey, fine-grained swaley

Figure 3.10. Thickening- and coarsening-upward sequence within Unit 6 (157.3-161.1 m). The uppermost part of the sequence contains poorly developed H.C.S.

Figure 3.11. Scours at the base of the 162.2-168.0 m interval (Unit 6).

cross-stratified sandstone. Swaley cross-stratification consists of a series of broad, gently curving, convex-down laminations or scour-like depressions (swales) that truncate one another at very low angles (less than 15°). Swales within this interval are 0.2-1.0 m in amplitude and greater than 10 m across. The upper contact of this sandstone is sharp and contains straight-crested symmetrical ripples that have an average wavelength of 20-30 cm and amplitude of 3-5 cm. A bioturbated horizon containing deformed Chondrites traces (V. Costley, pers. comm., 1981) occurs about 15-20 cm below the upper contact. The lower contact is also sharp and has a series of scours 30-40 cm deep and 200-300 cm across (Figure 3.11). The sandstone filling these scours is medium grey, fine-grained, and parallel laminated.

3.2.8 Unit 7 (168.0-173.5 m)

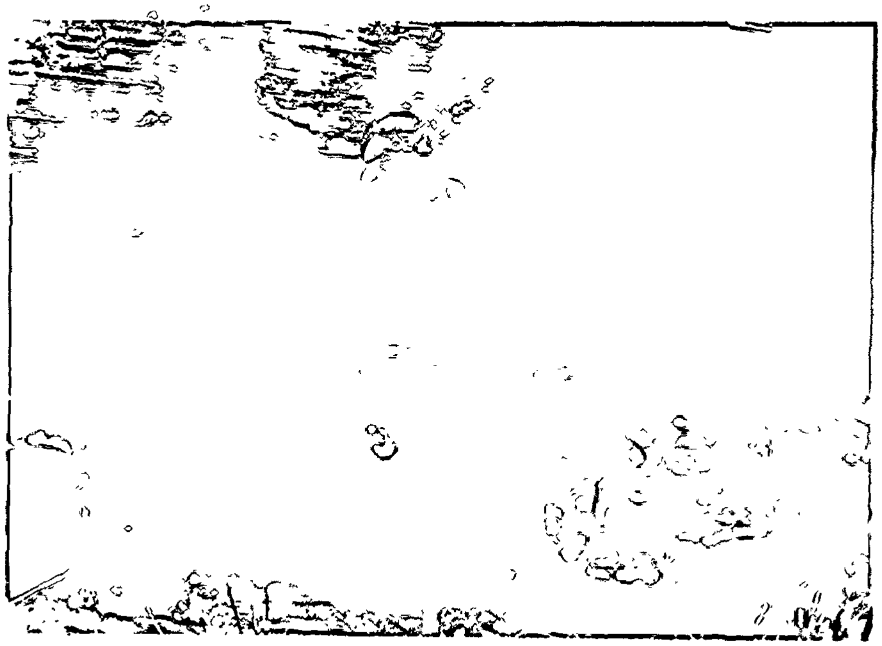
Unit 7 consists of dark greyish-black fissile shale. It contains small partially intact plant fragments that average 0.2 cm long and 0.05 cm wide, and some macerated carbonaceous material. Roots are present near the upper contact. The unit is capped with 21.0 cm of sheared, dark brownish-black, *in situ* coal.

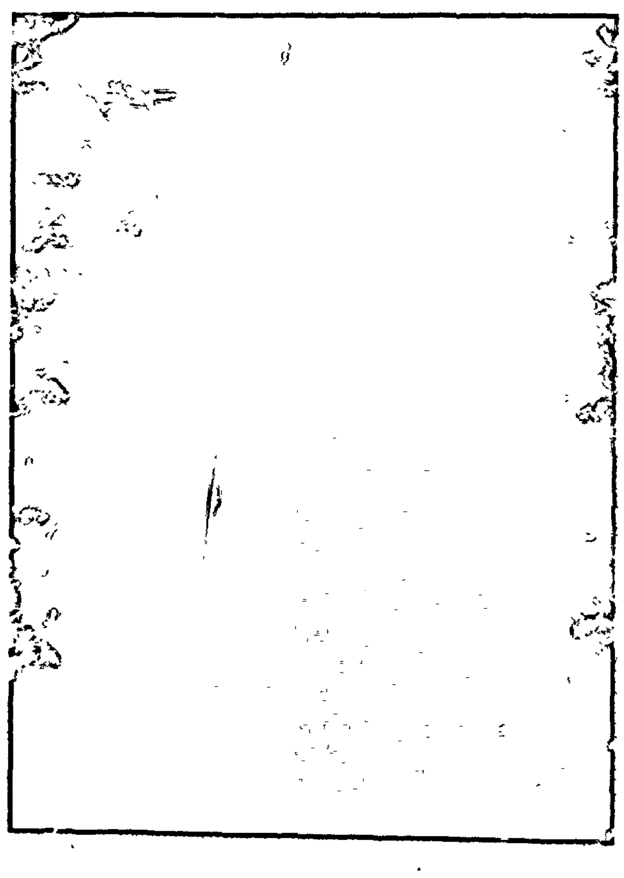
3.2.9 Unit 8 (173.5-194.7 m)

Unit 8 can be described in four separate intervals that occur between 173.5-186.5 m, 186.5-189.0 m, 189.0-192.6 m, and 192.6-194.7 m. The lowermost interval is a coarsening-upward sequence that begins with 6.2 m of calcareous silty shale. The shale is overlain by 2.1 m of dark grey, very fine-grained sandstones interbedded with dark grey shales. Sandstone beds average 10.0 cm in thickness, have sharp upper and lower contacts, and undulate and pinch and swell. They may represent very poorly developed H.C.S. Within these sandstone beds, small partially intact plant fragments (average 6.0 cm long and 1.5 cm wide) and macerated carbonaceous material were noted. Shale interbeds thin upward within the sequence and disappear at 181.8 m. Here, sandstones are medium-grained, thickly bedded (average 38.0 cm), and are swaley cross-stratified. Swales average 20.0-30.0 cm high and 150.0-200.0 cm across (Figure 3.12). Hummocks were observed in places but are rare. Abundant macerated plant fragments are present along laminations of swales and some horizontal burrows were noted. A 3-5 cm thick shale break overlies the swaley sandstone, occurring at 183.6 m. Above the shale break, the uppermost part of the sequence consists of medium-grained bioturbated sandstone. All

Figure 3.12. Swaley cross-stratified sandstone of Unit 8 (181.8 m).

Figure 3.13. *Ophiomorpha* burrows within the 173.5-186.5 m interval of Unit 8.





primary sedimentary structures have been destroyed by Ophiomorpha burrows up to 5.0 cm diameter (Figure 3.13). The upper contact of the sequence is sharp and has straight-crested symmetrical ripples with wavelengths of 5-10 cm and amplitudes of 2-4 cm.

The following species of marine fauna were identified by R.J. Price and C. Mahadeo (Amoco Canada) from the interval described above:

1) 176.0 m

Ostracods

Cytheridea bonaccordensis

Cytheridea brevisspinosa

2) 180.0 m

Foraminifera

Globulina prisca

Saccamina lathrami

The 186.5-189.0 m interval is interbedded medium grey, fine-grained sandstone and dark greyish-black shale. Sandstone beds average 12 cm in thickness (range 6-18 cm) and contain symmetrical ripple cross-laminations that average 4-5 cm in amplitude. Both sandstones and shales are weakly bioturbated.

FIGURE 3.14. Internal scours within the swaley cross-stratified sandstone of Unit 8 (189.0-192.6 m).

The 189.0-192.6 m interval is medium grey, fine-grained swaley cross-stratified sandstone. Swales average 20-30 cm high, 200 cm across, and have laminations averaging 5 mm thick. Occasional hummocks averaging 10 cm high and 100 cm across and internal scoured surfaces (Figure 3.14) are present throughout the interval. The sandstone has a sharp irregular base with localized lenses of chert pebbles and cobbles. Lenses average 10-11 cm thick (range 5-21 cm) and contain cobbles up to 10 cm in long dimension. The upper contact of the interval is poorly exposed but appears sharp.

The uppermost part of Unit 8 (192.6-194.7 m) is poorly exposed but comprises interbedded greenish-grey sandstone and silty shale. Sandstone beds average about 15 cm in thickness, pinch and swell, and have gradational upper and lower contacts. Abundant macerated plant fragments are scattered throughout this interval.

3.3 Unit Interpretations, Section 1

The salient characteristics and basic interpretations of units at Section 1 are listed in Table 3.1.

UNIT	SALIENT CHARACTERISTICS	BASIC INTERPRETATION
8	Coarsening-upward sequence containing swaley cross-stratification. This sequence is overlain by interbedded sandstone and shale and a second swaley cross-stratified sandstone.	Marine. Nearshore to shoreline.
7	Shale with *in situ* roots and coal.	Restricted marine.
6	Coarsening-upward sequence consisting of thin bioturbated sandstones, H.C.S., and swaley cross-stratified sandstone.	Storm influenced shallow marine and nearshore.
5	Dark grey shale containing coarsening-upward sequences and an H.C.S. bed.	Storm influenced shallow marine.
4 and 2	Interbedded sandstone, shale, mudstone, and coal. Abundant roots and plant fragments throughout the units.	Nonmarine. Fluvial flood-plain.
3 and 1	Fining-upward sandstones with lateral accretion surfaces and superimposed channels.	Nonmarine. Meandering fluvial.

Table 3.1. Salient characteristics and basic interpretations of units at Section 1. Units 1 through 4 represent the Gladstone Formation and Units 5 through 8 represent the Moosebar Tongue.

3.3.1 Nonmarine Units (Units 1-4)

Nonmarine units consist of sharp-based sandstones with roots at the top (Units 1 and 3), each of which is overlain by thin rooted sandstones interbedded with shales and coals (Units 2 and 4). Units 1 and 3 fine upward, have sharp flat bases, and contain lateral accretion surfaces and superimposed channels. They are multi-storied sandstones interpreted as point bar deposits of meandering fluvial channels and resemble the coarse-member fining-upward model of Allen (1965a, 1970a, 1970b).

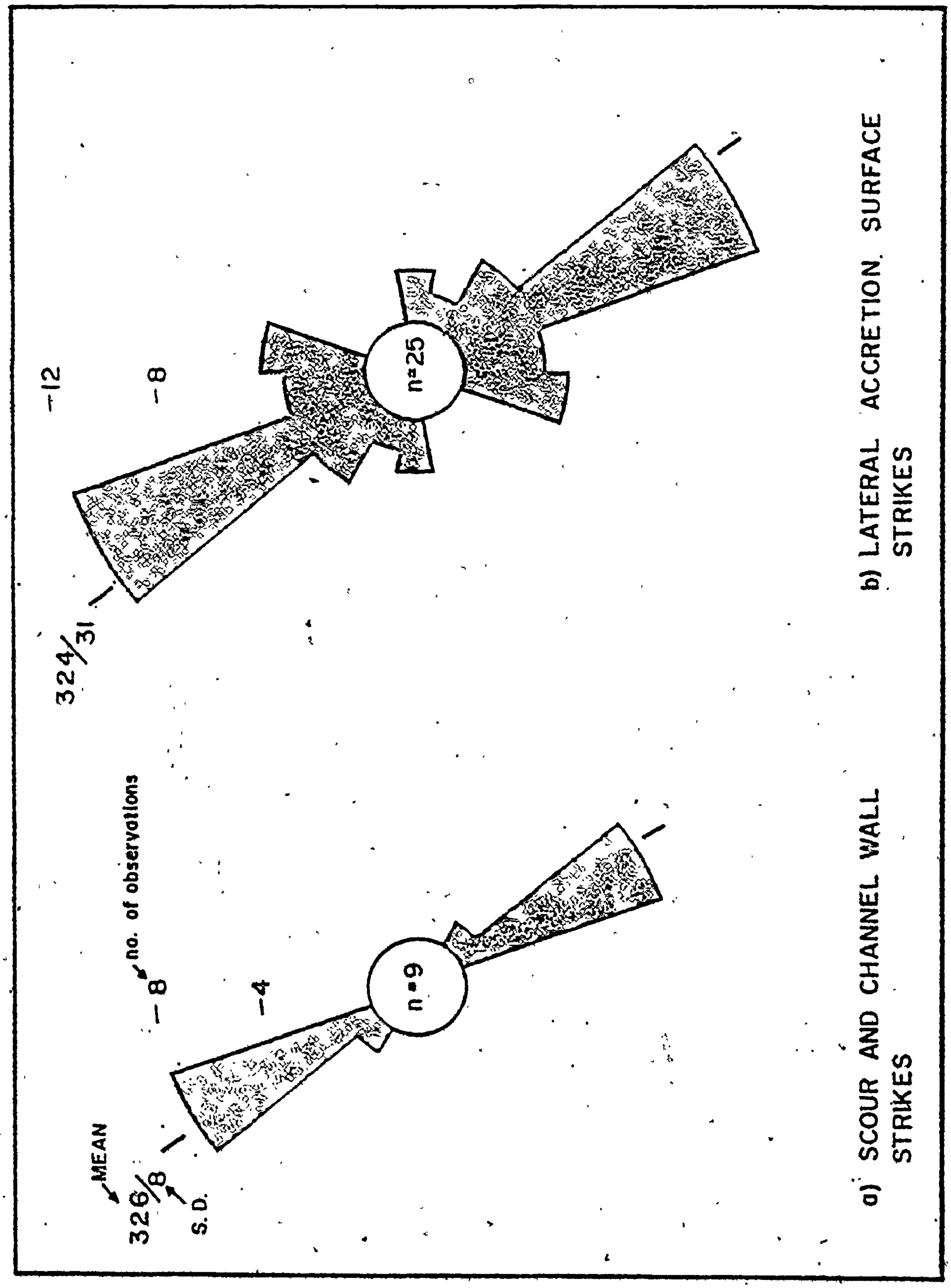
Multi-storied sandstones developed when channels of one fluvial cycle were superimposed on channels of an underlying cycle (Potter, 1963, p. 71). The flat basal erosion surfaces of Units 1 and 3 were produced during lateral channel migration as the scour pool was maintained at a relatively constant level (Moody-Stuart, 1966, Figure 1). Mud and very fine silt drapes are common on lateral accretion surfaces of Units 1 and 3 and are ascribed to fluctuating river discharge and discontinuous point bar accretion. Very fine silt and mud was deposited from suspension on the point bar surface during low flow stages or periods of channel inactivity.

Paleocurrent measurements from Units 1 and 3 were limited to trends of lateral accretion surfaces and channel wall planes. Flow in the thalweg was perpendicular to the dip of these features and in Units 1 and 3 was either towards NW or SE (Figure 3.15). From paleogeographic reconstructions and flow directions in overlying and underlying formations (as discussed in Chapter 2.4), flow is inferred to have been toward NW. Ripple cross-laminations near the top of Unit 3 are oriented ENE and WNW suggesting secondary flow within the ancient channel.

Thin sandstones interbedded with shales in Units 2 and 4 are interpreted as vertical accretion deposits. They were deposited on the floodplain during flood stages of the river when flow overtopped the banks. Intense rooting and accumulation of thin coal beds indicates growth of vegetation on the floodplain during normal river stages.

Thicker sandstones of Units 2 and 4 commonly occupy small shallow channels (1 m deep and 5-12 m across) or have sharp scoured bases. They contain internal erosion surfaces, abundant plant fragments, and are rooted. These sandstones are interpreted as crevasse splays that breached levees and spread laterally over finer grained floodplain deposits.

Figure 3.15. Paleocurrent data for Units 1 and 3.


MEAN
326/8
S.D.
8 no. of observations
4
n=9
a) SCOUR AND CHANNEL WALL STRIKES
324/31
12
8
n=25
b) LATERAL ACCRETION SURFACE STRIKES

The uppermost part of Unit 4 contains nonmarine to brackish ostracods and gastropods at 87.1 and 96.0 m (see Chapter 3.2.5). The species identified are believed to have inhabited coastal (fringing) lakes with intermittent sea connections (cf. Lake Maracaibo, Venezuela; R.J. Price, pers. comm., 1981). The coarsening-upward sandstone interval near the top of Unit 4 (92.3-95.5 m) may represent a prograding lacustrine shoreline or nearshore deposit. The sandstone interval between 89.5-91.5 m contains scours and small channels and is interpreted as a crevasse splay channel or possibly a small tributary channel that bordered the brackish lake.

Paleocurrent measurements from Units 2 and 4 commonly diverge from the NW flow trend associated with the underlying fluvial channels of Units 1 and 3. In some places, divergent angles are greater than 90° and suggest lateral spreading of fan-like crevasse splays over the floodplain.

3.3.2 Marine Units (Units 5-8)

Units 5-8 represent the marine Moosebar Tongue which was deposited in the Clearwater Sea as it transgressed southward in early Albian time (Jeletzky, 1971, p. 42-47). The sharp contact of Unit 5 with underlying nonmarine deposits of Unit 4 marks the initial transgression. A 0.4 m thick sandstone occurs here and is interpreted as a transgressive lag that may represent a remnant of a transgressed beach (Reineck and Singh, 1973, p. 296).

Units 5-7 are interpreted as a prograding shallow marine and shoreline sequence. Unit 5 is largely dark grey, fine-grained fissile shale. In the lowermost part of Unit 5 the shale contains nonmarine to brackish ostracods and gastropods similar to those found in the uppermost part of Unit 4. These fauna were probably reworked during transgression and transported offshore. Shales in the uppermost part of Unit 5 are similar to those in the lowermost part and contain marine fauna that indicate water depths of greater than 10-20 m (R.J. Price, pers. comm., 1981).

Two intervals within Unit 5 contain thickening-upward sandstone sequences. They occur at 116.5 m and 141.2 m, and are interpreted as storm deposits that were introduced into a relatively quiet shallow marine environment by storm generated density currents. A storm origin for these deposits is suggested by the presence of an H.C.S. bed at 141.2 m. H.C.S. was interpreted by Hamblin and Walker (1979), Bourgeois (1980), and Wright and Walker (1981) as having been deposited between storm wave base and fairweather wave base by storm generated density currents. The 116.5-124.0 m interval below the H.C.S. is characterized by planar or gently undulating, parallel laminated sandstone beds. It does not contain H.C.S. and is interpreted as having been deposited at or near storm wave base. The upper contacts of both intervals have symmetrical ripples that suggest wave reworking during post-storm conditions. Horizontal Rhizocorallium traces on the upper contact of the H.C.S. bed indicate colonization by deposit feeding organisms during quiet water periods (Seilacher, 1967).

Thin shell hash layers are present throughout the shallow marine shales of Unit 5. Shells within individual beds are randomly oriented with many assuming "unstable" concave-up positions. This suggests deposition from density currents (Middleton, 1967) which were most likely storm induced.

Near the top of Unit 5 at 147.1 m are small channels and gutter casts that erode through bioturbated siltstone. Channels and gutter casts are interpreted as having been eroded by storm generated density currents that formed during ebb storm-surges and transported sediment offshore.

Unit 6 coarsens upward from bioturbated sandstones into H.C.S. which is overlain by 6 m of swaley cross-stratified sandstone. The swaley cross-stratified sandstone has scours along the base, symmetrical ripples on the upper contact, a deformed Chondrites horizon 20-25 cm below the upper contact, and shows no signs of emergence. The overlying unit (Unit 7) comprises fine-grained shale with roots at the top, and it is capped with 21 cm of in situ coal.

Units 6 and 7 are interpreted as a prograding nearshore and shoreline sequence. The presence of H.C.S. near the middle of Unit 6 suggests storm activity and is interpreted as a lower shoreface deposit. The swaley cross-stratified sandstone is interpreted as a nearshore storm deposit and may represent a subaqueous bar. Deformed Chondrites traces near the top of the swaley sandstone suggest that the sediment was water laden during deposition, with deformation occurring during compaction. Scours at the base indicate that ebb storm-surge currents eroded sediment from the nearshore environment and transported it offshore. The association of swaley cross-stratification overlying H.C.S. has been observed in the Wapiabi-Belly River transition of southern Alberta (Walker et al., 1981) and the Moosebar-Gates transition of northeastern British Columbia (Leckie and Walker, in press), and has been interpreted as a storm-dominated shallow marine sequence.

Shales with <u>in situ</u> roots and coal (Unit 7) indicate emergence and are interpreted as a muddy shoreline. Their presence above swaley cross-stratified sandstone can be explained by the progradation of a restricted marine environment over a storm influenced nearshore bar. Fine-grained mud and silt accumulated in protected bay and marsh areas while sand was supplied to the bar by a deltaic distributary and was transported by longshore currents. Mud was winnowed from the swaley cross-stratified sandstone by longshore currents and storm waves leaving a clean, well sorted sand. A schematic illustration of this is shown in Figure 3.16.

Paleocurrent measurements in Units 5 and 6 were obtained from symmetrical ripple crests, gutter ~~casts, and~~ scour and channel walls. Symmetrical ripple crests have been observed on the Oregon continental shelf where they are nearly parallel to the shoreline in water depths of up to 200 m (Komar <u>et al</u>., 1972, p. 605). Symmetrical ripple crest orientations are therefore used as an approximation of the paleoshoreline orientation. Sixteen symmetrical ripple crests were averaged and indicate an ENE-WSW oriented paleoshoreline (Figure 3.17a). Scour walls, gutter casts, and channel walls near the top of Unit 5 and

Figure 3.16. Schematic illustration of depositional environments within Units 5,6 and 7. See text for discussion (Chapter 3.3.2).

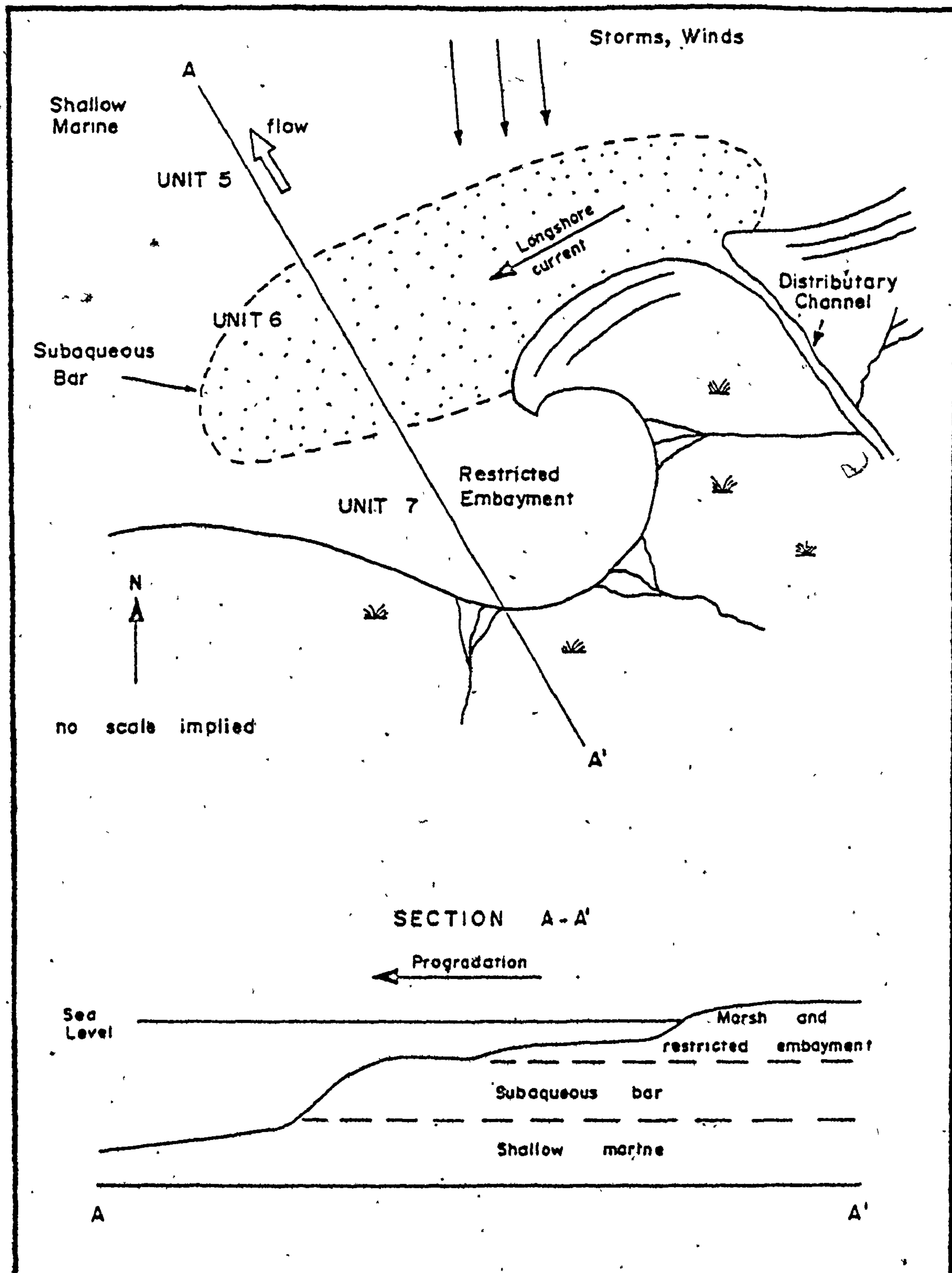
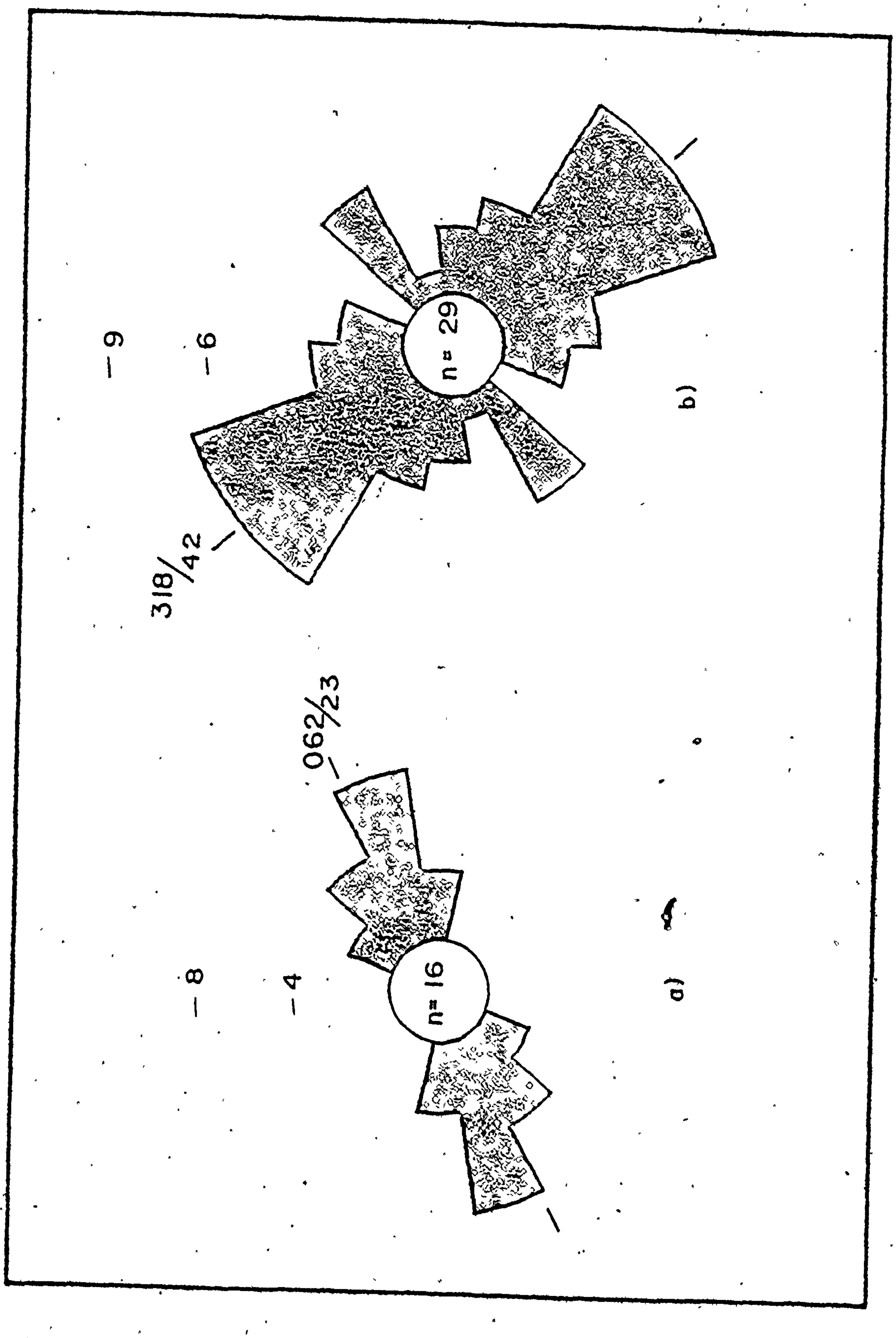

Storms, Winds
A
Shallow Marine
flow
UNIT 5
Longshore current
Distributary Channel
UNIT 6
Subaqueous Bar
Restricted Embayment
UNIT 7
N
no scale implied
A'
SECTION A-A'
Progradation
Sea Level
Marsh and restricted embayment
Subaqueous bar
Shallow marine
A
A'

Figure 3.17. Paleocurrent data for Units 5 and 6. a) symmetrical ripple crest strikes. b) strikes of channel walls, scour walls, and gutter cast axes.



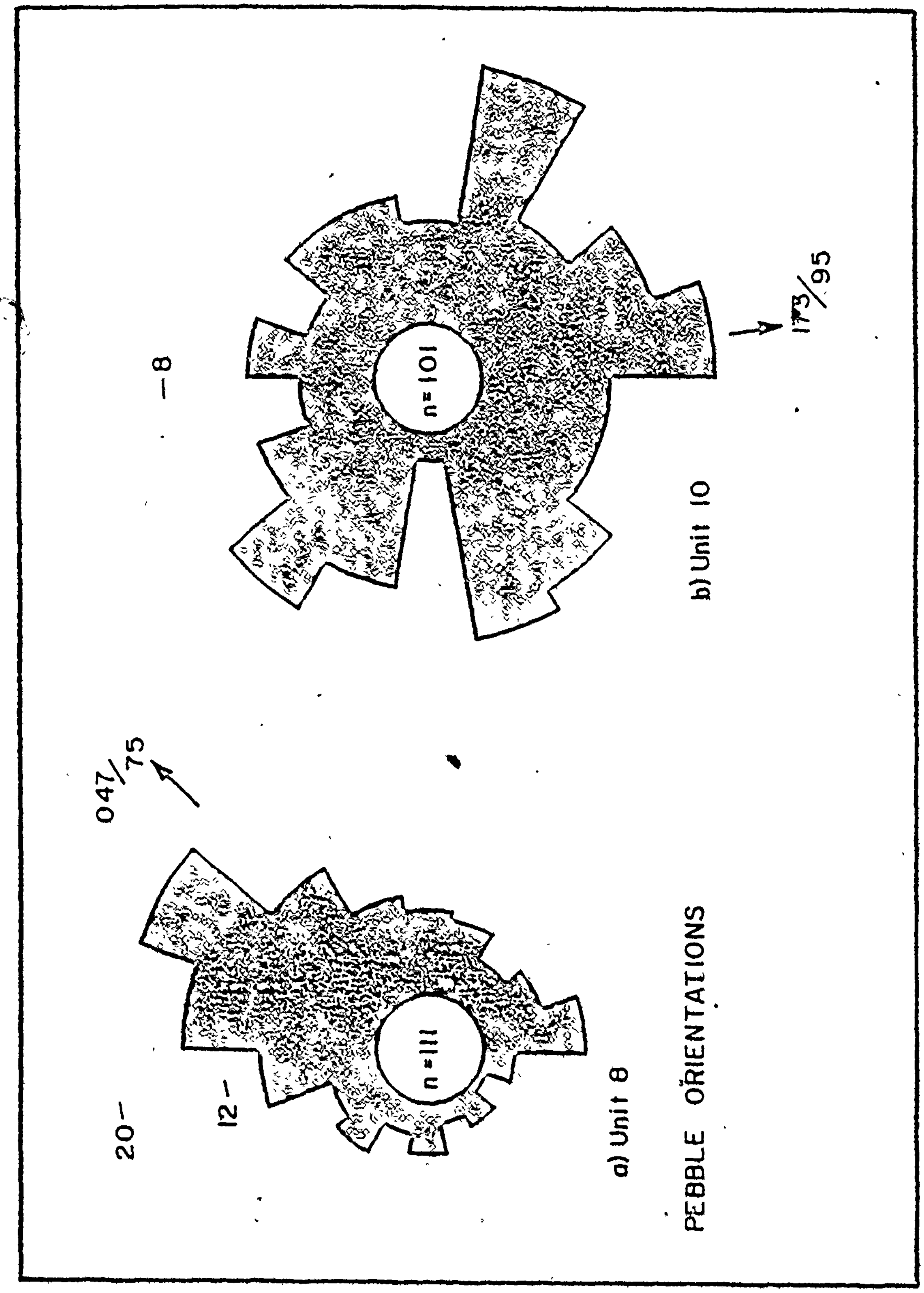
9
6
318/42
n= 29
b)
062/23
8
4
n= 16
a)

within Unit 6 are commonly oriented NW-SE, suggesting flow perpendicular to the shoreline (Figure 3.17b). Since the Clearwater Sea transgressed from the north, offshore paleoslope is inferred to be dipping NW.

A second transgression occurs within the Moosebar Tongue at the base of Unit 8. Unit 8 can be correlated with Unit 10 at Section 2, located approximately 2.5 km west on the Bighorn River. Unit 10 overlies mudstone, shale, and _in situ_ coal that was previously interpreted as having been deposited in a restricted marine environment (cf. Unit 7). Foraminifera and marine ostracods were found within Unit 8 and indicate water depths of greater than 10-20 m (R.J. Price, pers. comm., 1981).

The lowermost parts of Units 8 and 10 are coarsening-upward sequences that contain swaley cross-stratified sandstone and _Ophiomorpha_ traces. The sequences are interpreted as having been deposited in a storm-dominated, prograding nearshore or shoreline environment. Above the coarsening-upward sequences within Units 8 and 10 are interbedded symmetrical rippled sandstones and shales which are overlain by a second swaley cross-stratified sandstone. They are interpreted as having been deposited in a fluctuating nearshore or shoreline environment. Three symmetrical ripple crests

Figure 3.18. Paleocurrent data for Units 8 and 10. Data represent the a-b plane dip directions of pebbles.



PEBBLE ORIENTATIONS

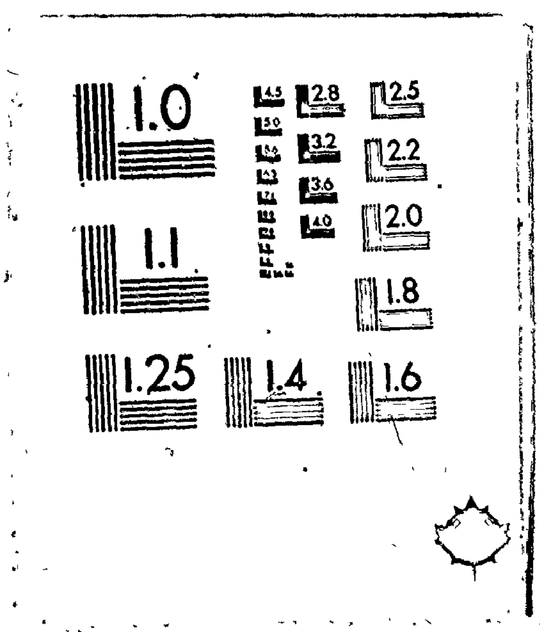
were measured in Units 8 and 10 and indicate a WSW-ENE oriented shoreline. Lenses of pebbles and cobbles are present at the base of the uppermost swaley sandstone and are interpreted as a lag deposit that was being washed around near the shore. The a-b plane dip directions of the pebbles were measured in Unit 8 and indicate flow towards SW (Figure 3.18a). Measurements are statistically significant at greater than 99.5 percent. The SW flow direction suggests the presence of onshore and longshore currents during the deposition of Unit 8. Pebble orientations were also measured in Unit 10 but were statistically significant at less than 75.0 percent (Figure 3.18b).

3.4 Unit Descriptions, Section 2 (Bighorn River West of Crescent Falls)

3.4.1 Introduction

Units 9, 10, and 11 at Section 2 represent the uppermost part of the marine Moosebar Tongue. Units 12 and 13 are transitional into the lowermost part of the nonmarine Beaver Mines Formation.

2



3.4.2 Unit 9 (0-15.4 m)

The base of Unit 9 consists of dark greyish-black, calcareous bioturbated mudstone containing a few small partially intact plant fragments. Capping the mudstone is 25 cm of coal which is overlain by 10.4 m of dark greyish-brown silty shale. Another coal bed 3 cm thick occurs 2 m from the base of the silty shale and 0.5 m of greyish-brown, parallel laminated siltstone occurs within the silty shale at 10.0 m.

The uppermost part of Unit 9 consists of thickening-upward, dark greyish-black, fine-grained sandstone and shale. Sandstone beds average 6 cm in thickness (range 3-12 cm), commonly contain parallel laminations and in places symmetrical ripple cross-laminations, and are bioturbated. Overlying these beds is 30 cm of light greyish-brown mudstone containing a 3-4 cm thick thoroughly rooted sandstone. A 30 cm thick *in situ* coal bed caps Unit 9.

3.4.3 Unit 10 (15.4-29.8 m)

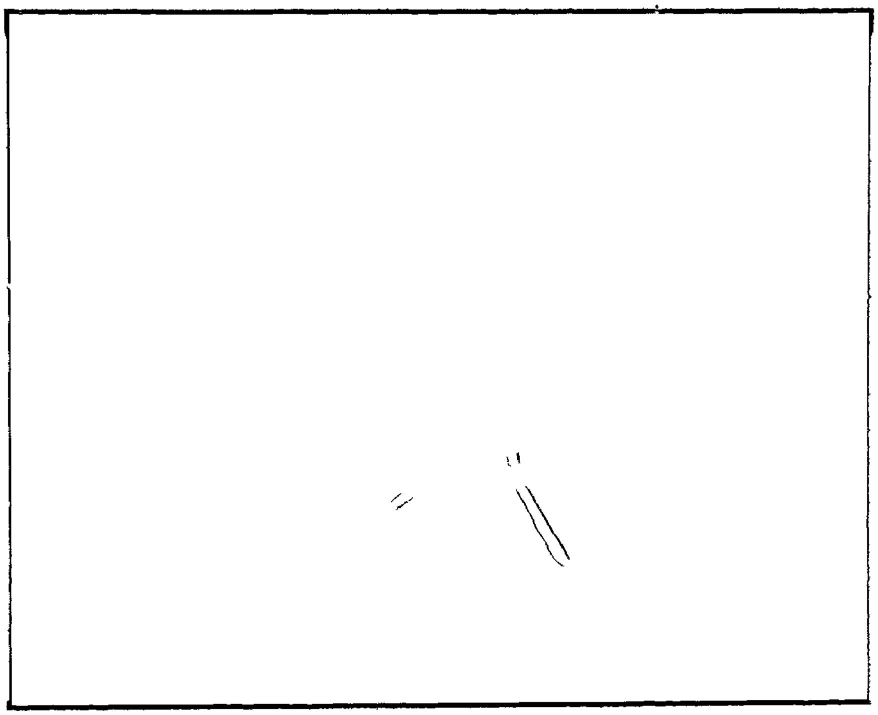
Unit 10 can be described in three intervals that occur between 15.4-22.5 m, 22.5-26.0 m, and 26.0-29.8 m. The uppermost two intervals are correlative with the

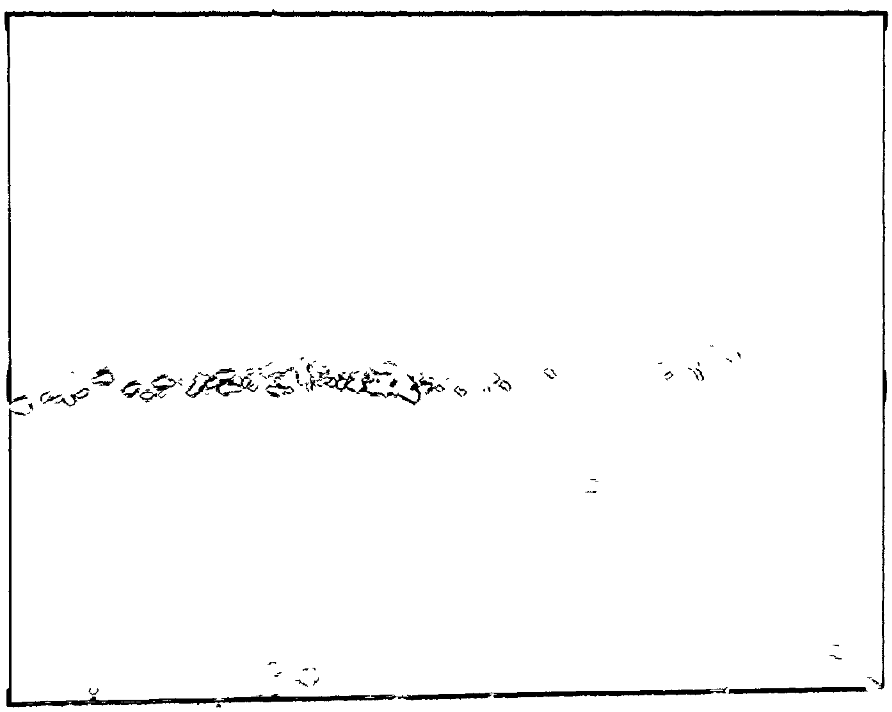
186.5-189.0 m and 189.0-192.6 m intervals of Unit 8 at Section 1. Lithologies and sedimentary structures at both localities are identical (see Chapter 3.2.9 for descriptions).

The lowermost interval (15.4-22.5 m) of Unit 10 differs from that of Unit 8. The bottom 2.7 m of the interval consists of medium grey, very fine-grained calcareous sandstone interbedded with siltstone and shale. The sandstone:siltstone plus shale ratio is about 1:2. Sandstone beds average 10-12 cm thick, pinch and swell, have sharp upper and lower contacts, and are parallel laminated. A light grey, very fine-grained fissile shale (15 cm thick) overlies the interbedded sandstone, siltstone, and shale. The upper 4.5 m of the interval consists of medium grey, medium-grained, swaley cross-stratified sandstone. Swales average 20-30 cm high and 150-200 cm across. The sandstone has sharp upper and lower contacts, with the upper contact containing sinuous-crested symmetrical ripples that average 2-3 cm in amplitude and 15 cm in wavelength. Prominent Ophiomorpha traces are found throughout the sandstone (Figure 3.19).

Figure 3.19. *Ophiomorpha* network in the swaley cross-stratified sandstone of Unit 10 (15.4-22.5 m).

Figure 3.20. Sandstone "stringer" within Unit 11. Hammer for scale.





3.4.4 Unit 11 (29.8-41.3 m)

Unit 11 comprises interbedded greyish-green sandstone and argillaceous siltstone and has a concretionary layer present at 31.3 m. The sandstone:argillaceous siltstone ratio is about 1:6. Individual sandstone beds are fine-grained, average 10-12 cm in thickness (range 3-50 cm), and contain parallel to gently curved laminations. One sandstone at 35.9 m is ripple cross-laminated with sets averaging 2-3 cm. Upper and lower sandstone contacts are more commonly gradational than sharp. At 34.8 m and 37.8 m are two parallel laminated calcareous sandstone "stringers" that have sharp upper and lower contacts, average 18 cm in thickness, and pinch and swell (Figure 3.20). They are continuous along the full lateral extent of the outcrop and have Cosmorphaphe ? traces on their upper contacts.

A species of foraminifera found at 37.0 m was identified by R.J. Price (Amoco Canada) as Bathysiphon sp. Macerated carbonaceous material is ubiquitous throughout the unit.

3.4.5 Unit 12 (41.3-51.2 m)

Unit 12 consists of light greenish-grey, medium-grained, poorly sorted argillaceous sandstone. It has a gradational base and contains abundant macerated carbonaceous material. Sedimentary structures present include parallel laminations and ripple cross-laminations (sets average 2-3 cm). Scouring into the lower and middle parts of this sandstone is a series of channels that average 0.5 m deep and 4-5 m across (Figure 3.21). A large channel comprises the uppermost part of Unit 12 but its dimensions could not be determined due to a covered interval. All channels are filled with medium grey, very fine-grained sandstone. Channel-fill is commonly parallel laminated; however, trough cross-beds are present at 50.4 m within the sandstone of the uppermost large channel (sets average 20-30 cm). Rare mudclasts that average less than 1 cm diameter, and abundant macerated carbonaceous material were noted within the channel-fills.

3.4.6 Unit 13 (51.2-70.0 m)

Unit 13 consists largely of interbedded greenish-grey sandstone and argillaceous siltstone. It contains channels in the upper 5-6 m, with the largest channel being about 3 m deep and at least 20 m across. Channel-fill consists of greenish-grey, medium-grained

Figure 3.21. Small channel eroding through the lower part of Unit 12.

sandstone that is trough cross-bedded at the base (sets average 15 cm) and ripple cross-laminated near the top (sets average 2-3 cm). Macerated carbonaceous material and small partially intact plant fragments are present within this channel-fill. Two smaller channels were also noted within Unit 13, averaging 1-2 m deep and about 5 m across. The fill of these channels is similar to that of the larger channel but lacks trough cross-beds. One channel is capped with approximately 5-6 cm of coal.

The interbedded sandstone and argillaceous siltstone comprising the majority of Unit 13 has a sandstone:argillaceous siltstone ratio of 1:5.4. Sandstone beds are medium-grained, have sharp upper and lower contacts, and average 60 cm in thickness (range 40-80 cm). They contain ripple cross-laminations with sets averaging 3-4 cm. Macerated carbonaceous material and small partially intact plant fragments were found throughout the sandstones and argillaceous siltstones. Roots were observed within the argillaceous siltstone at 54.0 m and 63.0 m. An iron-stained concretionary layer occurs at 64.8 m and small iron-stained oval concretions were found scattered throughout the argillaceous siltstone.

3.5 Unit Interpretations, Section 2

The salient characteristics and basic

UNIT	SALIENT CHARACTERISTICS	BASIC INTERPRETATION
13	Channelled sandstones and interbedded sandstone and rooted argillaceous siltstone.	Nonmarine. Fluvial-floodplain.
12	Poorly sorted argillaceous sandstone with internal channels in some places.	Marine. Shoreline.
11	Interbedded sandstone and argillaceous siltstone.	Marine. Nearshore.
10	Swaley cross-stratified sandstones and interbedded sandstone and shale.	Marine. Nearshore to shoreline.
9	Shale and mudstone with thin coal beds.	Restricted marine.

Table 3.2 Salient characteristics and basic interpretations of units at Section 2. Units 9 through 12 represent the Moosebar Tongue and Unit 13 represents the Beaver Mines Formation.

interpretations of units at Section 2 are listed in Table 3.2.

3.5.1 Marine Units (Units 9-12)

Units 9 and 10 can be correlated with Units 7 and 8 at Section 1. They were interpreted previously as restricted marine and storm-dominated nearshore marine environments respectively (see Chapter 3.3.2). Overlying these units is interbedded sandstone and argillaceous siltstone of Unit 11. Sandstone beds contain parallel to gently curved laminations and abundant macerated carbonaceous material. A species of foraminifera identified as Bathysiphon sp. was found within the argillaceous siltstone of Unit 11 at 37.0 m. Overlying Unit 11 is poorly sorted argillaceous sandstone of Unit 12 which has small channels eroding through it that average 0.5 m deep and 4.5 m across.

Units 11 and 12 are interpreted as having been deposited in protected nearshore and shoreline environments, respectively. Low energy is required to explain the poorly sorted and argillaceous nature of the sandstone comprising Unit 12. The shoreline may have been protected by an equivalent of an offshore bar (possibly the upper swaley cross-stratified sandstone of Unit 10) which prevented high energy storm waves from reaching the shoreline. Sediment from a nonmarine source therefore could have been deposited in a protected marine environment with little or no reworking.

Paleocurrent measurements were obtained from symmetrical ripple crests and channel walls. They are consistent with measurements from Section 1 and indicate an ENE-WSW oriented paleoshoreline. Channel wall orientations from Unit 12 indicate that flow was either toward NW or SE. Since the Clearwater Sea transgressed from the north, flow is inferred to be toward NW.

3.5.2 Nonmarine Unit (Unit 13)

Unit 13 consists of channelled sandstones, and interbedded sandstone and rooted argillaceous siltstone. It is interpreted as a fluvial floodplain deposit and indicates a return to nonmarine conditions following the regression of the Clearwater Sea. Paleocurrent measurements from Unit 13 indicate flow toward NE.

3.6 Unit Descriptions, Section 3 (Cadomin Railroad Cut)

3.6.1 Introduction

Units 14 and 15 represent the uppermost 88.7 m of the Gladstone Formation and are of nonmarine and brackish origins, respectively. Unit 16 represents the lowermost nonmariné deposits of the Beaver Mines Formation.

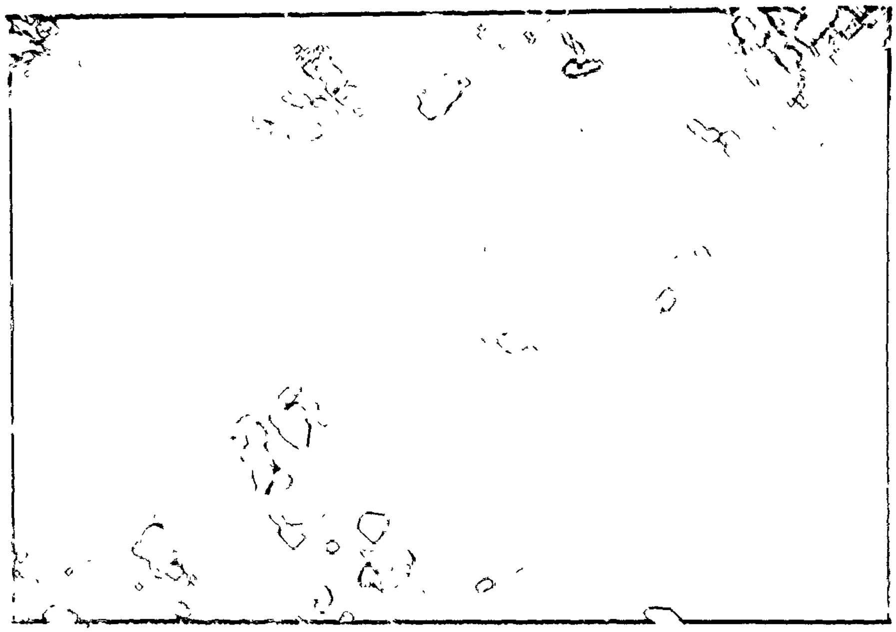
3.6.2 Unit 14 (0-71.4 m)

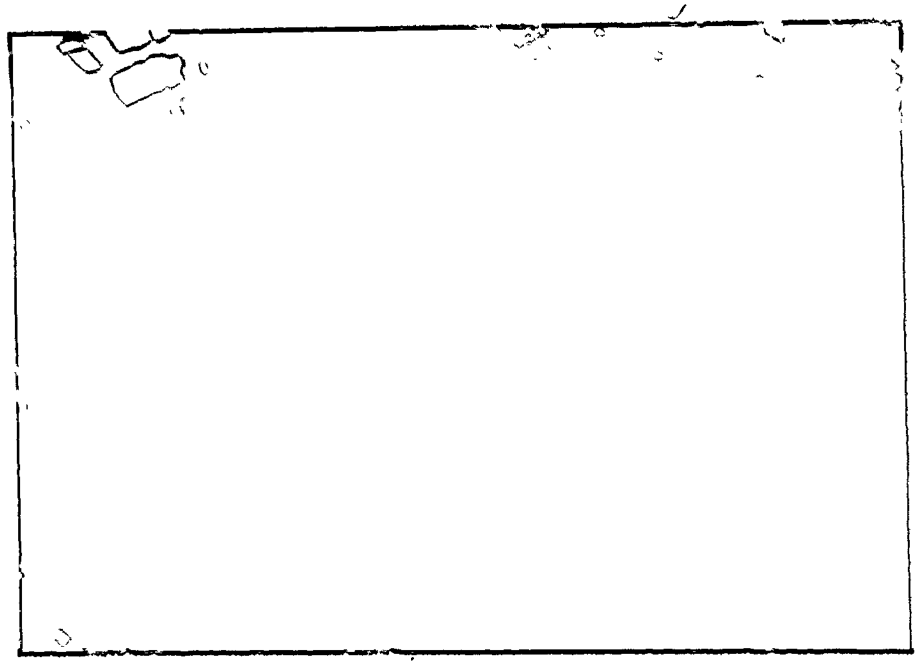
Unit 14 contains seven channelled sandstones that occur at: 0.0 m; 4.1 m; 14.2 m; 21.4 m; 49.2 m; 55.0 m; and 66.3 m. Between them is interbedded sandstone with either mudstone or shale, as well as minor siltstone and coal.

The seven channelled sandstones are brownish-grey to grey, fine- to coarse-grained, and average 2.7 m in thickness (range 1.7-3.5 m; Figure 3.22). They are composed of 2 or 3 channels that average about 0.5-1.0 m deep and 5.0-10.0 m across. Channel-fill is largely ripple cross-laminated (sets average 3.0 cm); however, at 0.0 m and 14.2 m trough cross-beds were noted (sets average 15.0 cm). Channels have sharp or gradational upper contacts and channel-fill commonly fines upward

Figure 3.22. Channelled sandstone within Unit 14.

Figure 3.23. Bioturbated fine-grained sandstone within the coarsening-upward sequence of Unit 15.





slightly and is overlain by thin shale or siltstone. The shale or siltstone may be partially or wholly removed by scouring of the overlying channel. Partially intact plant fragments and macerated carbonaceous material are present within the sandstone of each channel and the upper contacts are commonly rooted.

Between the channelled sandstones is interbedded greyish-brown to grey sandstone with either greyish-black fissile shale or light grey mudstone. The sandstone:shale plus mudstone ratio is 1:1.3. Sandstone beds average 0.4 m in thickness (range .03-4.8 m), are very fine- to fine-grained, and may have sharp or gradational upper and lower contacts. All sandstone beds contain ripple cross-laminations with sets averaging 1-2 cm. A thickly bedded sandstone at 36.6 m also has faint parallel laminations. Within the interbedded sandstone and shale or mudstone are 17 thin coal beds that average 36 cm in thickness (range 2-100 cm). Rare greyish-brown siltstones and iron-stained concretionary layers were also noted. Sandstones, siltstones, shales, and mudstones commonly contain partially intact plant fragments up to 5 cm wide and 10 cm long, and are rooted.

3.6.3 Unit 15 (71.4-88.7 m)

The lowermost part of Unit 15 (71.4-82.1 m) is a coarsening-upward sequence that begins with 0.5 m of dark grey fissile shale. The shale is overlain by 2.0 m of dark grey, calcareous siltstone containing 4 or 5 thin lenticular sandstones that are sharp-based, very fine-grained, and parallel laminated. Above the siltstone is 1.8 m of dark grey, very fine-grained, medium bedded sandstone. Beds average 25 cm in thickness (range 10-40 cm) and thicken upwards slightly. Thin gradational shale breaks occur between some beds. No primary sedimentary structures were observed within individual beds due to intense bioturbation (Figure 3.23). Bioturbation also causes upper and lower sandstone contacts to appear gradational. Overlying the bioturbated sandstone is 5-10 cm of grey fissile shale followed by 4.0 m of medium-grained, poorly developed, swaley cross-stratified sandstone (Figure 3.24). Swales within this interval average 0.3-0.4 m high and 5-10 m across; however, they are difficult to distinguish due to the limited lateral extent of the outcrop. Approximately 1.1 m from the base of the swaley sandstone is a 40 cm thick shale break. It contains thin thoroughly bioturbated sandstones that range from 1 to 5 cm in

Figure 3.24. Poorly developed swaley cross-stratified sandstone at the top of the coarsening-upward sequence of Unit 15.

thickness. The swaley cross-stratified sandstone has roots at the upper contact and is capped with 2 thin *in situ* ooal beds (10 cm and 50 cm thick) that are separated by 1.1 m of light grey, ripple cross-laminated sandstone.

The uppermost part of Unit 15 (82.1-88.7 m) consists of interbedded grey sandstone and shale. The sandstone:shale ratio is 1:1. Sandstone beds are very fine- to fine-grained, have sharp upper and lower contacts, and average 22.0 cm in thickness (range 5-150 cm). Primary sedimentary structures have been destroyed in all but the uppermost sandstone by large vertical *Ophiomorpha* burrows.

Nonmarine to brackish fauna found near the base and at the top of Unit 15 were identified by R.J. Price (Amoco Canada) as:

Ostracods

Limnocythere calmontensis

Metacypris persulcata

Gastropod

Liaplacoides ? sp.

The following species of nonmarine to brackish fauna were reported by Mellon (1967) from near the base of Unit 15:

Molluscs

Murraia sp. cf. *M. fabensis*

Murraia n.sp.

Musculiopsis sp. cf. *M. russelli*

Campeloma sp. indet.

3.6.4 Unit 16 (88.7-190.0 m)

Unit 16 sharply overlies Unit 15 and is largely covered with the exception of the lowermost 14.3 m and between 166.0-168.1 m. The lowermost 14.3 m of Unit 16 consists of dark grey fissile shale that contains marine fauna identified by R.J. Price (Amoco Canada) as:

Foraminifera

Haplophragmoides topagorukensis

Haplophragmoides linki

Cagena ? sp.

Dentalina ? sp.

Mollusc genus and species indet.

Mellon and Wall (1961, 1963) identified the following species of marine fauna from the same interval:

Foraminifera

Haplophragmoides spp.

Psamminopelta sp. cf. *P. bowsheri*

Gyroidina sp. cf. *G. nitida*

Quadrimorphina albertenensis

The interval between 166-168.1 contains 40 cm of light grey, fine-grained H.C.S. Hummocks average 20 cm high and 200 cm across and the H.C.S. has sharp upper and lower contacts. The upper contact contains symmetrical ripples that average 3 cm in amplitude and 10 cm in wavelength. Above and below the H.C.S. is interbedded light grey sandstone and shale. The sandstones are very fine-grained and average 5 cm in thickness. They have sharp upper and lower contacts and are slightly bioturbated.

3.6.5 Unit 17 (190-204 m)

Unit 17 is poorly exposed but consists of approximately 13 m of greenish-grey, medium-grained sandstone overlain by 1-2 m of *in situ* coal. The base of the sandstone is not exposed but the lowermost part of the unit contains trough cross-beds. Brownish coloured weathering of the outcrop makes trough sets indistinguishable for detailed measurement. The middle part of the sandstone is parallel laminated and the upper 3-4 m is ripple cross-laminated. The upper contact is sharp and contains abundant roots. Two internal erosive surfaces were noted within the sandstone and these occur at 194.6 m and 200 m. Partially intact plant fragments of various sizes were found throughout the sandstone.

3.7 Unit Interpretations, Section 3

The salient characteristics and basic interpretations of units at Section 3 are listed in Table 3.3.

3.7.1 Lower Nonmarine Units (Units 14 and 15)

Unit 14 consists of sandstones that occupy small channels (average 0.5-1.0 m deep and 5-10 m across), interbedded with sandstone, shale, mudstone, and coal. Channel-fill contains ripple cross-laminations, trough cross-beds in some places, and abundant macerated plant fragments and roots. Interbedded sandstone, shale, and mudstone also contain macerated plant fragments and are commonly rooted. Larger channelled sandstones of comparable size to those at Section 1 (Units 1 and 3) are conspicuously absent in Unit 14.

UNIT	SALIENT CHARACTERISTICS	BASIC INTERPRETATION
17	Coarse-grained sandstone containing trough cross-beds, ripple cross-laminations, and parallel laminations. *In situ* coal caps the sandstone.	Nonmarine. Meandering fluvial.
16	Dark grey foraminifera-bearing shale.	Shallow marine.
15	Coarsening-upward sequence which is overlain by interbedded sandstone and shale. Nonmarine to brackish fauna are found throughout the unit.	Brackish lacustrine.
14	Thin rooted sandstones interbedded with shale and coal. Small channelled sandstones are present throughout the unit.	Nonmarine. Lower alluvial plain.

Table 3.3 Salient characteristics and basic interpretations of units at Section 3. Units 14 and 15 represent the Gladstone Formation, Unit 16 represents the Moosebar Tongue, and Unit 17 represents the Beaver Mines Formation.

Small channelled sandstones are interpreted as crevasse splays and small branching fluvial channels of the lower alluvial plain. Interbedded sandstone, shale, and mudstone is interpreted as vertical accretion deposits. Abundant plant fragments, roots, and coal suggest a relatively thick vegetative cover on the lower alluvial plain. Paleocurrent trends within Unit 14 are highly variable and are attributed to the branching of small fluvial channels and to crevasse splay and overbank deposition on the floodplain.

Unit 15 contains a coarsening-upward sequence in its lowermost part that begins with shale and siltstone which is overlain by very fine-grained bioturbated sandstones and poorly developed swaley cross-stratified sandstone. The upper contact of the swaley sandstone is rooted and an *in situ* coal caps the sequence. The uppermost part of Unit 15 consists of bioturbated sandstones interbedded with shales. Nonmarine to brackish fauna were found within the shales of Unit 15 (see Chapter 3.6.3).

Unit 15 is interpreted as a brackish lacustrine deposit. This interpretation is based largely on the paleoecological interpretation of fauna found within the unit. The fauna are envisaged as having inhabited a coastal (fringing) lake with intermittent sea connections (cf. Lake Maracaibo, Venezuela; R.J. Price, pers. comm., 1981). The coarsening-upward sequence capped with in situ coal in the lowermost part of the unit is interpreted as a prograding lacustrine shoreline. The occurrence of poorly developed swaley cross-stratification within the coársening-upward sequence suggests a relatively high energy environment. This could occur in a brackish lake with a large fetch which is intermittently connected to a storm-dominated sea. Overlying interbedded sandstone and shale in the uppermost part of Unit 15 is interpreted as having been deposited in a fluctuating nearshore brackish lacustrine environment.

3.7.2 Marine Unit (Unit 16)

Unit 16 is largely covered; however, 14.3 m of dark grey fissile shale occurs at the base of the unit and sharply overlies the uppermost sandstone of Unit 15. This shale contains marine foraminifera (see Chapter 3.6.4) and is interpreted as having been deposited in a quiet shallow marine environment (greater than 10-20 m water depth; R.J. Price, pers. comm., 1981). The uppermost sandstone of Unit 15 is interpreted as a transgressive lag deposit and may represent a remnant of a transgressed beach.

An H.C.S. bed occurs in a small outcrop within the covered interval of Unit 16 (166.0-168.1 m). Its presence suggests a storm influenced marine environment in the uppermost part of Unit 16; however, this is speculative due to a lack of other marine indicators in the uppermost part of the unit.

3.7.3 Upper Nonmarine Unit (Unit 17)

Unit 17 is poorly exposed but consists of greenish-grey, medium-grained sandstone containing trough cross-beds, parallel laminations, and roots at the upper contact. It is overlain by 1-2 m of *in situ* coal. Unit 17 represents a return to nonmarine conditions following the regression of the Clearwater Sea and may have been deposited in a meandering fluvial environment. The presence of 1-2 m of *in situ* coal suggests a thick vegetative cover on the alluvial plain.

3.8 Unit Descriptions, Section 4 (Elbow River)

3.8.1 Introduction

Unit 18 represents the nonmarine Cadomin Formation which is the lowermost formation of the

Blairmore Group. Unit 19 and the lowermost part of Unit 20 are of nonmarine and brackish origins, respectively, and represent the Gladstone Formation. The uppermost part of Unit 20 contains marine fauna and is equivalent to the Moosebar Tongue. Unit 21 represents the lowermost part of the nonmarine Beaver Mines Formation.

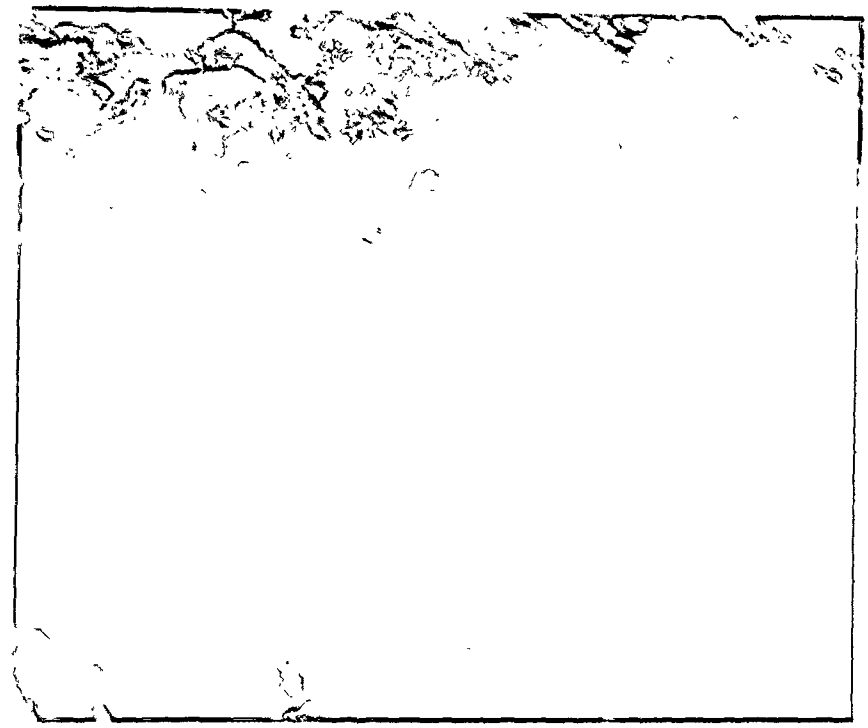
3.8.2 Unit 18 (0-22 m)

Unit 18 consists of conglomerate and sandstone that overlie fine-grained rooted sandstones, shales, and thin coals of the Kootenay Formation with regional unconformity. Locally, the lower contact of Unit 18 is irregular and erosive and the unit comprises a series of lenticular channels that average 2-4 m deep and about 10-40 m across which scour into one another (Figure 3.25).

Within the bottom 12 m of Unit 18, approximately four lenticular channels are present. Each is filled with 1-2 m of conglomerate overlain by 1-2 m of coarse-grained, trough cross-bedded sandstone with sets averaging about 30 cm. The conglomerate is clast-supported and consists of rounded to well rounded dark grey, green, and white chert pebbles that average 2-4 cm in long dimension. Rare quartzite pebbles were also noted within the conglomerate.

Figure 3.25. Irregular erosive base of a channel in the lowermost part of Unit 18.

Figure 3.26. Pinching and swelling lenticular sandstone near the base of Unit 19 (24.0-31.0 m). Scale is about 1.0 m.



The uppermost 10 m of Unit 18 is also channelled. Channels are filled with medium- to coarse-grained trough cross-bedded sandstone (sets average 30 cm) with some localized pebble horizons occurring near the base. The pebbles are in 1-5 cm thick bands and are similar in composition to those described above. They are slightly smaller in size however, averaging 1-2 cm in long dimension.

The uppermost channel of Unit 18 is slightly deeper (6.0 m) than the underlying channels. It is filled with coarse-grained, trough cross-bedded sandstone in the lower 2.0 m (sets average 30 cm) and medium-grained, ripple cross-laminated sandstone in the upper 4.0 m (sets average 3-4 cm).

All channel-fill in Unit 18 contains abundant randomly oriented plant fragments. These fragments may be large coaly "logs" (5-10 cm wide and 10-50 cm long), smaller leaf impressions (1-2 cm wide and 5-10 cm long), or minute macerated carbonaceous material. Also, the tops of many channels are capped with 10-30 cm of coal which is commonly partially or wholly removed by the scouring effect of the overlying channel.

3.8.3 Unit 19 (22.0-65.5 m)

Unit 19 contains three discrete sandstone intervals that occur at 24.0-31.0 m, 55.0-57.5 m, and 61.6-65.5 m. Between these intervals is interbedded sandstone with either grey shale or mudstone.

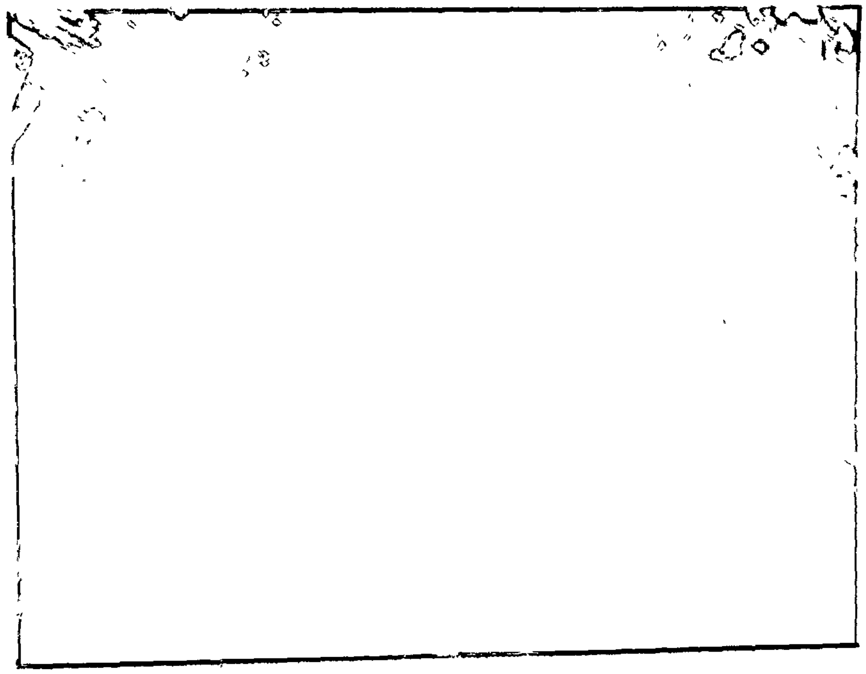
The 24.0-31.0 m interval consists of very fine-grained, dark grey, very thickly bedded sandstone. Four sandstone beds are exposed and have an average thickness of 1.5 m. Their thicknesses tend to vary considerably due to the pinching and swelling and lenticular nature of the beds (Figure 3.26). The base of each bed within the interval appears sharp while the top appears slightly gradational. Close examination was precluded due to inaccessibility; however, ripple cross-laminations and a few isolated trough cross-beds were observed in the lowermost bed.

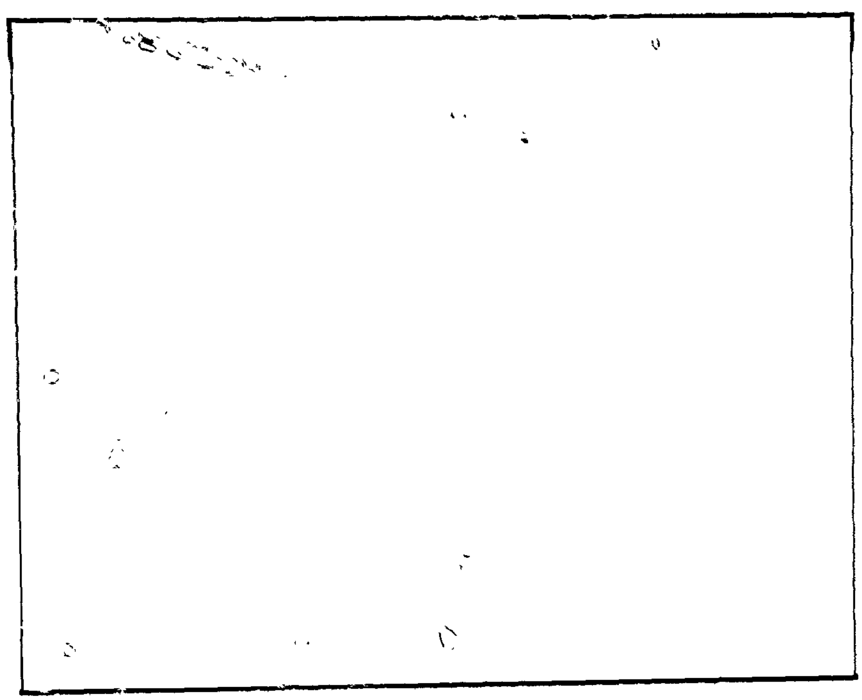
The 55.0-57.5 m interval consists of light grey coarse-grained sandstone with a sharp erosive base. Within this sandstone are 3-4 shallow channels 0.5-1.0 m deep and about 10-20 m across that scour into one another. Each channel contains trough cross-beds at the base (sets average 30 cm) and ripple cross-laminations near the top (sets average 2-3 cm). At least one channel contains a lateral accretion surface set that is 1.0 m in thickness. Individual lateral accretion surfaces within the set are 0.5 m thick and dip at about 9°. These lateral accretion surfaces consist of trough cross-beds at the base (sets average 25 cm) and a 5-6 cm thick ripple cross-laminated layer near the top. This thin layer parallels the upper contact of each lateral accretion surface and contains approximately two ripple cross-laminated sets that average 3 cm in thickness (Figure 3.27). Each lateral accretion surface has a 1-2 cm thick mudstone draping it. The upper 30 cm of this interval is gradational into black, fissile shale containing small indeterminate pelecypod shells averaging 1 cm diameter.

The 61.6-65.5 m interval consists of medium greyish-brown sharp-based sandstone containing lateral accretion surfaces (Figure 3.28). Lateral accretion surfaces average 30 cm in thickness and have an average dip of 10° (range 4°-18°) toward NE. They contain trough cross-beds at the base, ripple cross-laminations at the top, and each structure is draped with approximately 5-10 cm of mudstone or very fine-grained siltstone. Laterally along the outcrop, lateral accretion surfaces end abruptly and are replaced by 2.2 m of dark greyish-brown mudstone. A 1.6 m thick, medium-grained, sharp-based sandstone underlies this mudstone. It is

Figure 3.27. Ripple cross-laminated layer at the top of lateral accretion surfaces (55.0-57.5 m).

Figure 3.28. Lateral accretion surface set within Unit 19 (61.6-65.5 m). Set is 3.9 m thick.





trough cross-bedded at the base with sets averaging 30 cm, and contains a few small mudclasts (average 1 cm diameter). The upper 30-40 cm of the sandstone is ripple cross-laminated (sets average 3 cm) and the contact with the overlying mudstones is sharp. Approximately 6-10 m laterally along the outcrop from the last lateral accretion surface this sandstone curves gently upwards and is truncated by the overlying beds of Unit 20.

Between the intervals described above is interbedded sandstone with either grey shale or mudstone. The sandstone:shale plus mudstone ratio is 1.7:1. Most of the sandstones are medium grey, fine- to coarse-grained, and contain ripple cross-laminations with sets averaging 2-3 cm. Individual sandstone beds average 50 cm in thickness (range 5-180 cm), undulate slightly, and their upper and lower contacts are more commonly gradational than sharp. Within the sandstones, shales, and mudstones are small partially intact plant fragments, macerated carbonaceous material, and roots.

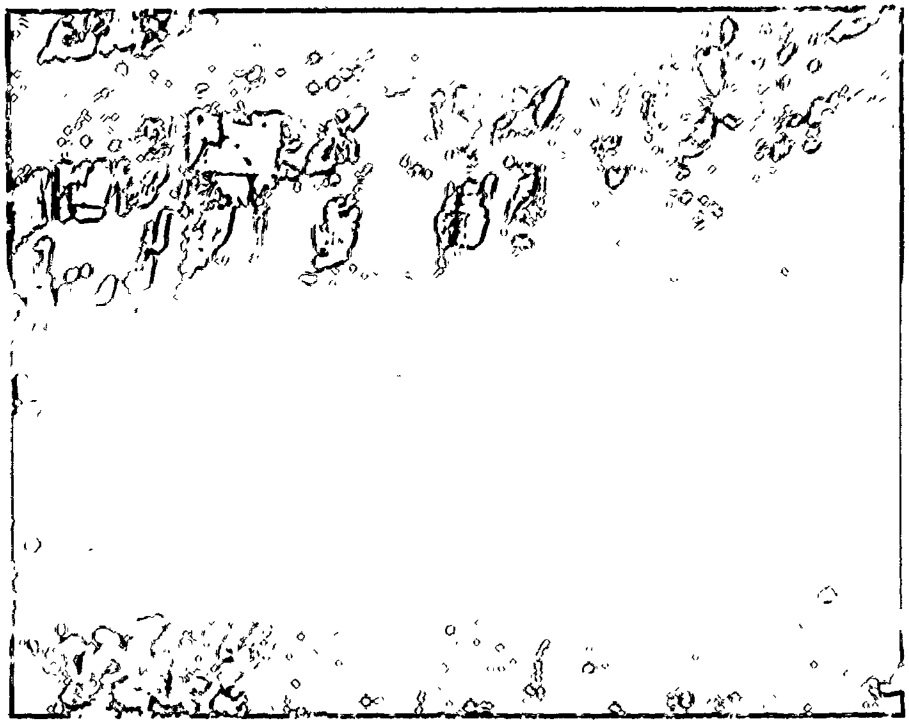
3.8.4 Unit 20 (65.5-116.5 m)

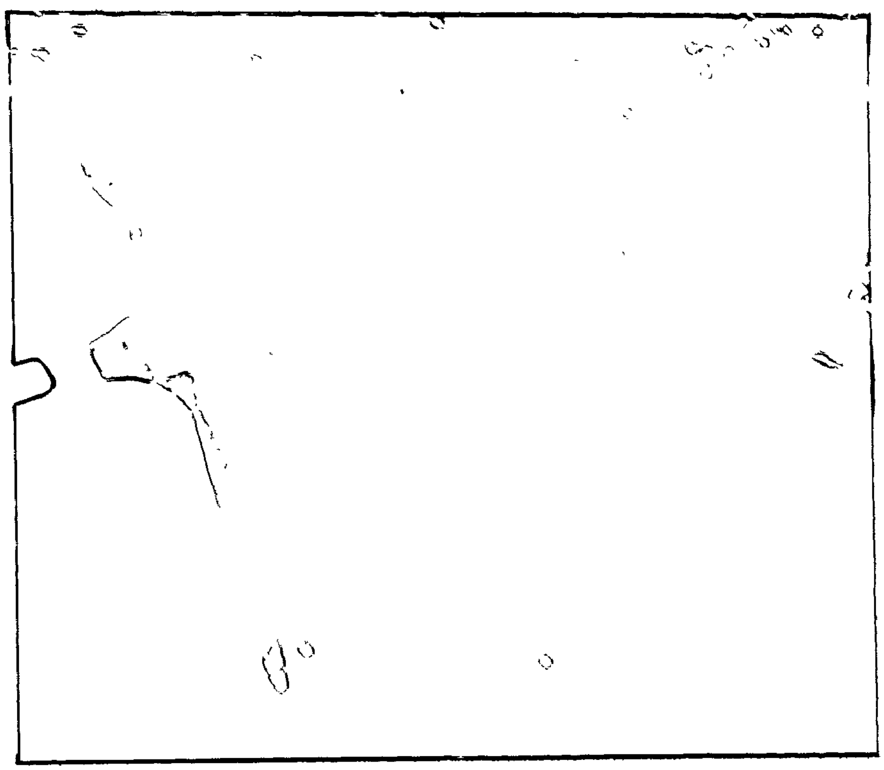
Unit 20 consists largely of medium grey, very fine- to fine-grained calcareous sandstone interbedded with calcareous siltstone, shale, and mudstone. The sandstone:siltstone, shale, and mudstone ratio is approximately 1:1. Two fine-grained, bioturbated silty limestones also occur within Unit 20 at 96.8 m and 114.4 m.

Sandstones and shales or mudstones of Unit 20 commonly form a series of coarsening-upward sequences that range in thickness from about 2-7 m (Figure 3.29). A typical sequence has a sharp base and begins with 1-2 m of shale or mudstone that commonly contains small indeterminate pelecypods. Overlying the shale or mudstone is 1-2 m of interbedded thin sandstone and shale (or mudstone). The sandstone:shale ratio increases from 1:1 to 10:1 within the middle 1-2 m of a sequence. Individual sandstone beds are very thin (less than 3 cm) and often have gradational, poorly defined upper and lower contacts due to intense bioturbation (Figure 3.30). Bioturbation has also destroyed most primary sedimentary structures present in the sandstones; however, very faint symmetrical ripple cross-laminations are sometimes preserved. The upper part of a typical coarsening-upward sequence consists of 1-2 m of thickly bedded, bioturbated sandstone. Commonly, very faint parallel laminations or symmetrical ripple cross-laminations are present. In five sequences, the sandstone contains no primary sedimentary structures due to intense bioturbation. Also, from 71.5-78.6 m, four sequences are present that have thin

Figure 3.29. Typical coarsening-upward sequence within Unit 20. Scale is about 3 m.

Figure 3.30. Bioturbation in the middle part of a typical coarsening-upward sequence in Unit 20.





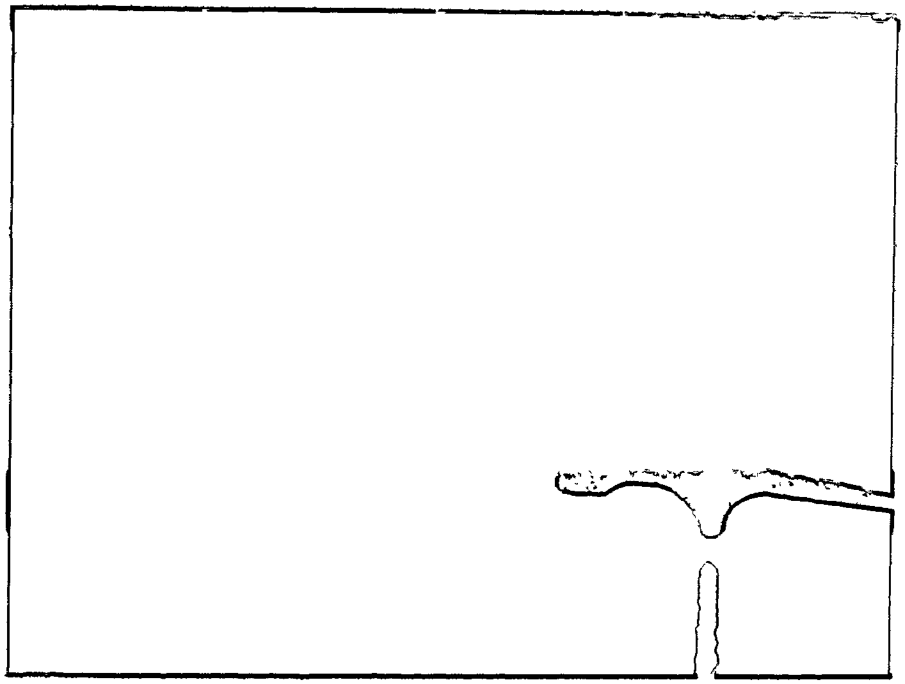
shell-rich layers in their uppermost parts. The layers are 1-2 cm thick and contain either partially intact gastropod shells and disarticulate pelecypod shells, or crushed shell fragments.

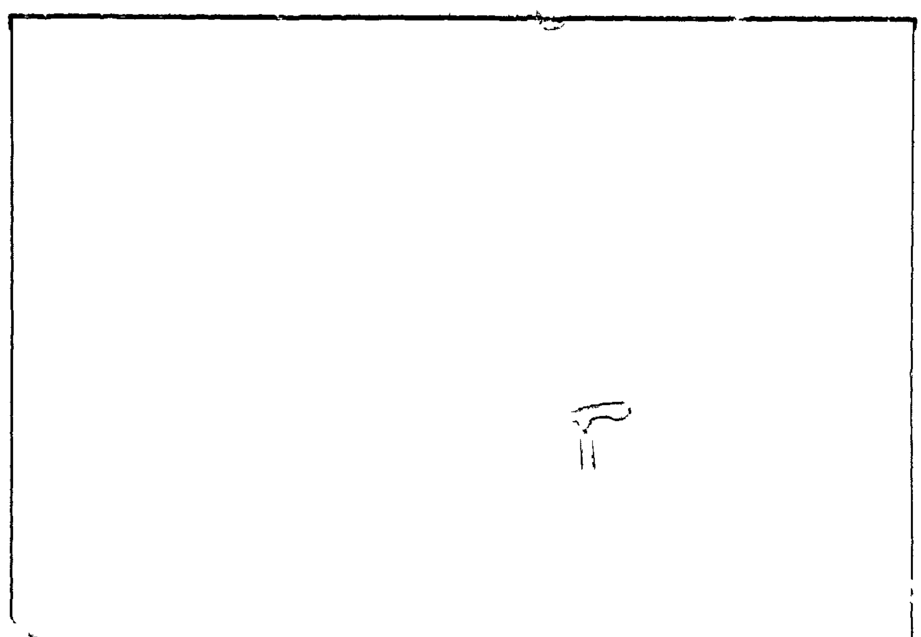
One interval within Unit 20 (105.2-112.0 m) consists of very fine-grained, very thinly bedded sandstone. Individual beds average 2 cm in thickness (range 1-5 cm), contain symmetrical ripple cross-laminations, and are thoroughly bioturbated. The upper contact of this sequence "fades away" gradually, from thinner and thinner sandstone beds back into overlying fine-grained shale.

Another interval within Unit 20 (102.3-105.2 m) has 9-10 thin graded beds in its lowermost part that average 3 cm in thickness. They have sharp bases and their upper contacts contain symmetrical ripples. The uppermost 1.2 m of this interval is a fine-grained, sharp-based, thickly bedded sandstone (beds average 30 cm in thickness) containing trough cross-beds with sets averaging 10 cm. Bioturbation in this sandstone is sparse but consists of vertical tubes extending down from a bedding horizon located 30 cm from the upper contact (Figure 3.31).

Figure 3.31. Vertical burrows extending down from a bedding plane in the 102.3-105.2 m interval of Unit 20.

Figure 3.32. Sharp erosive base of the 147.8-153.2 m interval of Unit 21.





From shale samples collected throughout Unit 20, the following species of fauna were identified by R.J. Price (Amoco Canada):

1) 66.6 m

Ostracods

Metacypris persulcata

Gastropods

Liaplacoides ? spp.

2) 68.0 m

Ostracods

Metacypris ? sp.

Gastropods genus and species indet.

3) 75.0 m

Ostracods

Metacypris persulcata

Metacypris angularis

Gastropods

Viviparus ? sp.

Liaplacoides ? sp.

4) 82.0 m

Ostracods

Metacypris persulcata

Limnocythere calmontensis

Gastropods

Viviparus ? sp.

Liaplacoides ? sp.

5) 112.0 m

Ostracods

Cytherida bonaccordensis

Ostracods genus and species indet.

The fauna found between 66.6 and 82.0 m are of nonmarine to brackish origin and the fauna at 112.0 m are of marine origin.

3.8.5 Unit 21 (116.5-157.5 m)

Unit 21 contains two sandstone intervals that occur at 121.8-125.0 m and 147.8-153.2 m. Between these intervals is interbedded greenish-grey to green sandstone, siltstone, shale, and mudstone.

The 121.8-125 m interval consists of greenish-grey, medium-grained, thickly bedded sandstone with a sharp, scoured base. Individual beds average 50 cm in thickness (range 10-100 cm), pinch and swell slightly, and in places have thin siltstones between them (average 5 cm in thickness). Within the sandstones ripple cross-laminations predominate; however, near the middle of the interval faint parallel laminations and trough cross-beds were observed. The upper contact of this interval is gradational and contains roots.

The 147.8-153.2 m interval consists of green coarse-grained sandstone with a sharp erosive base (Figure 3.32). The lower 4.5 m is trough cross-bedded with sets averaging 35 cm. The upper 1.0 m contains ripple cross-laminations with sets averaging 2-3 cm. Abundant macerated carbonaceous material is present throughout the interval, especially on trough foresets. The upper contact is gradational into thin rooted sandstones, siltstones, and shales similar to those described below.

The remainder of Unit 21 consists of interbedded greenish-grey to green sandstone, siltstone, shale, and mudstone. The sandstone:siltstone plus shale and mudstone ratio is 1:1.4. The sandstone is medium- to coarse-grained and is ripple cross-laminated (sets average 3 cm). Individual beds average 0.5 m in thickness (range 0.2-1.3 m), undulate slightly, and commonly have gradational upper and lower contacts. Sandstones, siltstones, shales, and mudstones all contain small partially intact plant fragments (1-2 cm diameter), macerated carbonaceous material, and roots.

3.9 Unit Interpretations, Section 4

The salient characteristics and basic interpretations of units at Section 4 are listed in Table 3.4.

Unit 18 (Cadomin Formation) consists of a series of lenticular channels that average 2-4 m deep and about 10-40 m across. Channels in the lowermost 12.0 m of the unit are filled with 1-2 m of conglomerate overlain by coarse-grained, trough cross-bedded sandstone. In the uppermost 10.0 m of the unit, channels are filled with coarse-grained trough cross-bedded sandstone overlain by medium-grained ripple cross-laminated sandstone. In places, channels are capped with thin coals.

The lowermost part of Unit 18 is interpreted as a sheet-like pebbly braided fluvial deposit. This interpretation is consistent with that of McLean (1976, p. 325; 1977, p. 809) who proposed a braided stream origin for the Cadomin Formation at some localities. The conglomerate was interpreted by McLean (1976, 1977) as a

UNIT	SALIENT CHARACTERISTICS	BASIC INTERPRETATION
21	Sharp-based, fining-upward, trough cross-bedded sandstone.	Nonmarine. Meandering fluvial.
20	Interbedded calcareous sandstone, siltstone, shale, and mudstone. Coarsening-upward sequences are common throughout the unit. Abundant nonmarine to brackish fauna in the lowermost part of the unit. Marine fauna in the uppermost part of the unit.	Brackish lacustrine and shallow marine.
19	Sandstones containing lateral accretion surfaces. Interbedded rooted sandstone, siltstone, shale, and mudstone.	Nonmarine. Meandering fluvial-floodplain.
18	Lenticular channels filled with conglomerate and trough cross-bedded sandstone.	Nonmarine. Braided fluvial.

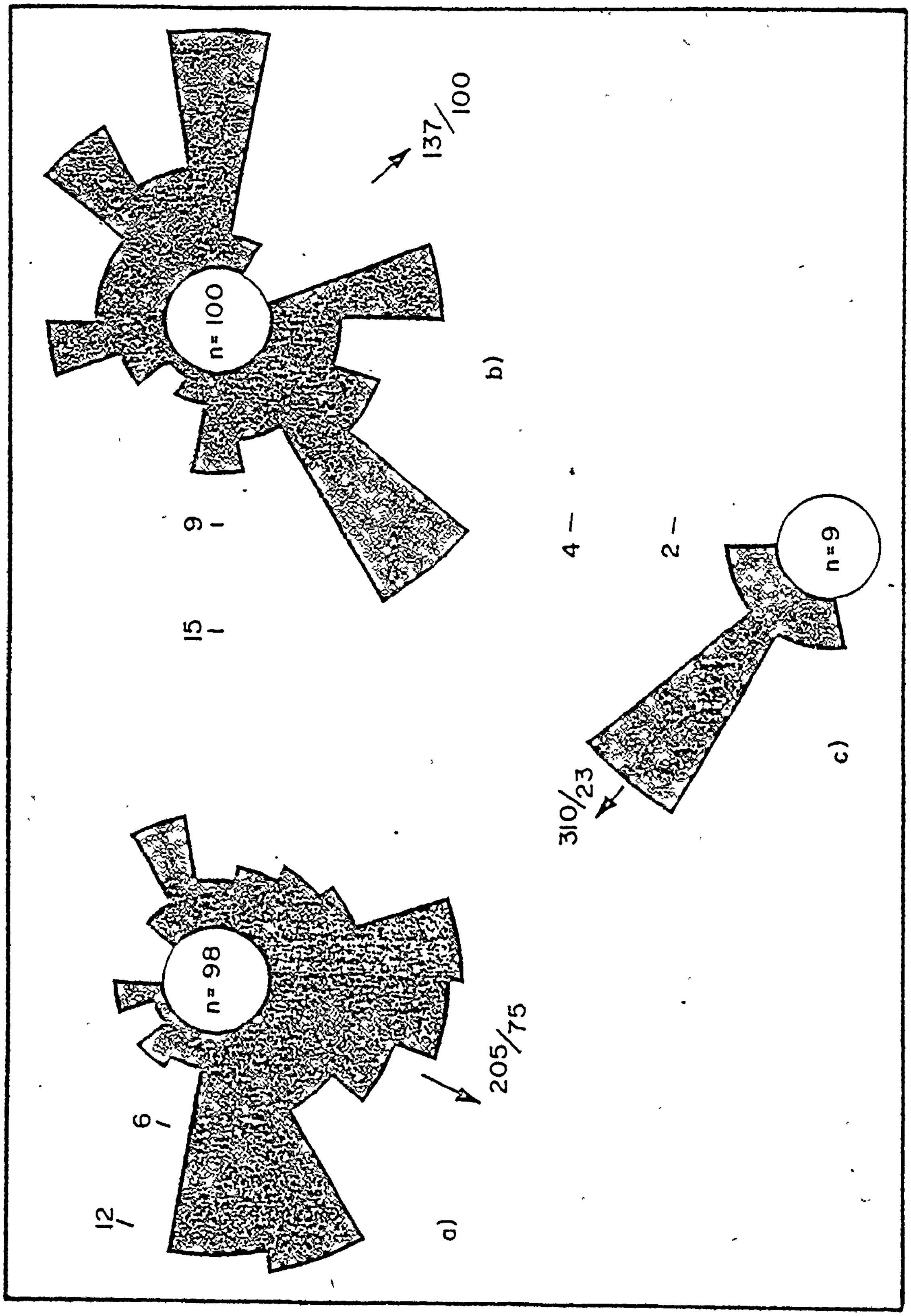
Table 3.4 Salient characteristics and basic interpretations of units at Section 4. Unit 18 represents the Cadomin Formation and Unit 19 and the lowermost part of Unit 20 represent the Gladstone Formation. The uppermost part of Unit 20 represents the Moosebar Tongue and Unit 21 represents the Beaver Mines Formation.

longitudinal gravel bar deposit similar to modern gravel bars described by Rust (1972) from the Donjek River in the Yukon. The trough cross-bedded sandstone overlying the conglomerate in each channel is interpreted as channel-fill deposited when the active channel was gradually abandoned. The presence of thin coals in some places indicates a vegetative cover on parts of the inactive alluvial plain.

The uppermost part of Unit 18 is interpreted as a low sinuosity (braided?) sandy fluvial deposit. It is interpreted as such because: 1) it overlies a pebbly braided fluvial deposit; 2) it underlies a fine-grained nonmarine sequence (Unit 19) containing sandstones with lateral accretion surfaces that are interpreted below as deposits of meandering fluvial channels; and 3) there are no fine-grained overbank deposits associated with the channels as would normally be expected if this were a meandering fluvial deposit. Also, the uppermost part of Unit 18 is similar to ancient sandy braided fluvial deposits described by Campbell (1976) from the Morrison Formation (Jurassic) of New Mexico.

Pebble orientations were measured within the lowermost channel of Unit 18 (1.0 m). The a-b plane dip direction of the pebbles is toward SW, indicating flow toward NE (Figure 3.33a). Measurements were statistically

Figure 3.33. Paleocurrent data for Unit 18. a) a-b plane dip directions of pebbles measured at 1.0 m. b) a-b plane dip directions of pebbles measured at 4.0 m. c) trough foreset dip directions measured at 16.0 m.



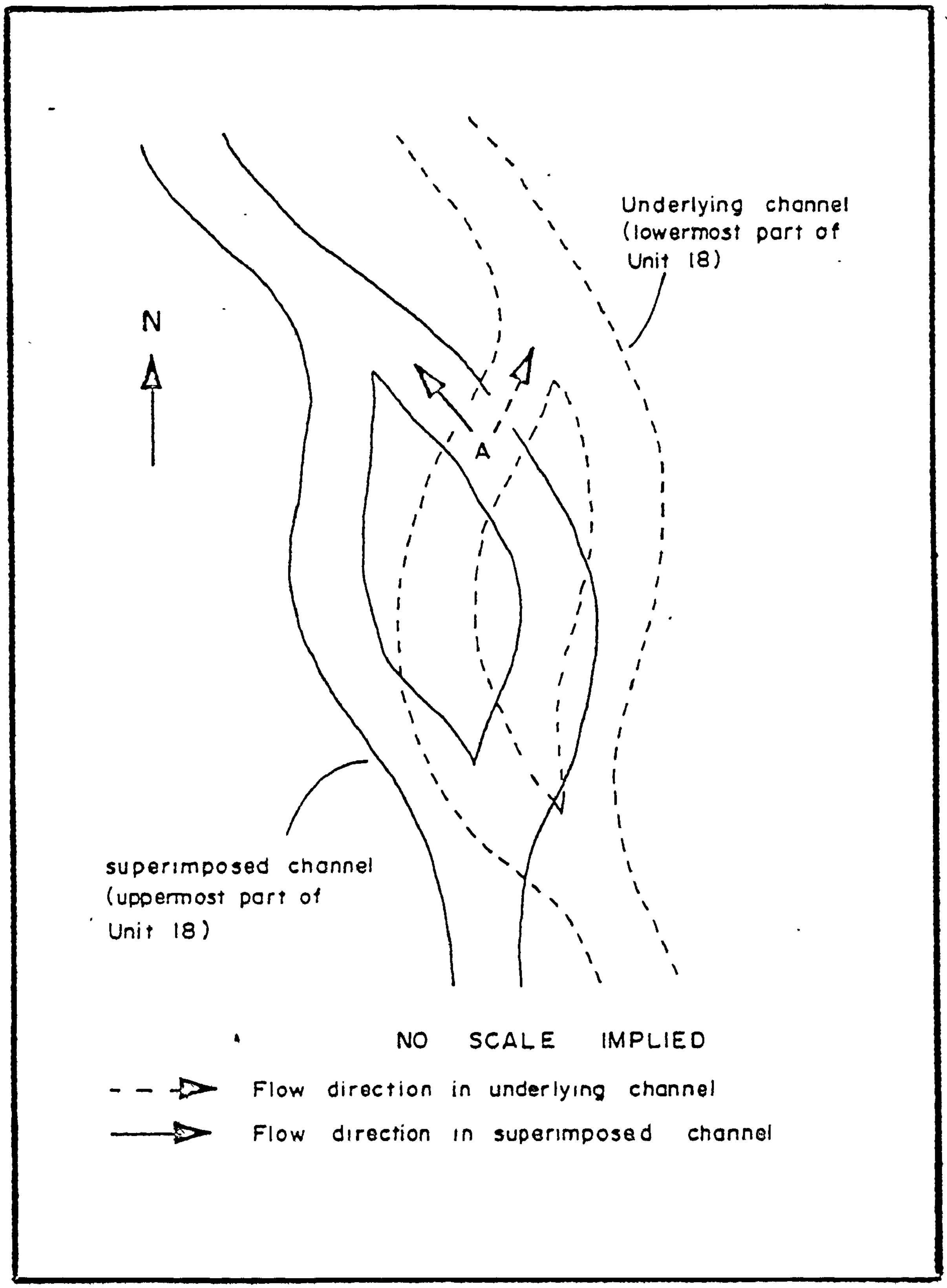
a)
n=98
205/75
12
6
b)
n=100
137/100
15
9
4
2
c)
n=9
310/23

significant at greater than 99.5 percent. Pebble orientations were also measured within an overlying channel (4.0 m) but were statistically significant at less than 75.0 percent (Figure 3.33b). This suggests a lack of pebble imbrication within this particular channel.

In the uppermost part of Unit 18 (16.0 m), trough foreset dip directions were measured and indicate flow toward NW (Figure 3.33c). Measurements were statistically significant at greater that 99.5 percent. The flow direction obtained from trough foresets at 16.0 m differs from the flow direction obtained from pebble orientations at 1.0 m by 75 degrees. This difference can be explained by the superimposition of a younger channel on an underlying older channel within the depositional basin. This is illustrated in Figure 3.34. At point A, the flow direction in the underlying channel was toward NE while flow in the overlying superimposed channel was toward NW.

Unit 19 is a fine-grained nonmarine sequence that contains three discrete sandstone intervals. The lowermost interval (24.0-31.0 m) consists of fine-grained, thickly bedded, lenticular sandstone. Individual beds pinch and swell considerably and commonly contain ripple cross-laminations. Trough cross-beds occur in some places. This interval is interpreted as a crevasse splay that was deposited on the floodplain when levees of the

Figure 3.34. Schematic illustration showing the difference in flow directions between the upper and lower parts of Unit 18. At point A, flow in the underlying channel is toward NE while flow in the overlying superimposed channel is toward NW.

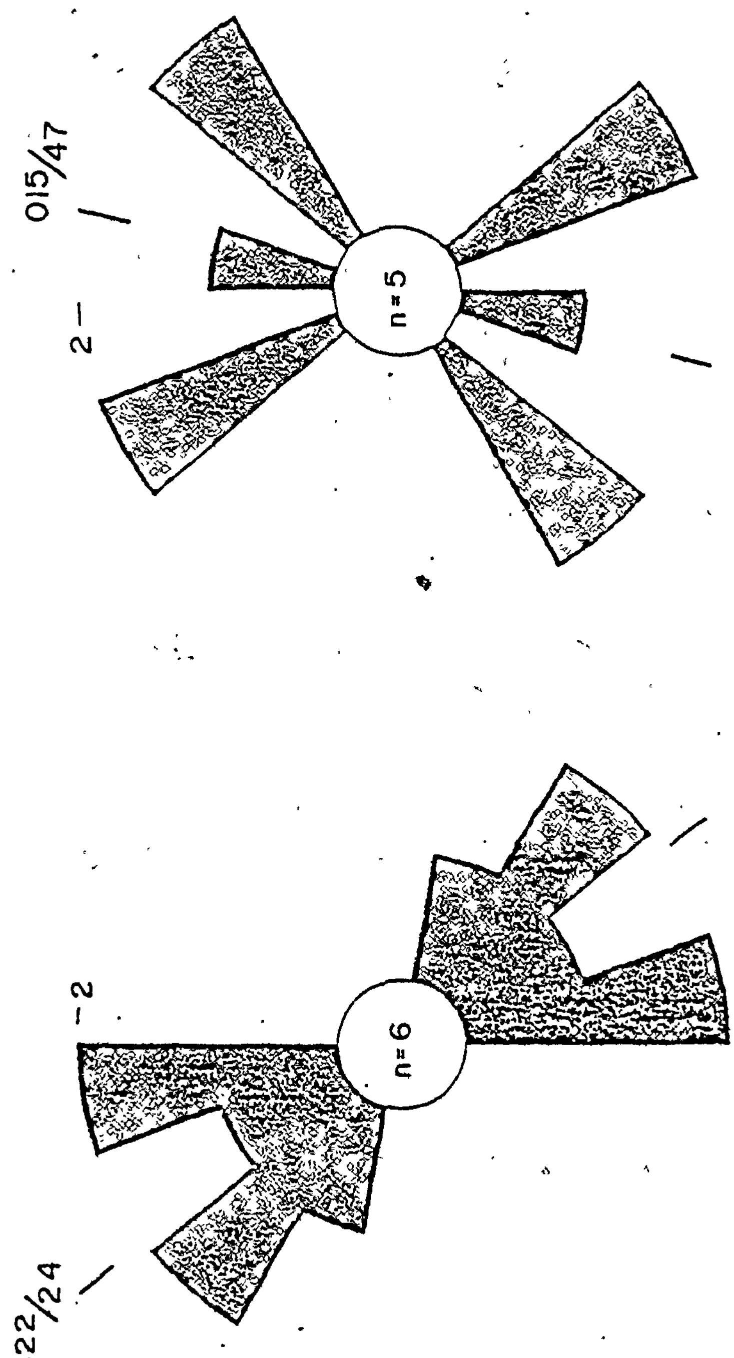

Underlying channel
(lowermost part of
Unit 18)
N
A
superimposed channel
(uppermost part of
Unit 18)
NO SCALE IMPLIED
Flow direction in underlying channel
Flow direction in superimposed channel

main channel were breached. An alternative interpretation of the interval is a series of fluvial channels, suggested by the thickness of the interval (greater than 7 m). The ripple cross-laminations that predominate throughout the interval in a fluvial channel interpretation are the result of chute cut-off and a gradual decrease in flow conditions (Allen, 1965b, p. 119; Walker and Cant, 1979, p. 24).

The sandstone interval between 55.0-57.5 m within Unit 19 consists of a series of channels 0.5-1.0 m deep and about 10-20 m across. One channel-fill contains lateral accretion surfaces that have ripples migrating up them at a high divergent angle to the generally N-S paleoflow trend obtained from measurements of channel wall and lateral accretion surface planes (Figure 3.35). This interval is interpreted as a small-scale meandering fluvial channel, possibly a tributary channel. The ripple orientations suggest secondary flow within the channel.

The uppermost sandstone interval of Unit 19 (61.6-65.5 m) is sharp-based and contains lateral accretion surfaces. These surfaces are replaced laterally along the exposure by 2.2 m of mudstone which is underlain by 1.6 m of sharp-based sandstone. Lateral accretion surfaces are interpreted as a point bar deposit of an isolated meandering fluvial channel. Mud drapes occur on

Figure 3.35. Paleocurrent data for Unit 19.



b) CHANNEL WALL STRIKES

a) LATERAL ACCRETION SURFACE STRIKES

lateral accretion surfaces and indicate fluctuating river discharge or periods of channel inactivity. The mudstone underlain by sharp-based sandstone is interpreted as fine-grained channel-fill that was deposited in an abandoned channel following avulsion. Isolated point bar sequences with mud-filled channels have been recognized by Puigdefabregas and Van Vliet (1978) in the Lower Eocene Montañana Group of the Southern Central Pyrenees and are similar to the sequence interpreted above.

Paleocurrent measurements of lateral accretion surfaces and channel wall planes in the meandering fluvial channels of Unit 19 indicate flow generally toward N or S (Figure 3.35). From paleogeographic reconstructions and flow directions associated with the underlying fluvial deposits of Unit 18, flow within the meandering fluvial channels of Unit 19 is inferred to be toward N.

Between the sandstone intervals discussed above are either grey shales or mudstones with thin interbedded sandstones. They commonly have gradational contacts and contain roots in some places. They are interpreted as vertical accretion deposits that were deposited on the floodplain when the river overtopped its banks during flood stage.

Unit 20 consists largely of interbedded calcareous sandstones and calcareous shales or mudstones that commonly form a series of coarsening-upward sequences within the unit. Fauna found in the lowermost part of the unit are of nonmarine to brackish origin while fauna found in the uppermost part are of marine origin.

The lowermost part of Unit 20 is interpreted as having been deposited in a brackish lacustrine environment. This interpretation is based largely on the paleoecological interpretation of ostracods found between 66.6-82.0 m. The ostracods are envisaged as having inhabited a coastal (fringing) lake with intermittent sea connections (cf. Lake Maracaibo, Venezuela; R.J. Price, pers. comm., 1981). Individual coarsening-upward sequences that commonly occur throughout Unit 20 are interpreted as prograding nearshore or shoreline deposits. Sediment was most likely supplied to the nearshore or shoreline environment by longshore drift induced through wave activity (Sly, 1978, p. 73). Intense bioturbation suggests a steady but relatively slow rate of sedimentation, thus allowing burrowing organisms to completely rework the sediment (Seilacher, 1978, p. 190).

The repetitive nature of coarsening-upward sequences within Unit 20 suggests fluctuating lake levels. As lake level dropped, the shoreline (or nearshore environment) prograded and a coarsening-upward sequence was deposited. When lake level rose again this shoreline was transgressed, and quiet offshore conditions prevailed with fine-grained sediment being deposited from suspension.

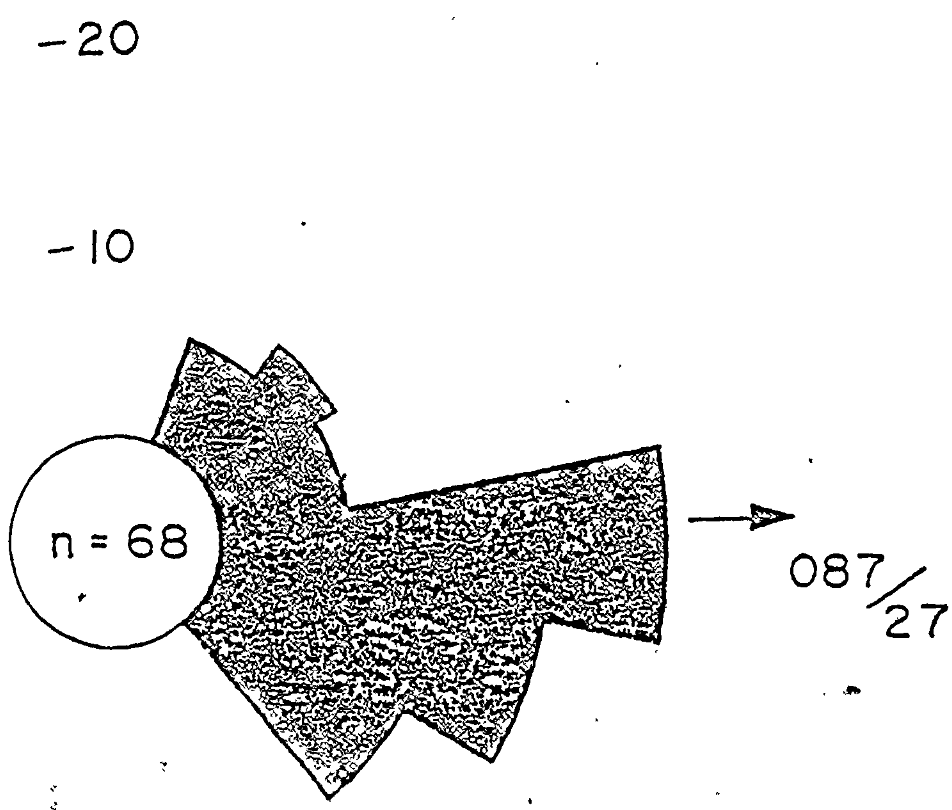
In the uppermost part of Unit 20, marine ostracods were found at 112.0 m. This marine horizon represents the approximate southernmost extent of the Moosebar Tongue. The paleoecological interpretation of ostracods indicates water depths of greater than 10-20 m (R.J. Price, pers. comm., 1981); however, deposition was probably at depths very close to 10-20 m and the Clearwater Sea was very shallow at this latitude. A fine-grained, bioturbated silty limestone overlies this marine horizon and may represent a shore-zone marine carbonate mudflat which is transitional to overlying non-marine deposits of Unit 21.

The change from brackish lacustrine to marine deposition occurs between 82.0-112.0 m, but the exact position of the transgression is difficult to place due to lithologic similarities and a lack of faunal indicators within the 82.0-112.0 m interval.

The uppermost unit of Section 4 (Unit 21) contains two distinct sandstone intervals that occur at 147.8 m and 121.8 m. The sandstone interval at 147.8 m has a sharp erosive base, fines upward, and is largely trough cross-bedded. It is interpreted as a point bar deposit of a meandering fluvial channel. Paleocurrent measurements of trough foresets within this interval indicate flow towards E (Figure 3.36) and are statistically significant at greater than 99.5 percent. The sandstone interval at 121.8 m is sharp-based, thickly bedded, and has roots at the upper contact. It is interpreted as a crevasse splay that was deposited on the floodplain when levees of the main channel were breached. A single paleocurrent measurement from the 121.8 m interval indicates flow roughly perpendicular to the eastward flow associated with the overlying fluvial channel (147.8 m).

Between the two sandstone intervals of Unit 21 are interbedded sandstones, siltstones, shales, and mudstones. They commonly have gradational contacts and are rooted in some places. They are interpreted as vertical accretion deposits and were deposited on the floodplain when the river overtopped its banks during flood stages.

Figure 3.36. Paleocurrent data for Unit 21.



TROUGH FORESET DIP DIRECTIONS

3.10 Unit Descriptions, Section 5 (Littlehorn Creek)

3.10.1 Introduction

Units 22 through 25 at Section 5 represent the uppermost 161.5 m of the Beaver Mines Formation and are of nonmarine origin. Unit 26 represents the marine Blackstone Formation which is the lowermost formation of the Alberta Group.

3.10.2 Unit 22 (0.0-16.5 m)

Unit 22 consists largely of greenish-grey, coarse-grained sandstone. It sharply overlies interbedded greenish-grey, very fine-grained rooted sandstones and dark green shales. The base of Unit 22 is irregular and erosive and the lowermost 6.5 m contains trough cross-beds with sets averaging 35 cm. At 6.5 m the sandstone fines upward for approximately 1.0 m. Here it is medium-grained and contains ripple cross-laminations with sets averaging 2-3 cm. At 7.5 m a siltstone break occurs which is parallel to the base of the unit and is 1.0 m in thickness. The siltstone is dark green and contains large coaly "logs".

Overlying the siltstone is 6.0 m of coarse-grained trough cross-bedded sandstone (sets average 25.0 cm) that has a slightly gradational base. The sandstone fines upward in the uppermost 2.0 m where it is ripple cross-laminated (sets average 2-3 cm). The upper contact of Unit 22 is gradational into siltstone, then shale of Unit 23 (Figure 3.37). Macerated carbonaceous material is present throughout Unit 22 and partially intact plant fragments are found in the uppermost 5.0 m.

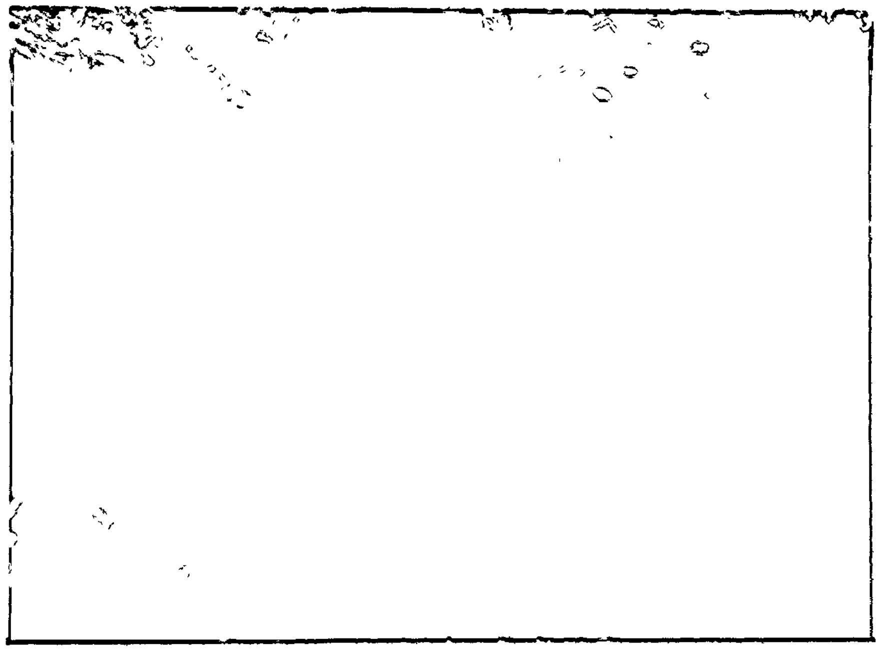
3.10.3 Unit 23 (16.5-64.3 m)

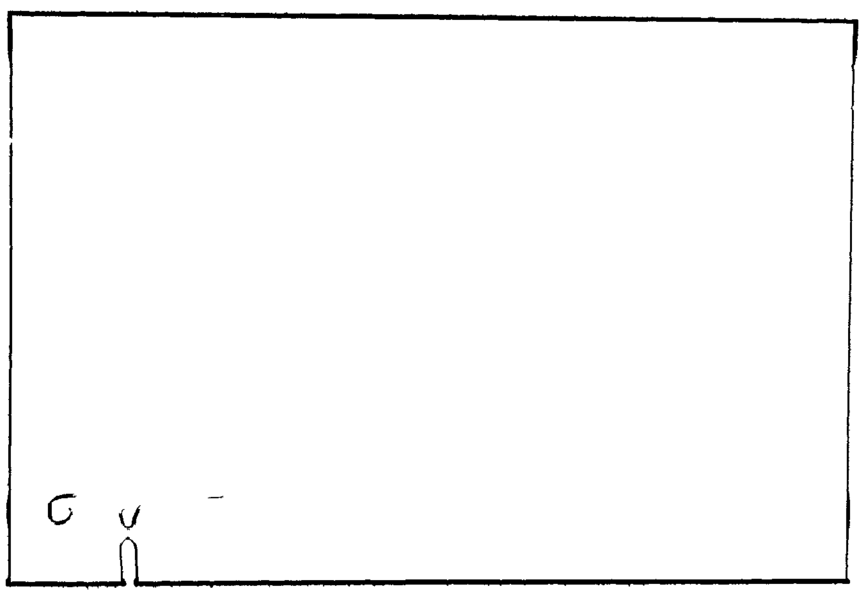
Unit 23 consists of interbedded green sandstone, siltstone, shale, and a very minor amount of coal. The sandstone: siltstone plus shale and coal ratio is 1:1.6. Sandstone beds are very fine- to medium-grained and average 0.9 m in thickness (range 0.1-3.5 m). They undulate slightly, contain ripple cross-laminations (sets average 2.5 cm), and upper and lower contacts are more commonly gradational than sharp. One sandstone, occurring at 57.3 m, is sharp-based and contains small channels that average 0.5 m deep and about 5 m across.

Macerated carbonaceous material, partially and wholly intact plant fragments (Pseudocycas? sp.; Figure 3.38), and roots were found throughout Unit 23.

Figure 3.37. Fining-upward sandstone of Unit 22 and overlying siltstones and shales of Unit 23. Top is to the right.

Figure 3.38. Large intact plant fragments (Pseudocycas ? sp.) within Unit 23.





Three thin coal beds were also observed within the unit. These average 7 cm in thickness and occur at 55 m, 57.1 m, and 64.2 m.

3.10.4 Unit 24 (64.3-99.5 m)

Unit 24 has a sharp erosive base and consists largely of very coarse- to fine-grained green sandstone. At the base of the unit is 0.5-1.0 m of matrix-supported conglomerate. It is composed of chert pebbles and some rock fragment pebbles that average 2.0 cm in long dimension. The conglomerate may or may not be cross-bedded; however, this could not be clearly ascertained in the outcrop due to limited exposure. Overlying the conglomerate is 1.6 m of very coarse- to coarse-grained trough cross-bedded sandstone with sets averaging 30 cm. An internal erosive surface occurs at 66.4 m which is overlain by 6.6 m of very coarse- to coarse-grained, fining-upward, trough cross-bedded sandstone (sets average 25.0-35.0 cm).

The middle part of Unit 24 (73.0-84.0 m) is medium-grained sandstone that contains trough cross-bedded (sets average 25 cm) and parallel laminated intervals. Parallel laminated intervals average 1.0 m in thickness and occur at 73.0 m and 79.1 m. Small mudclasts 2-3 cm diameter were noted within the middle part of Unit 24 at 79.0 m.

The uppermost part of Unit 24 is fine-grained sandstone that has a 5 cm thick horizontal shale break at 89 m and two erosive surfaces at 92.0 m and 97.3 m. Ripple cross-laminations predominate within this part of the unit (sets average 1.5 m); however, about 1 m of parallel laminated sandstone occurs above each of the two erosive surfaces. Mudclasts averaging 3 cm diameter were found in the uppermost part of the unit. The upper contact of Unit 24 is rooted and is gradational into interbedded sandstone, siltstone, and shale of Unit 25.

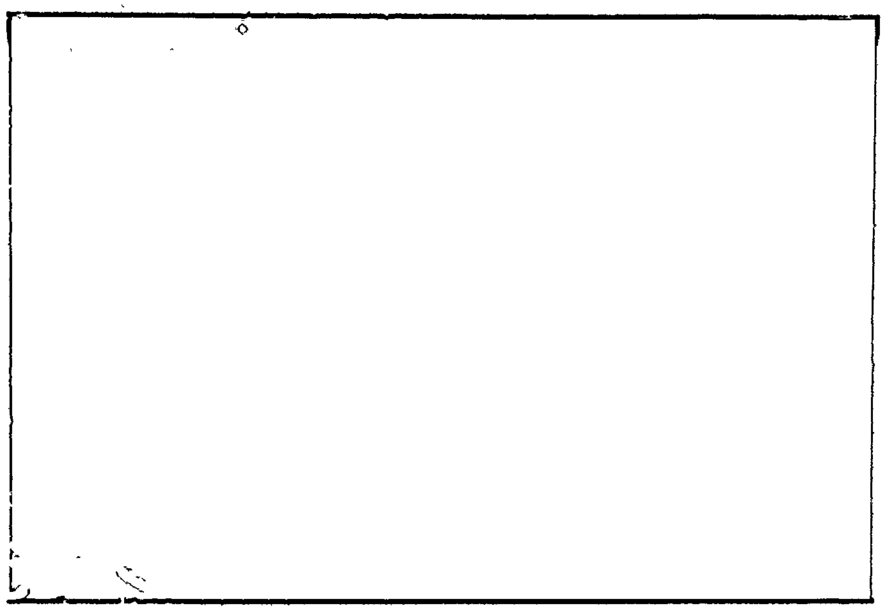
Throughout Unit 24, abundant macerated carbonaceous material commonly occurs on trough foresets. Small partially intact plant fragments (average 1-2 cm wide and 2-4 cm long) were also noted in places throughout the unit.

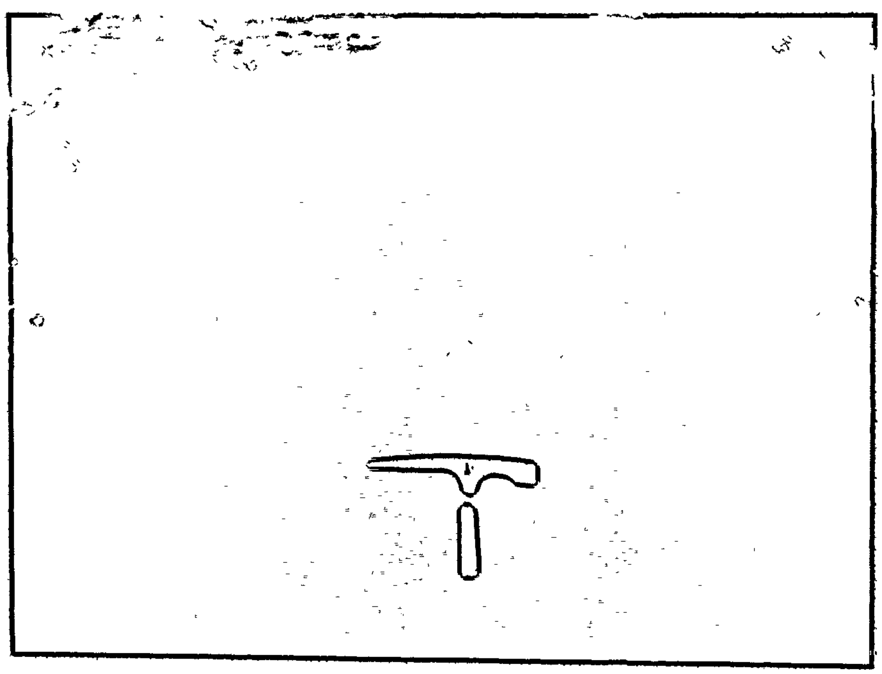
3.10.5 Unit 25 (99.5-161.5 m)

Unit 25 consists of interbedded green sandstone, siltstone, and shale with minor conglomerate and coal (Figure 3.39). The sandstone:siltstone plus shale, conglomerate, and coal ratio is 1:1.4. Individual sandstone beds are very fine- to medium-grained, average

Figure 3.39. Interbedded sandstones, siltstones, and shales of Unit 25. Top is to the right.

Figure 3.40. Thin conglomerate at the Beaver Mines-Blackstone contact. Top is toward the bottom of the photograph.





30 cm in thickness (range 2-370 cm), and are ripple cross-laminated (sets average 2-4 cm). Upper and lower contacts are more commonly gradational than sharp, and some beds undulate and pinch and swell slightly. At 148.5 m a sharp-based sandstone occurs that contains channels averaging 1.5 m deep and about 8-10 m across.

The upper contact of Unit 25 is knife-sharp and has 14 cm of conglomerate present (Figure 3.40). The conglomerate appears to be poorly imbricated and is composed of chert pebbles and rock fragment pebbles that average 3-4 cm in long dimension.

Throughout Unit 25, macerated carbonaceous material, partially intact plant fragments (up to 5 cm wide and 10 cm long), and roots were noted. A 10 cm thick coal bed was also observed at 156.0 m.

3.10.6 Unit 26 (161.5-202.0 m)

Unit 26 (Blackstone Formation) consists largely of dark grey fissile shale that weathers to a dark maroon colour. It sharply overlies 14.0 cm of conglomerate that occurs at the top of Unit 25. Three sandstone sequences that thicken and coarsen upwards slightly are present within Unit 26 and occur between 181.7-185.5 m, 187.5-190.2 m, and 192.2-193.7 m.

Figure 3.41. Lower two sandstone sequences in the Blackstone Formation. Top is to the right. Hammer for scale.

The lower two sequences are shown in Figure 3.41. They begin with interbedded sandstone and shale that has a sandstone:shale ratio of about 1:15. Individual sandstone beds average 1 cm in thickness, are very fine-grained, have sharp bases, and contain ripple cross-laminations. They commonly have bioturbated upper contacts. Near the middle of each sequence sandstone beds are similar but slightly thicker, averaging 2.0 cm. The upper part of each sequence consists of 1 or 2 sharp-based, fining-upward sandstone beds that average 10 cm in thickness and contain parallel laminations overlain by ripple cross-laminations.

The sequence from 192.2-193.7 m differs from those described above in its uppermost part. Here it contains 5.0 cm of very coarse-grained massive sandstone overlain by 8.0 cm of massive pebbly sandstone. Pebbles average less than 1.0 cm in long dimension and are commonly composed of chert.

3.11 Unit Interpretations, Section 5

The salient characteristics and basic interpretations of units at Section 5 are listed in Table 3.5.

UNIT	SALIENT CHARACTERISTICS	BASIC INTERPRETATION
26	Dark grey fissile shale containing coarsening-upward sequences.	Shallow marine.
24	Sharp-based, fining-upward sandstone. The sandstone is trough cross-bedded in its lowermost part, ripple cross-laminated in its uppermost part, and parallel laminated in some places.	Nonmarine. Meandering fluvial.
25 and 23	Interbedded rooted sandstone, siltstone, and shale. Small channelled sandstones in some places.	Nonmarine Fluvial-floodplain.
22	Sharp-based, fining-upward, trough cross-bedded sandstone.	Nonmarine. Meandering fluvial.

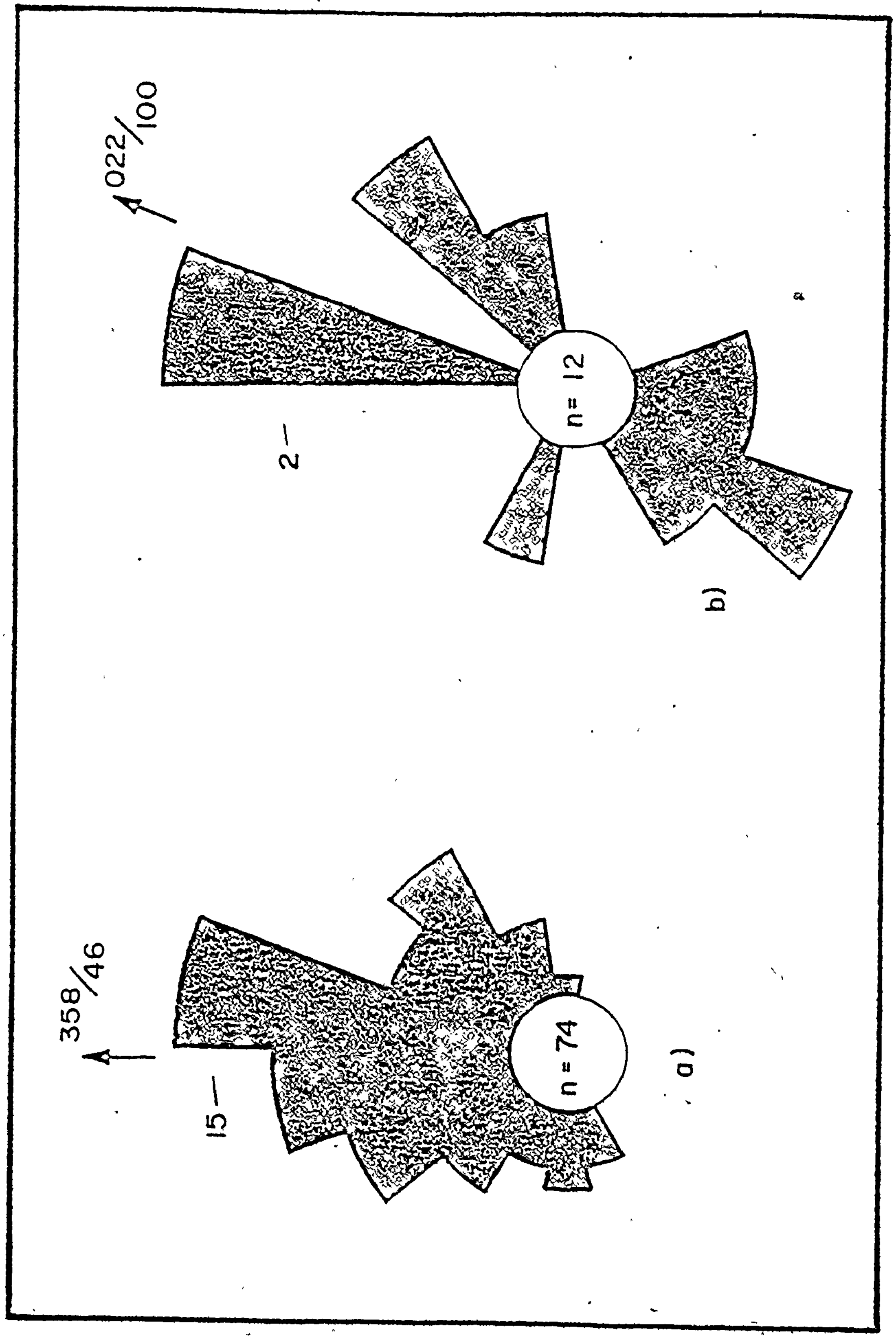
Table 3.5. Salient characteristics and basic interpretations of units at Section 5. Units 22 through 25 represent the Beaver Mines Formation and Unit 26 represents the lowermost part of the Blackstone Formation.

3.11.1 Nonmarine Units (Units 22-25)

Unit 22 has a sharp erosive base, fines upward, and is largely trough cross-bedded. A thin sub-horizontal siltstone break occurs near the middle of the unit and the sandstone just below the siltstone break is medium-grained and ripple cross-laminated. Unit 22 is interpreted as a point bar deposit of a meandering fluvial channel. The siltstone break near the middle of the unit indicates fluctuating river discharge, or a period of channel inactivity with the channel subsequently being reoccupied.

Paleocurrent measurements of trough foresets between 0.0-3.0 m within Unit 22 indicate flow toward N (Figure 3.42a). Measurements were statistically significant at greater than 99.5 percent. Trough foresets were also measured between 3.0-6.5 m. The rose diagram obtained for this interval is shown in Figure 3.42b and has a bipolar distribution. The average inclination of southerly and northerly dipping foresets in Figure 3.42b is 5.6 and 5.7 degrees, respectively, suggesting that the bipolarity represents a random distribution. An alternative explanation for the bipolar distribution is the presence of "canoe-shaped" sets of trough cross-beds (Dott, 1973, p. 781). These sets have slight upward foreset dips in their downstream parts which yield a flow

Figure 3.42. Paleocurrent data for Unit 22. a) trough foreset dip directions between 0-3 m. b) trough foreset dip directions between 3-6.5 m.

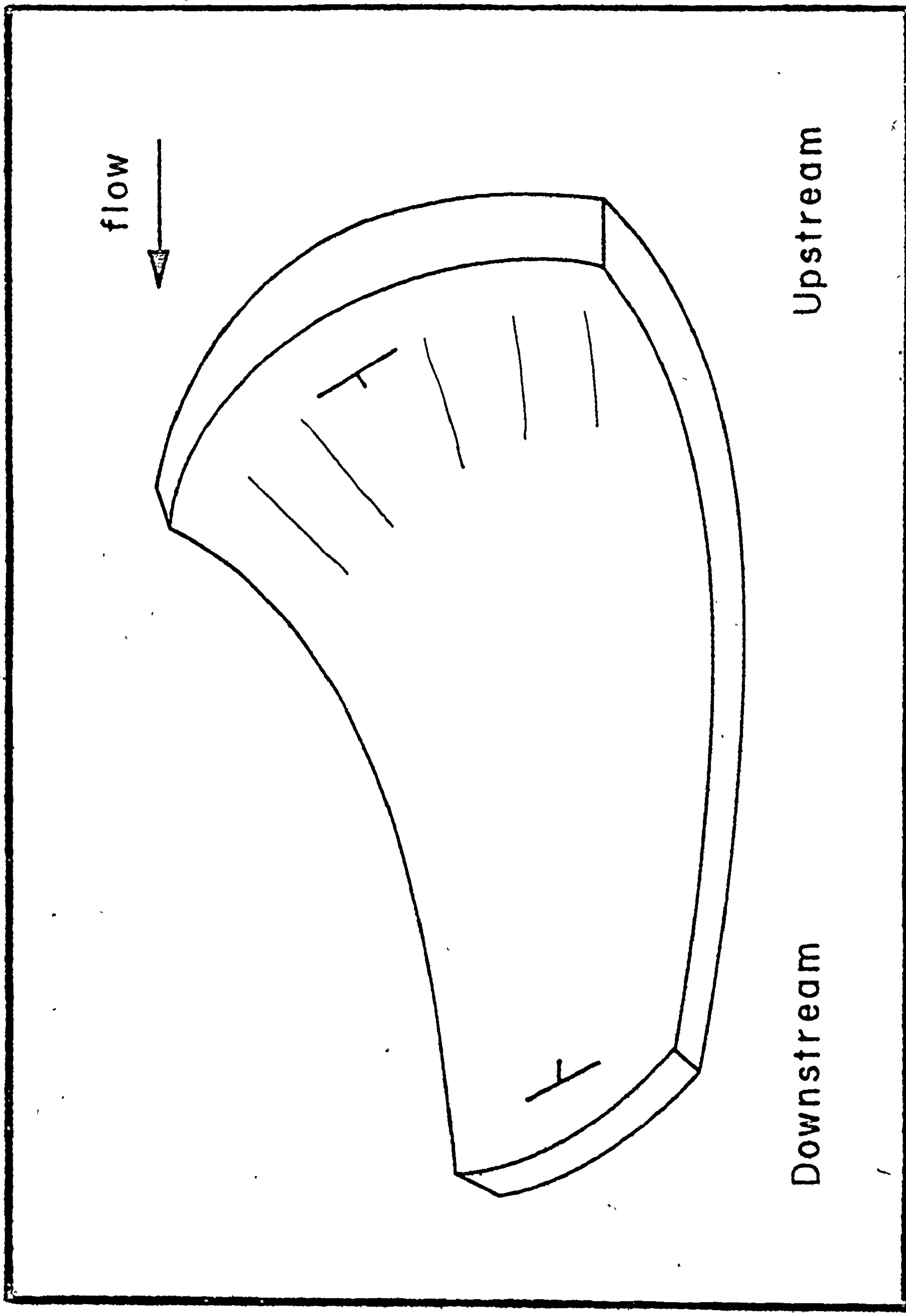

358/46
15
n = 74
a)
022/100
2
n = 12
b)

direction that is 180 degrees from the true flow direction. This is illustrated in Figure 3.43. A bipolar distribution of trough foreset dip directions due to tidal influence is unlikely because: 1) roots are present in overlying and underlying deposits in close proximity to Unit 22; 2) there is no evidence of marine fauna; 3) the marine Moosebar Tongue is well below Unit 22 stratigraphically (at least 50 m); and 4) trough foreset dip directions in the underlying interval (0.0-3.0 m) are strongly unimodal.

Units 23 and 25 consist of interbedded sandstone, siltstone, and shale that commonly has gradational contacts and in some places contains roots. These units are interpreted as vertical accretion deposits and were deposited on the floodplain when the river overtopped its banks during flood stages. Two sandstones within Units 23 and 25 contain small channels that average 0.5-1.0 m deep and 5.0-10.0 m across. They are interpreted as crevasse splays that were deposited on the floodplain when levees of the main channel were breached.

Flow directions within Units 23 and 25 commonly diverge from those associated with the larger channels of Units 22 and 24. The flow directions range from WSW to NE. This suggests lateral overbank flow away from the main fluvial channels during flood stages of the river.

Figure 3.43. Schematic illustration of a "canoe-shaped" trough with foresets in the downstream part dipping gently upstream.

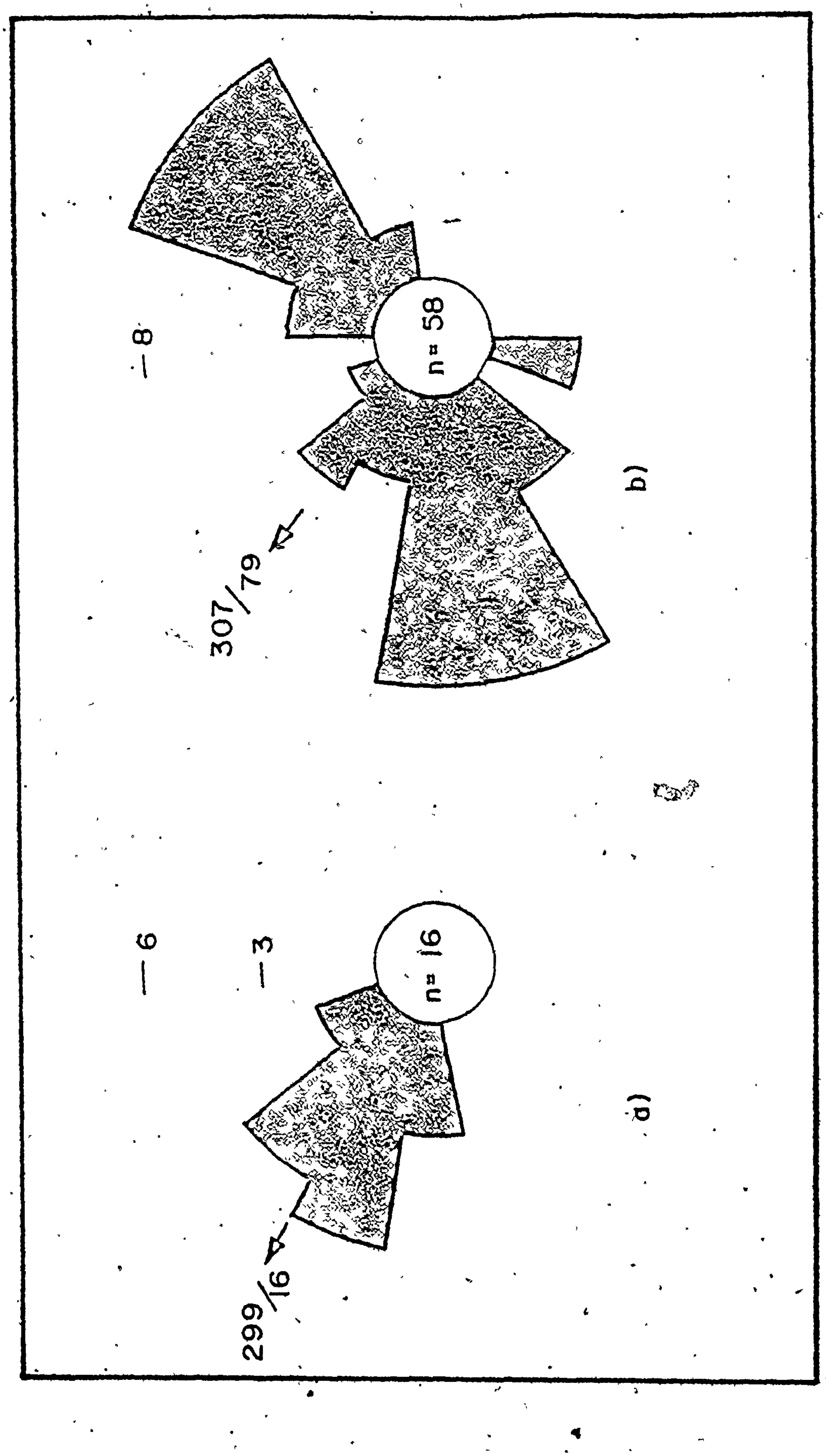

flow
Upstream
Downstream

Unit 24 is a sharp-based fining-upward sandstone that is trough cross-bedded in the lowermost part and ripple cross-laminated in the uppermost part. It has conglomerate at the base that may or may not be cross-bedded and the sandstone is parallel laminated in some places. Roots occur at the upper contact. Unit 24 is interpreted as a point bar deposit of a large-scale meandering fluvial channel. The conglomerate at the base is interpreted as a channel lag (Collinson, 1978, p. 50) and the erosional surface 2.1 m from the base suggests scouring at the river bed during flood stages. A thin shale break at 89 m indicates fluctuating river discharge or a period of channel inactivity. The two erosional surfaces overlain by parallel laminated and ripple cross-laminated sandstone in the uppermost part of the unit are interpreted as slough deposits of the upper point bar. Sloughs are occupied during flood stages of the river as it tries to straighten its course.

Plan views of troughs were present within Unit 24 at 67.0 m and measurement of their axes orientations indicates flow toward NW (Figure 3.44a). Measurements were statistically significant at greater than 99.5 percent.

Trough foreset dip directions were measured between 75.0-79.1 m within Unit 24. The rose diagram

Figure 3.44. Paleocurrent data for Unit 24. a) trough axes orientations (67.0 m). b) trough foreset dip directions (75.0-79.1 m).



8
307/79
n= 58
b)
6
3
299/16
n= 16
d)

obtained for this interval is shown in Figure 3.44b and has a bimodal distribution. The bimodal distribution of trough foresets is due to the shape of the trough sets and where they are cross-sectioned in outcrop. If an elongate trough set is cross-sectioned perpendicular to flow (along line A-A', Figure 3.45), the probability of encountering trough foresets that dip in the direction of flow is low. However, the probability of encountering trough foresets that dip toward the trough axis is high and results in a bimodal distribution (Figure 3.45b). Bisecting the two modes in the 75.0-79.1 m interval indicates flow toward NW, which is consistent with trough axes measurements at 67.0 m (Figure 3.44a).

Pebble orientations were measured at the base of Unit 24. The a-b plane dip direction of these pebbles is towards NNE suggesting flow toward SSW (Figure 3.46). Measurements are statistically significant at greater than 99.5 percent. A SSW flow direction differs from other flow directions in Unit 7 by about 105 degrees and from the flow direction in Unit 22 by about 180 degrees. These differences in flow direction can be partially explained if the conglomerate is cross-bedded. In cross-bedded conglomerates, the a-b plane of the pebbles dips downstream with respect to the horizontal (Johansson,

Figure 3.45: a) Plan view of an elongate trough set showing foreset dip directions around set. b) Hypothetical rose diagram obtained from foreset dip directions encountered in a cross-section at A-A' (or parallel to A-A').

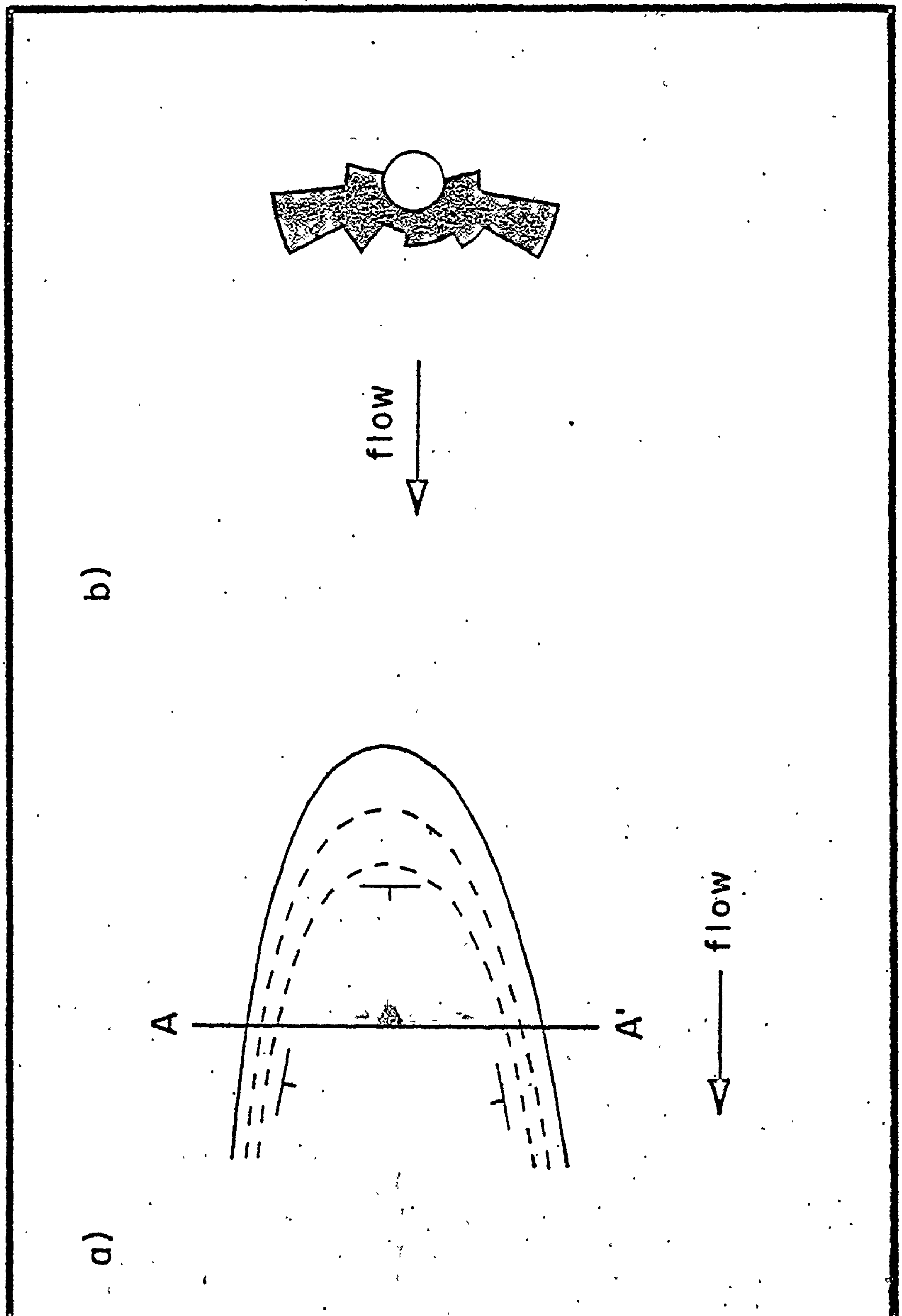
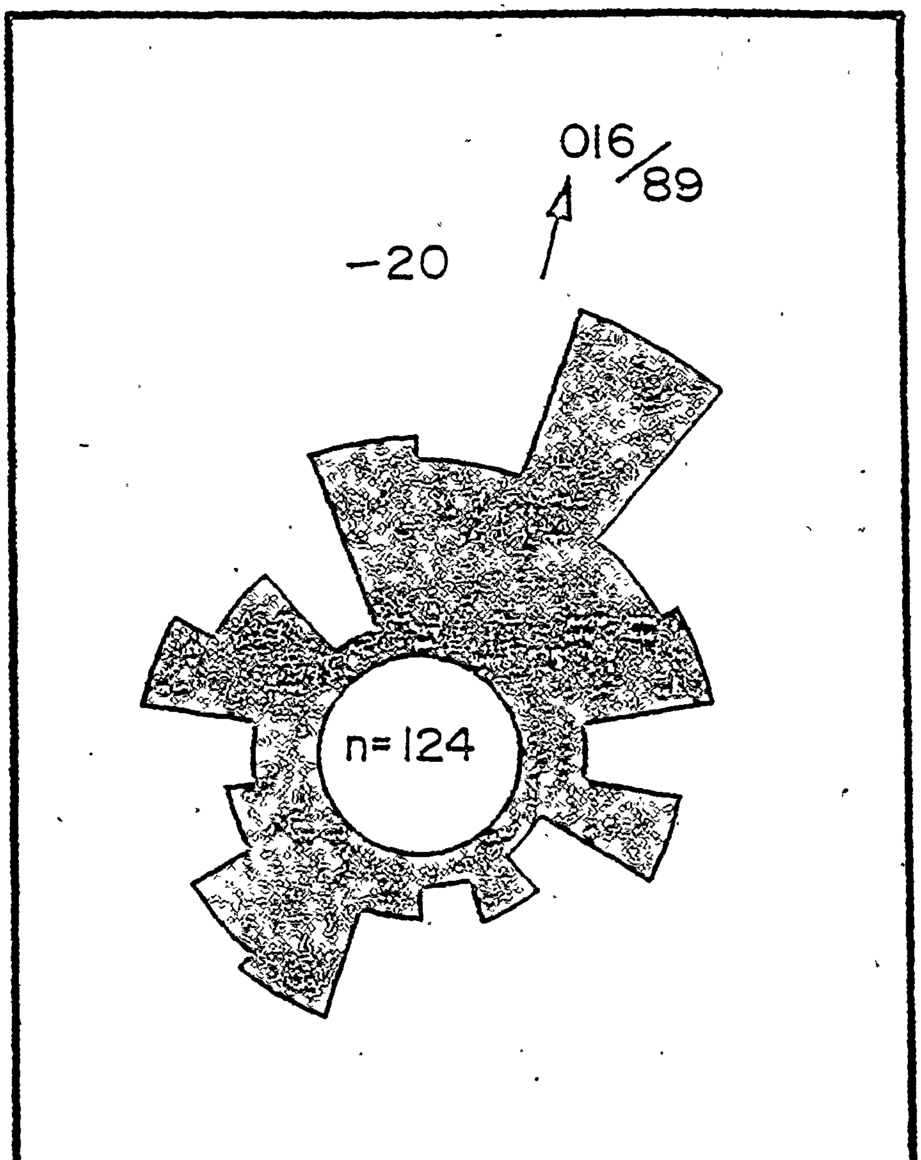

a)
b)
flow
flow
A
A'

Figure 3.46. Paleocurrent data for Unit 24 (64.3 m). Data represent the a-b plane dip directions of pebbles.

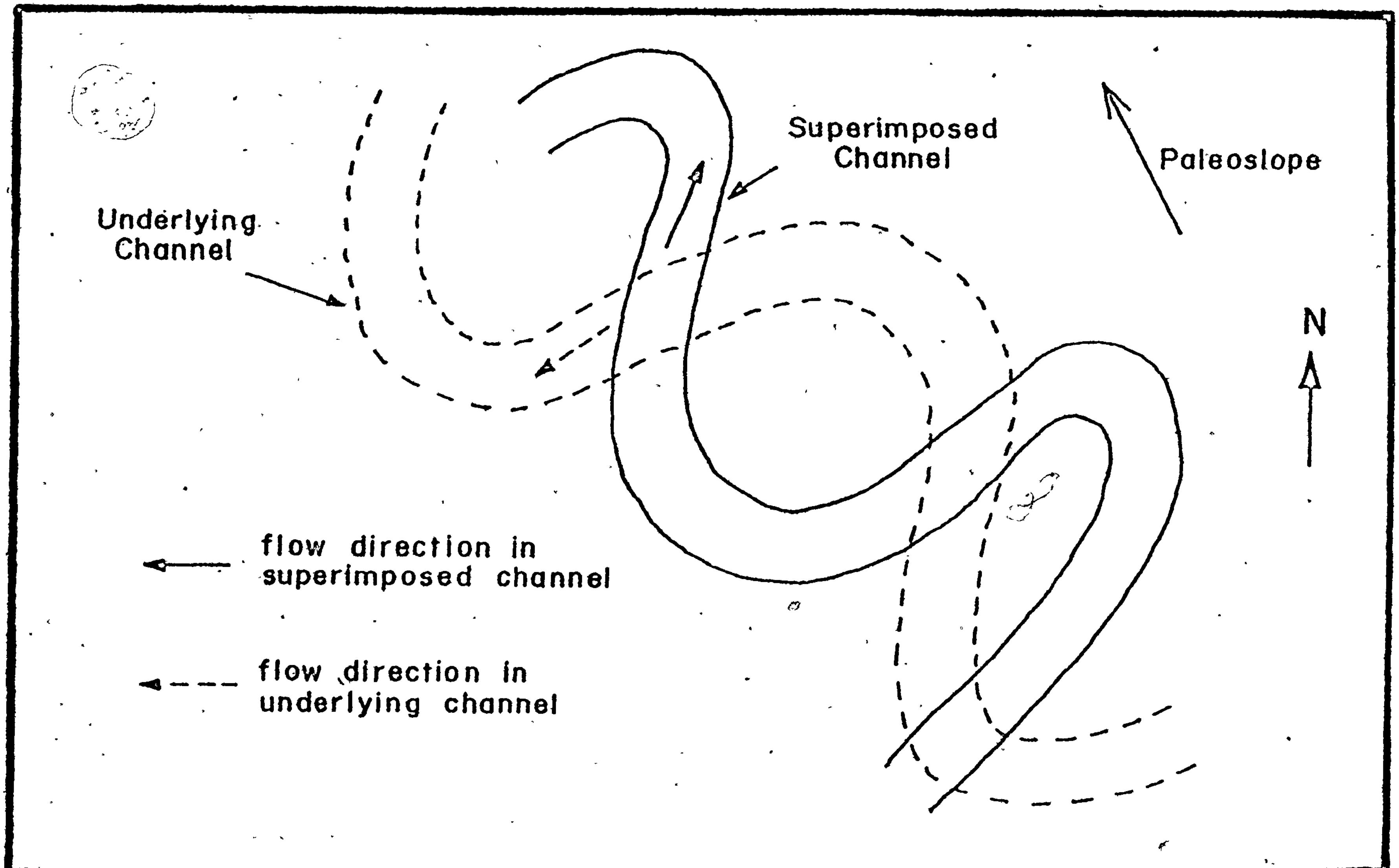

016/89
-20
n=124

1976, Figure 30). Therefore, in Figure 3.46 flow would be in the direction of imbrication, which is NNE. This direction is consistent with the flow direction in Unit 22 but still differs from the flow directions in the overlying sandstones of Unit 24 by about 75 degrees. The 75 degree difference can be explained by the downstream migration of a meanderloop superimposing a NW flow direction on a NNE flow direction (see Figure 3.34). Alternatively, if the conglomerate is not cross-bedded, the differences in flow directions within Unit 24 and between Units 22 and 24 can be explained by a high sinuosity meandering fluvial system. High sinuosity allows for the superimposition of channels with opposing flow directions as illustrated in Figure 3.47. Paleohydraulic reconstructions indicate that the fluvial channels of the Beaver Mines Formation were not highly sinuous (see Chapter 4.3), therefore, the first interpretation is preferred.

3.11.2 Marine Unit (Unit 26)

Unit 26 (Blackstone Formation) consists of dark grey marine shale containing three sandstone sequences that thicken and coarsen upward slightly. It sharply

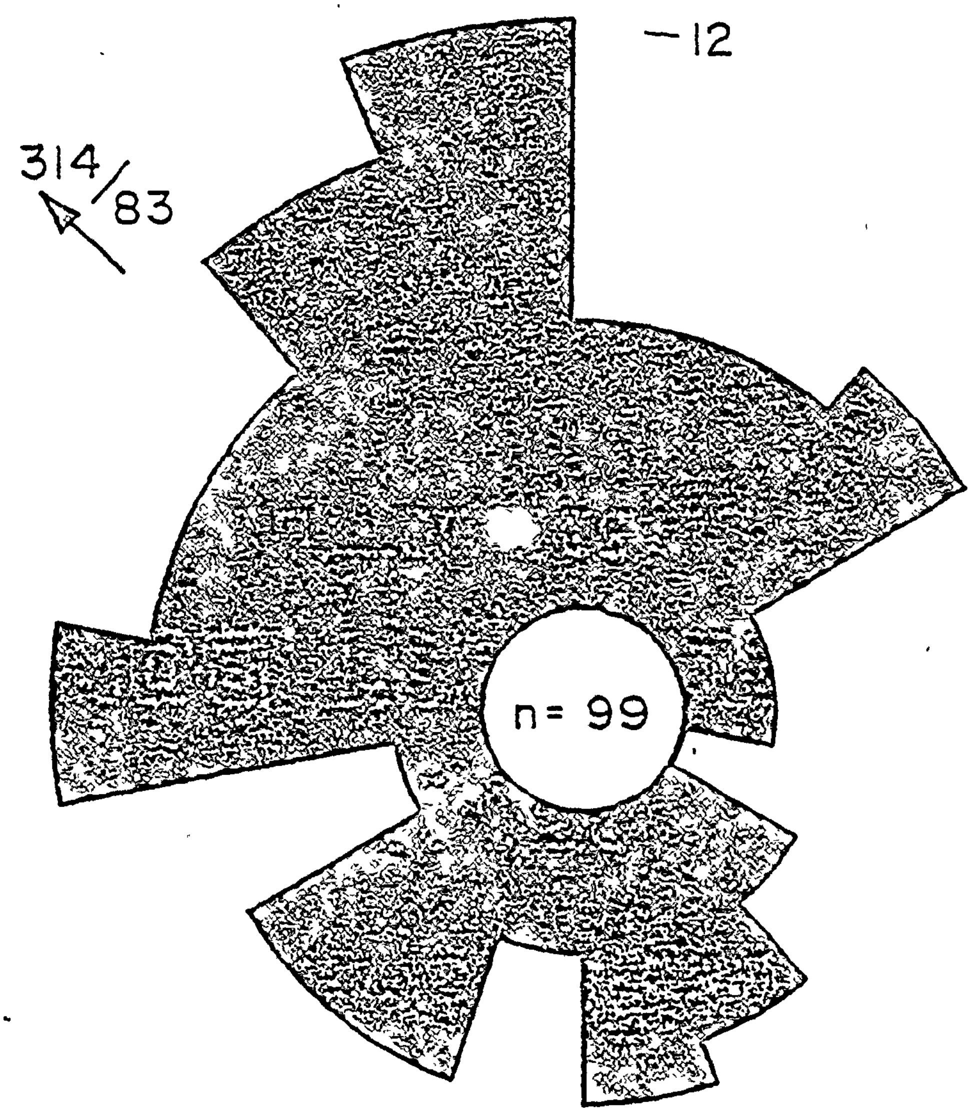
Figure 3.47. Schematic illustration showing the difference in flow directions in Units 22 and 24 due to the superimposition of high sinuosity channels.


Superimposed Channel
Paleoslope
Underlying Channel
N
flow direction in superimposed channel
flow direction in underlying channel

overlies 14.0 cm of imbricated conglomerate that occurs at the top of Unit 25. The conglomerate is interpreted as a transgressive lag deposit with imbrication forming as pebbles were rolled landward along the transgressive surface, possibly by high energy storm waves. The a-b plane dip directions of the pebbles were measured and indicate flow toward SE (Figure 3.48). Measurements are statistically significant at greater than 99.5 percent.

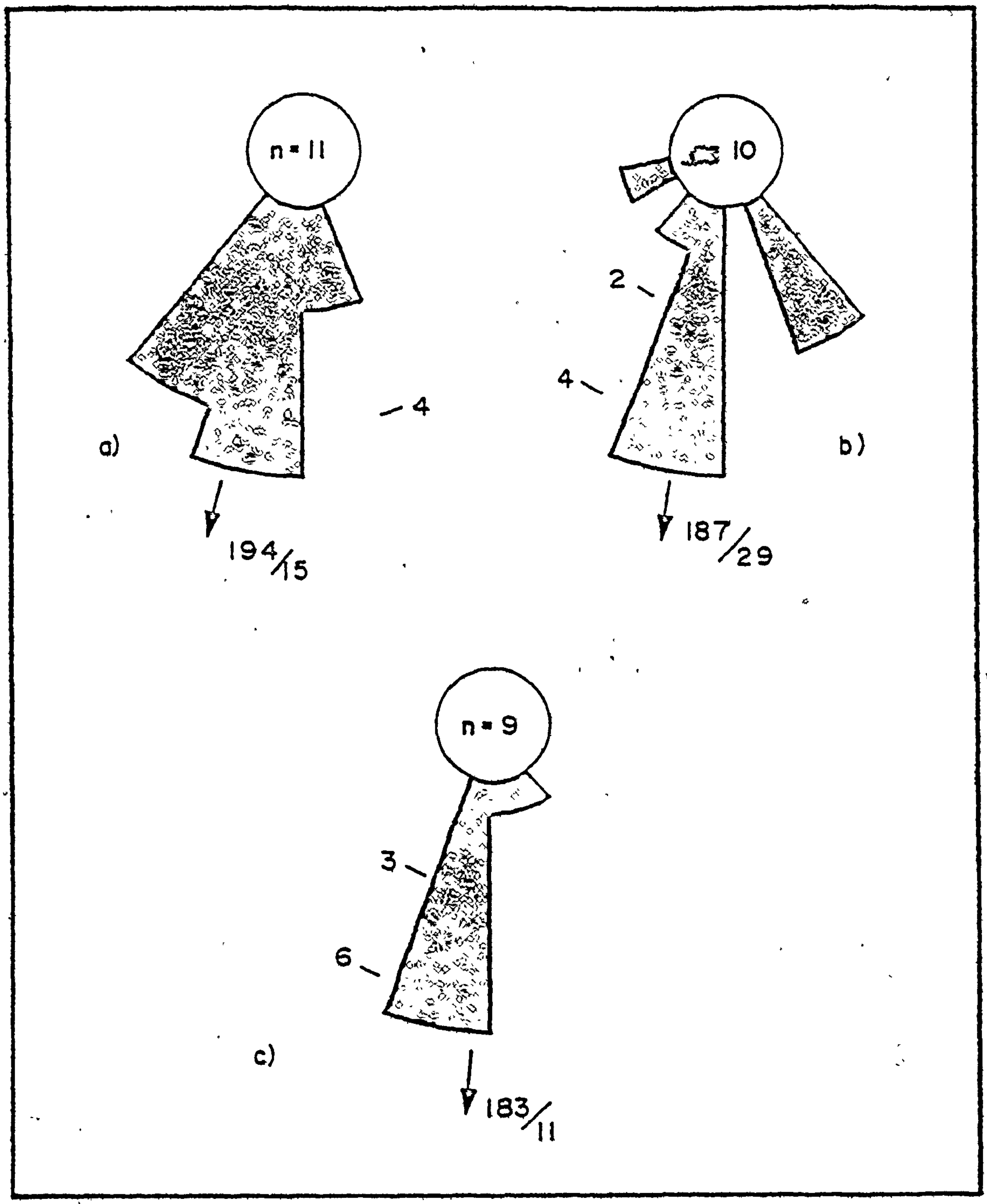
The thickening- and coarsening-upward sequences within Unit 26 consist of sharp-based, very fine- to fine-grained sandstones that contain ripple cross-laminations, or parallel laminations overlain by ripple cross-laminations, and commonly have bioturbated upper contacts. They are interpreted as turbidites (C and BC turbidites; Bouma, 1962) that were intermittently introduced into a quiet offshore marine environment. Paleocurrent measurements of asymmetrical ripple crest orientations indicate flow toward S (Figure 3.49). Measurements are statistically significant at greater than 99.5 percent. Southward flow directions in the Blackstone Formation are briefly discussed in Chapter 4.4.

Figure 3.48. Paleocurrent data for the conglomerate at the top of Unit 25. Data represent the a-b plane dip directions of pebbles.

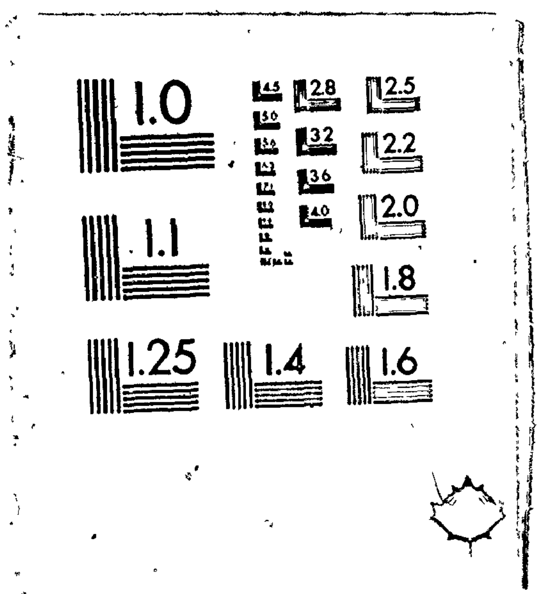


PEBBLE ORIENTATIONS

Figure 3.49. Paleocurrent data for Unit 26. Data represent asymmetrical ripple foreset dip directions. a) 182.0 m. b) 185.0 m. c) 193.0 m.


n = 11
4
a)
194/15
10
2
4
b)
187/29
n = 9
3
6
c)
183/11

3



3.12 Unit Descriptions, Section 6 (Burnt Timber Creek)

3.12.1 Introduction

At Section 6, most of the Beaver Mines Formation is exposed and it is represented by Units 27, 28, and 29. All of these units are of nonmarine origin. Unit 30 represents the lowermost part of the marine Blackstone Formation.

3.12.2 Unit 27 (0-103 m)

Unit 27 consists largely of interbedded green sandstone, siltstone, shale, and mudstone. The sandstone:siltstone plus shale and mudstone ratio is 1:1.3. Sandstone beds are very fine- to medium-grained, contain ripple cross-laminations (sets average 2-4 cm), and in some places contain parallel laminations. The beds average 0.4 m in thickness (range 0.05-2.5 m), undulate and pinch and swell, and commonly have gradational upper and lower contacts. At 40 m, one sandstone contains trough cross-beds with sets averaging 15 cm. Also, at 77 m, angular chert pebbles averaging 1-2 cm in long dimension were found scattered on the upper contact of a sandstone. Macerated carbonaceous material, partially intact plant fragments, and roots are present throughout the sandstones, siltstones, shales, and mudstones.

Within Unit 27, a thicker sandstone bed containing different sedimentary structures from those described above occurs between 48.0-59.0 m. This sandstone is greenish-grey, medium-grained, and is trough cross-bedded in the lowermost 6 m (sets average 25 cm). Overlying the trough cross-bedded sandstone is 5 cm of ripple cross-laminated sandstone with sets averaging 2.5 cm. Three 5 cm thick mudstone breaks occur near the middle of the interval (44.2 m). These are sharply overlain by 1.5 m of medium-grained, trough cross-bedded sandstone (sets average 25 cm) followed by 3.5 m of fine-grained, ripple cross-laminated sandstone (sets average 2-3 cm). Small mudclasts up to 3 cm diameter and macerated carbonaceous material were noted within this interval. Upper and lower contacts of the interval were covered.

3.12.3 Unit 28 (103.0-144.1 m)

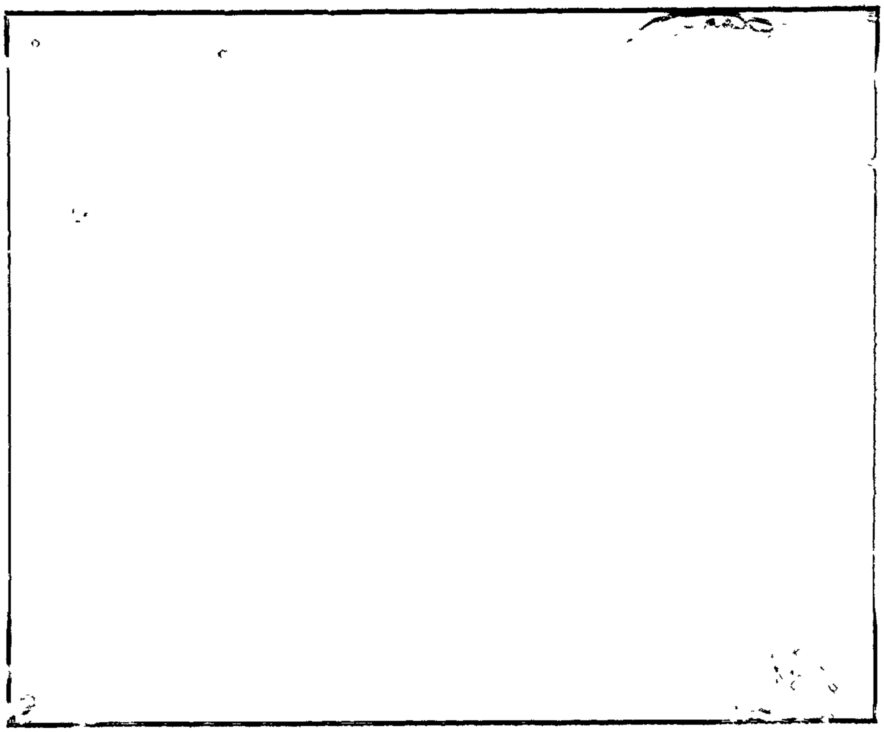
Unit 28 can most easily be described in three intervals. The intervals consist largely of light green sandstone and occur between 103.0-125.5 m, 128.5-134.0 m, and 136.0-144.1m. Between these intervals is interbedded green sandstone and mudstone.

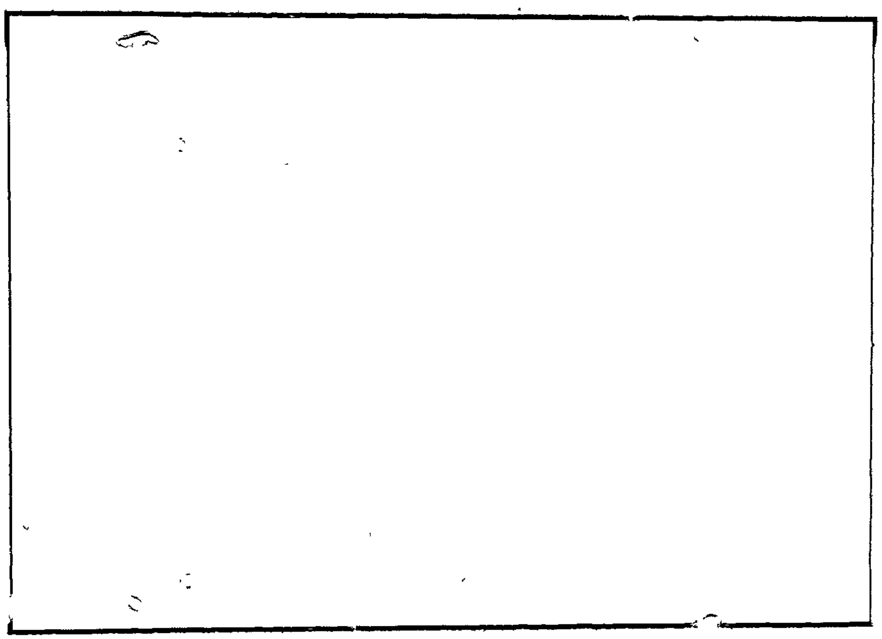
The lowermost interval has a sharp erosive base and is conglomeratic in the bottom 0.5 m. The conglomerate is matrix-supported and consists of rounded to sub-rounded chert and rock fragment pebbles that average 2-3 cm in long dimension. The conglomerate fines upward into approximately 2 m of very coarse-grained sandstone containing faint trough cross-beds. At 105.5 m, a thin pebble layer recurs; however, the pebbles are slightly smaller averaging 1-2 cm in long dimension. Above this pebble layer, the remainder of the interval consists of trough cross-bedded sandstone (sets average 25 cm; Figure 3.50) that fines upward slightly from very coarse- to coarse-grained. Two 5-10 cm thick mudstone breaks occur at 112 m and 113 m within the trough cross-bedded sandstone. Throughout the interval are partially intact plant fragments up to 2 cm wide and 10 cm long, and macerated carbonaceous material.

The 128.5-134 m interval has a sharp erosive base (Figure 3.51) and the lowermost 4 m consists of coarse-grained, trough cross-bedded sandstone with sets averaging 25 cm. The sandstone fines upward from coarse-

Figure 3.50. Trough cross-beds within Unit 28.

Figure 3.51. Sharp erosive base of the 128.5-134 m interval of Unit 28.





to medium-grained in the uppermost 1.5 m and here, trough cross-beds are replaced by ripple cross-laminations (sets average 3-4 cm). Macerated carbonaceous material is present throughout the interval and the upper contact is sharp and rooted.

The uppermost interval is similar to the 128.5-134 m interval, however, parallel laminations were noted at 140 m. Laterally along the sandstone these are replaced by trough cross-beds. Also, in the upper 2.5 m the sandstone contains three 0.5-1.0 m thick alternations of ripple cross-laminations and trough cross-beds.

Between the three sandstone intervals described above is interbedded green sandstone and mudstone with a sandstone:mudstone ratio of approximately 1:1. Sandstone beds are fine- to medium-grained, contain ripple cross-laminations (sets average 2-3 cm), and average 2.5 cm in thickness (range 1-5 cm). Upper and lower contacts may be sharp or gradational. Small partially intact plant fragments and roots were found within the sandstones and mudstones.

3.12.4 Unit 29 (144.1-213.4 m)

Unit 29 consists of interbedded green sandstone, siltstone, shale, and mudstone with three distinct sandstone intervals occurring between 158.5-162.3 m, 194.3-199.3 m, and 210.8-213.4 m.

The lowermost interval is a sharp-based, light green, medium-grained sandstone containing trough cross-beds at the base (sets average 15-20 cm), overlain by ripple cross-laminations (sets average 2-3 cm). Two 1-3 cm thick shale breaks occur at 159.9 m and 160.2 m. Above the second shale break, trough cross-beds are overlain by ripple cross-laminations (sets average 2-3 cm). The upper contact of the sandstone is sharp, and mudclasts and small partially intact plant fragments are found throughout the interval.

The 194.3-199.3 m interval consists of light green, medium-grained sandstone with a sharp erosive base. It contains trough cross-beds in the lowermost 4.0 m with sets averaging 25 cm. The upper 1.0 m of the interval is ripple cross-laminated with sets averaging 2 cm and the upper contact is sharp.

The uppermost interval of Unit 29 is whitish-grey, medium-grained sandstone. The base of the interval is covered but the lowermost exposed part is trough cross-bedded with sets averaging 20 cm. Troughs are overlain by ripple cross-laminations with sets averaging 3 cm. Two 5 cm thick shale breaks occur at 212.1 and 212.8 m within this interval. The sandstone between and above these shale breaks appears to be massive. The upper contact is sharp and has an undulatory, "knobbly" surface (Figure 3.52). "Knobs" average 20-30 cm in diameter and are separated by depressions up to 25 cm deep. A bentonite layer (Ollerenshaw, 1978, p. 69) overlies this sandstone, filling depressions between "knobs" and forming a planar contact with the overlying Blackstone Formation. Macerated carbonaceous material was noted throughout this sandstone interval.

Between the intervals described above is interbedded sandstone, siltstone, shale, and mudstone. The sandstone:siltstone, shale and mudstone ratio is 1:3.4. Sandstone beds are very fine- to medium-grained, average 50 cm in thickness (range 13-150 cm), and commonly have gradational upper and lower contacts. All sandstone beds contain ripple cross-laminations with sets averaging 2-4 cm and in some places the sandstone beds undulate and pinch and swell. Small partially intact plant fragments and roots are found throughout the sandstones, siltstones, shales, and mudstones.

Figure 3.52. Upper contact of Unit 29.
Note "knobbly" surface.

3.12.5 Unit 30 (213.4-247 m)

Unit 30 represents the Blackstone Formation and consists of dark grey marine shale that weathers to a dark maroon colour. A few thin, lenticular, very fine-grained sandstone beds and large maroon coloured concretions occur near the base of the unit.

Within Unit 30, two coarsening-upward sequences are present between 241-243.2 m and 245.7-246.7 m. These sequences begin with 1-2 cm thick, medium grey, very fine-grained sandstones interbedded with dark grey shales. The sandstone:shale ratio increases from 1:3 at the base of each sequence to about 7:1 near the middle of each sequence. The upper part of each sequence consists of medium grey, fine-grained, medium bedded sandstone. Beds average 10-15 cm in thickness and lack shale partings between them. Intense bioturbation of the sandstone has destroyed most primary sedimentary structures that may have originally been present.

3.13 Unit Interpretations, Section 6

The salient characteristics and basic interpretations of units at Section 6 are listed in Table 3.6.

UNIT	SALIENT CHARACTERISTICS	BASIC INTERPRETATION
30	Dark grey fissile shale containing thin bioturbated sandstones.	Shallow marine.
29 and 27	Interbedded sandstone, siltstone, shale, and mudstone. Roots are common in both units and most sandstone beds have gradational contacts.	Nonmarine. Fluvial floodplain.
28	Sharp-based, fining-upward, trough cross-bedded sandstone. Interbedded sandstone and shale is found between these sandstones.	Nonmarine. Meandering fluvial.

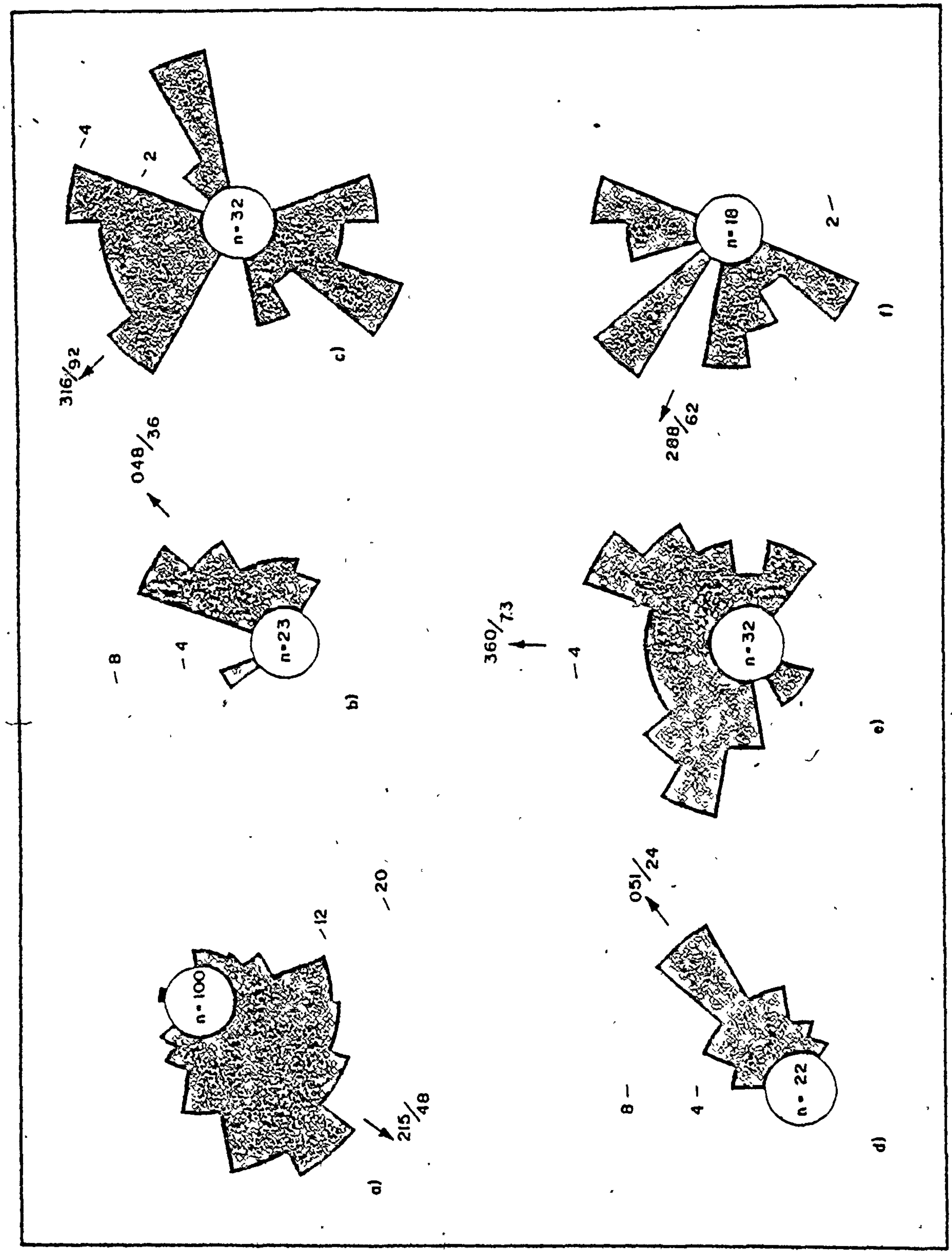
Table 3.6. Salient characteristics and basic interpretations of units at Section 6. Units 27 through 29 represent the Beaver Mines Formation and Unit 30 represents the lowermost part of the Blackstone Formation.

3.13.1 Nonmarine Units (Units 27-29)

Unit 28 contains three sharp-based, fining-upward, trough cross-bedded sandstone intervals between which are interbedded sandstones and mudstones. The sandstone intervals are interpreted as point bar deposits of meandering fluvial channels. Conglomerate at the base of the lowermost sandstone is interpreted as a channel lag and a recurring pebble layer 2.5 m from the base suggests an increase in river competency during flood stages.

Paleocurrent measurements of trough foresets and pebble orientations within the fluvial channels of Unit 28 indicate flow toward NW and NE (Figure 3.53) and suggest a meandering thalweg. Paleoslope is inferred to be toward N. Pebble orientations at 103.0 m (Figure 3.53a) and trough foreset dip directions at 108.0 m (Figure 3.53b), 119.0 m (Figure 3.53d), and between 138.0-141.0 m (Figure 3.53f) are statistically significant at greater than 99.5 percent. Trough foreset measurements between 129.0 - 133.0 m (Figure 3.53e) are statistically significant at greater than 97.5 percent. At 117.0 m (Figure 3.53c), trough foreset measurements are statistically significant at greater that 75.0 percent but a polymodal distribution

Figure 3.53. Paleocurrent data for Unit 28. a) a-b plane dip directions of pebbles (103.0 m). b) trough foreset dip directions (108-111.5 m). c) trough foreset dip directions (117 m). d) trough foreset dip directions (119 m). e) trough foreset dip directions (129-133 m). f) trough foreset dip directions (138-141 m).



a)
n=100
215/48
12
20
b)
n=23
048/36
4
8
c)
n=32
316/92
2
4
d)
n=22
051/24
4
8
e)
n=32
360/73
4
f)
n=18
288/62
2

suggests that there is no preferred orientation of trough foreset dip directions.

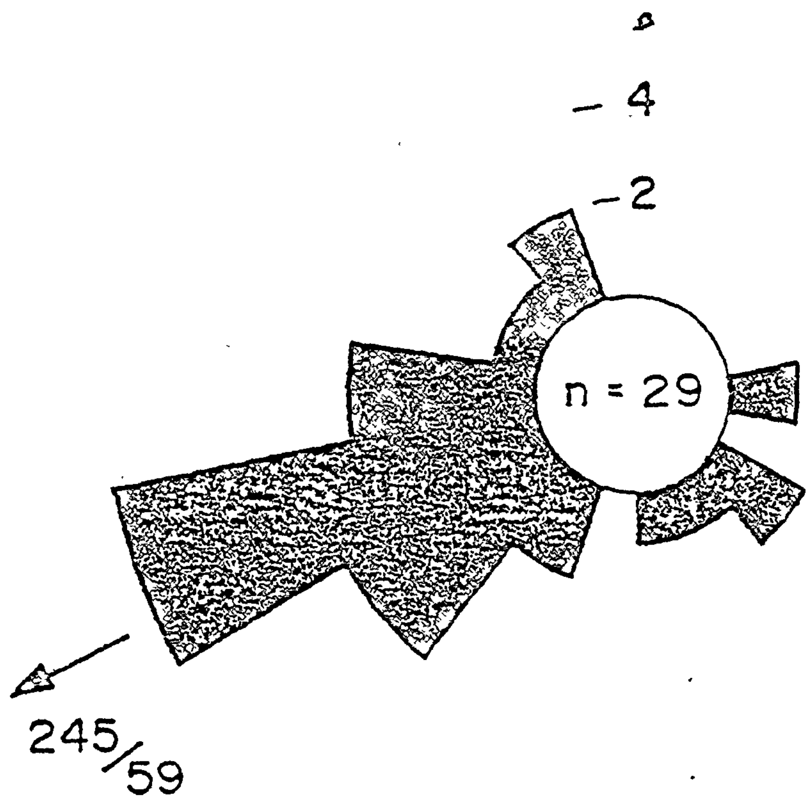
Units 27 and 29 consist largely of interbedded sandstone, siltstone, shale, and mudstone that contain roots in some places. They are interpreted as vertical accretion floodplain deposits. Highly variable paleocurrent directions, especially within Unit 27, indicate lateral overbank flow away from the main fluvial channel during flood stages of the river.

Four thicker trough cross-bedded sandstones are also present within Units 27 and 29. They are interpreted as crevasse splays that were deposited on the floodplain when levees of the main channel were breached. The lowermost sandstone (48.0 m) is 11.0 m in thickness and may alternatively be interpreted as a meandering tributary channel. Paleocurrent measurements of trough foresets within this sandstone indicate flow toward SW (Figure 3.54). Measurements are statistically significant at greater than 99.5 percent.

3.13.2 Marine Unit (Unit 30)

Unit 30 (Blackstone Formation) consists of dark grey marine shale that contains two coarsening-upward

Figure 3.54. Paleocurrent data for Unit 27 (50.5 m).



TROUGH FORESET DIP DIRECTIONS

sequences. It overlies a whitish-grey, medium-grained, nonmarine sandstone present at the top of Unit 29 which has an irregular "knobbly" upper surface. A bentonite layer overlies this sandstone, filling depressions between "knobs" and forming a planar contact with the overlying shales of Unit 30.

The "knobbly" upper surface present at the top of Unit 29 is possibly the result of partial cementation of a subaerially exposed sandstone. Uncemented and poorly cemented parts of the sandstone were eroded during transgression prior to the deposition of the Blackstone Formation leaving a series of "knobs". Volcanic ash subsequently settled through the water column filling depressions and forming a planar contact with the overlying shales of Unit 30. The volcanic ash was later altered to bentonite because of the instability of the glassy material comprising the ash (Blatt et al., 1980, p. 392).

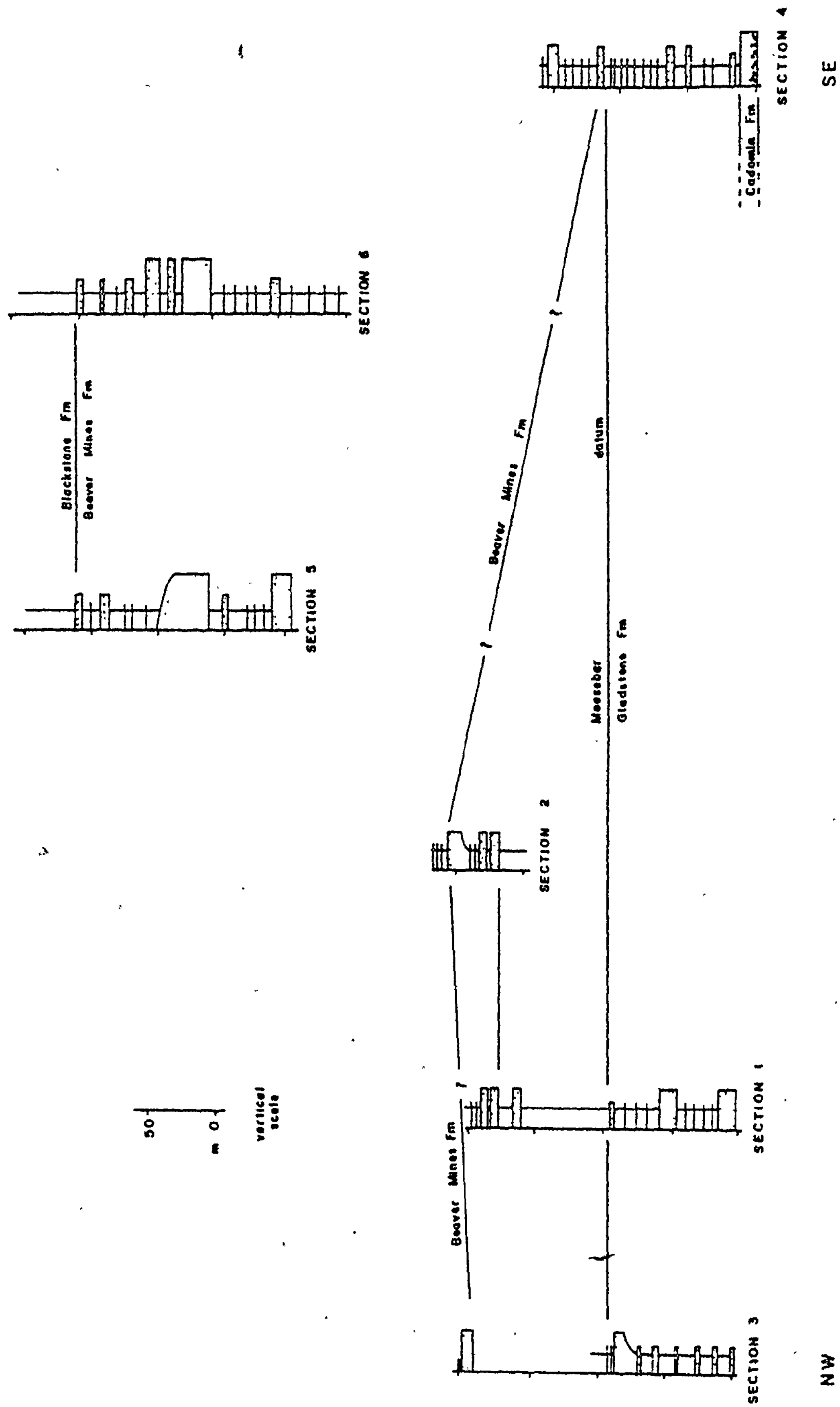
The two coarsening-upward sequences within Unit 30 consist of very fine-grained bioturbated sandstones. In some places the bases of the sandstones appear gradational due to intense bioturbation, but in other places they are sharp and have sole marks preserved. The sandstone sequences indicate sudden introductions of sand into a quiet offshore marine environment, probably by turbidity currents. The sands were later colonized by deposit feeding organisms that obliterated most of the original primary sedimentary structures. Two prod marks at the base of one sandstone bed within Unit 30 indicate flow toward SSW. A discussion of the SSW flow directions in the Blackstone Formation is found in Chapter 4.4.

3.14 Correlation of Measured Sections

To this point, sections measured for this thesis have been described and interpreted individually with no discussion of correlation. Chapter 3.14 briefly discusses the correlation of measured sections throughout the study area and also discusses the thickness and extent of the Moosebar Tongue in the south-central Foothills region.

The correlation of measured sections is shown in Figure 3.55. The Gladstone Formation-Moosebar Tongue contact was used as a datum and correlation was based on a marine horizon containing an early Albian fauna near the middle of the Blairmore Group. Problems were encountered in correlating sections because of the great lateral distance between some sections (up to 300 km between Section 3 and 4) and because the two sections measured in

Figure 3.55. Correlation of measured sections. No horizontal scale implied.


NW
SE
SECTION 3
SECTION 1
SECTION 2
SECTION 5
SECTION 6
SECTION 4
Beaver Mines Fm
Beaver Mines Fm
Blackstone Fm
Beaver Mines Fm
datum
Moosebar
Gladstone Fm
Cadomin Fm
50
m 0
vertical scale

the Beaver Mines Formation (Sections 5 and 6) cannot be correlated with underlying strata. These two sections can be correlated with each other at the Beaver Mines-Blackstone contact.

The Moosebar Tongue was identified at four localities in the study area of this thesis. At Section 3 (the most northerly section measured), the Moosebar Tongue appears to be at least 90 m thick. Much of it is covered, precluding an accurate determination of its thickness. At Sections 1 and 2 (2.5 km apart) the total thickness of the Moosebar Tongue is 115 m. A distinct sandstone bed can be correlated between these two sections thus providing a composite stratigraphic column through the entire Moosebar Tongue. The Moosebar Tongue was also identified at Section 4 (the most southerly section measured) where it is at least 10 m thick but may be up to 40 m thick. The exact thickness at this locality is difficult to determine because of lithologic similarities with underlying strata and a lack of faunal indicators below the identified marine horizon.

Correlation of measured sections confirms that the Moosebar Tongue thins southward. Its recognition at Section 4 is the most southerly reported to date and represents the maximum southerly extent of the early Albian Clearwater Sea in the present day Foothills region.

CHAPTER 4

Discussion

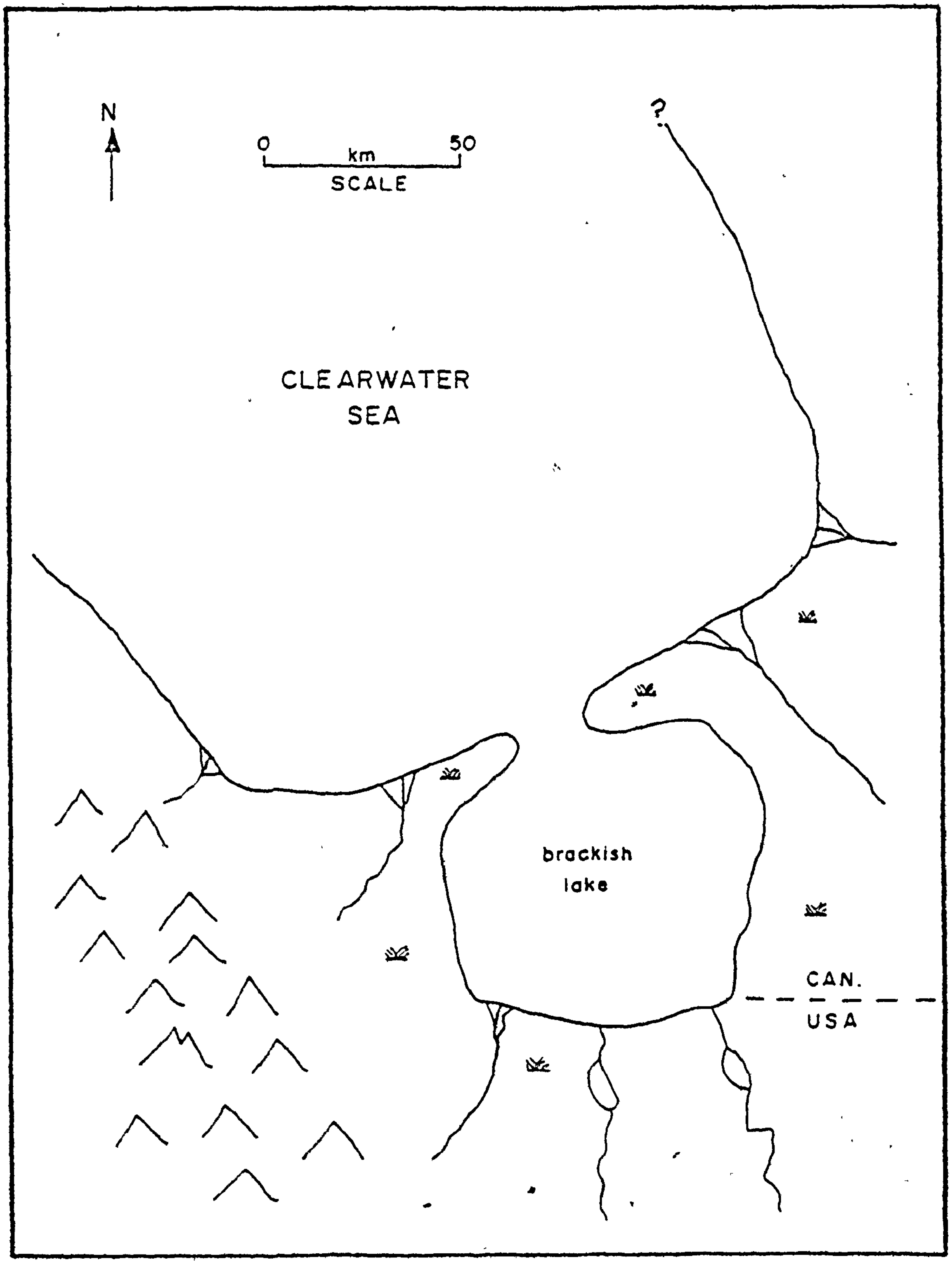
4.1 Paleogeographic Implications and Depositional Summary

During deposition of the Cadomin Formation in earliest Blairmore time, paleogeographic reconstructions indicate that a series of humid-climate alluvial fans to the west fed a NNW flowing trunk stream that occupied an eastern "Spirit River Channel" (Figure 2.3). The Spirit River Channel was confined to the east by a westward facing structural escarpment in Jurassic sub-crop (the Fox Creek Escarpment; McLean, 1977). The Cadomin Formation measured for this thesis lies near the axis of the proposed Spirit River Channel and paleocurrent data confirm the existence of a northward flowing trunk stream during earliest Blairmore time (Figure 3.33). Deposition was in pebbly braided and low sinuosity (braided?) sandy fluvial environments (see Chapter 3.9).

Subsequent to the deposition of the Cadomin Formation, fine- to medium-grained sandstones of the lower Gladstone Formation were deposited. In Sections 1 and 3, some sandstones contain lateral accretion surfaces and are interpreted as having been deposited in a meandering fluvial environment (see Chapter 3.3.1 and 3.9). Rivers were of high sinuosity (see Chapter 4.3) and flowed northwards toward the boreal Clearwater Sea that occupied parts of northeastern British Columbia and northern Alberta (see Chapters 3.3.1 and 3.9). Meandering fluvial deposition resulted as stream gradient was lowered during the southward transgression of this sea. In the northernmost measured section (Section 3), channelled sandstones in the lowermost part of the Gladstone Formation are thin and lack lateral accretion surfaces (see Chapter 3.6.2). These sandstones are interpreted as crevasse splays and small branching fluvial channels of the lower alluvial plain (see Chapter 3.7.1). The small fluvial channels most likely debouched into a large brackish lake that bordered the Clearwater Sea during Aptian time (see below).

At its maximum extent the Clearwater Sea initially transgressed as far south as the present-day position of the Elbow River southwest of Calgary (see Chapter 3.9) and covered most of central Alberta and northeastern British Columbia. Bordering the sea was a large brackish lake analagous to Lake Maracaibo of Venezuela (Figure 4.1; see Chapters 3.3.1, 3.7.1, and 3.9). The brackish lake is represented by deposits of the

Figure 4.1. Paleogeographic reconstruction of the Foothills region during middle Blairmore time.


N
0
km
50
SCALE
?
CLEARWATER
SEA
brackish
lake
CAN.
USA

upper Gladstone Formation (i.e. the Calcareous Member and equivalent strata). Intermittent sea connections probably allowed the environment to fluctuate between brackish and freshwater as both brackish and freshwater fauna were found within the uppermost part of the Gladstone Formation (see Chapters 3.2.5, 3.6.3, and 3.8.4). Mellon (1967, p. 75) states that nonmarine faunal assemblages within the Blairmore Group have little value as indicators of precise age. The large brackish lake that deposited the upper Gladstone interval therefore need not have covered all of south-central Alberta at one time; instead, it may have moved southward ahead of the Clearwater Sea during its initial transgression.

In the central Foothills region, a marine sequence of calcareous silty shales and swaley cross-stratified sandstones overlies a rooted shale and *in situ* coal (see Chapters 3.2.8 and 3.2.9). This indicates that a second transgression occurs within the Moosebar Tongue and that the Clearwater Sea advanced southward a second time during the early Albian. It probably did not extend as far south during the second transgression as it did during the initial transgression. This is suggested by the thinner sequence of marine deposits overlying the second transgressive surface compared to that overlying the initial transgressive surface.

Deposition in the Clearwater Sea was in a storm-dominated, high energy environment. This is suggested by the presence of H.C.S. and swaley cross-stratification within the Moosebar Tongue (see Chapters 3.2.6, 3.2.7, 3.2.9, 3.3.2, 3.4.3, 3.5.1, 3.6.4, and 3.7.2). The shoreline of the Clearwater Sea in the study area of this thesis was oriented ENE-WSW (Figure 3.17a) and it appears to have advanced by the progradation of nearshore bars (see Chapter 3.3.2). These bars protected the shoreline from high energy storm waves thus allowing fine-grained shales and poorly sorted sandstones to be deposited in restricted marine environments (Figure 3.16; Chapter 3.5.1). Well developed beaches are lacking within the Moosebar Tongue in the study area of this thesis. There is also no evidence for tidal activity, suggesting a microtidal environment (<2.0 m). This differs from deposition in the Moosebar-Gates transition of northeastern British Columbia where tidal deposits have been reported by Leckie and Walker (in press). The absence of tides may indicate that the basin was more enclosed in the study area of this thesis than in northeastern British Columbia.

Following the regression of the Clearwater Sea from the present-day Foothills region in early to middle Albian time, a coastal plain environment prevailed (Holter and Mellon, 1972; McLean, 1979, in press). As regression continued, the coastal plain sequence was overlain by a fluvial sequence deposited by meandering rivers (see Chapters 3.9, 3.11.1, and 3.13.1). Paleohydraulic reconstructions indicate that these rivers were larger and less sinuous than those of the underlying Gladstone Formation (see Chapter 4.3). The largest river present during Beaver Mines time was similar in size to the modern Missouri River. In the central Foothills region (i.e. Sections 5 and 6), point bar sequences are of comparable thicknesses and paleocurrent measurements (mainly from trough cross-beds) indicate that large rivers flowed generally northwards (see Chapter 3.11.1 and 3.13.1), subparallel to the elongate foreland basin, debouching into an Arctic embayment.

During late Albian to Cenomanian time marine conditions returned to the interior of western Canada. This marine incursion is represented by the Blackstone Formation of the Foothills region which disconformably overlies the Beaver Mines Formation in the sections measured for this thesis. The disconformity is the result of erosion during transgression prior to the deposition of marine Blackstone shales. Reeside (1957, p. 517) and Stott (1963, p. 147) noted that the late Albian-Cenomanian sea transgressed from the north. This transgression was probably slow and the sea eventually connected with the northward advancing Gulf of Mexico sea for at least part of Blackstone time (Jeletzky, 1971, p. 44-45).

4.2 Comparison of Deposition in the Marine Moosebar Tongue with Other Ancient Shallow Marine Shelf Sequences of the Alberta Basin

Modern and ancient shallow marine shelf sequences occurring in the literature are commonly discussed in terms of tide-dominated systems and storm-dominated systems. Although descriptions of purely tide- or storm-dominated systems are rare (Walker, 1979, p. 84), these two "end members" provide a basis for the interpretation of shallow marine sand bodies.

The Moosebar Tongue in the study area of this thesis lacks evidence for tidal activity. It does, however, contain H.C.S. and swaley cross-stratification that occur in the following sequence:

Top	shoreline (muddy)
↑	swaley cross-stratified sandstone
	H.C.S.
	marine shales

The upward trend of this sequence reflects nearshore and shoreline progradation in a storm-dominated system (see Chapters 3.3.2 and 4.1).

In the Alberta basin, sequences similar to the above sequence have been observed in the Fernie-Kootenay transition (Hamblin, 1978; Hamblin and Walker, 1979; R.G. Walker, pers. comm., 1981), the Wapiabi-Belly River transition (Walker *et al*., 1981; Bullock, 1981; Hunter, 1980), the Moosebar-Gates transition (Leckie and Walker, in press), and the Cardium Formation (W.L. Duke, pers. comm., 1980). Many of these sequences are as follows:

Top ↑

shoreline (commonly a beach)
swaley cross-stratified sandstone
H.C.S.
turbidites

These sequences have also been interpreted as prograding nearshore and shoreline deposits of storm-dominated systems. The Moosebar-Gates transition also contains evidence for tidal activity, suggesting a more equal mixture of fairweather and storm processes (Leckie and Walker, in press).

The sequence observed in the Moosebar Tongue in the study area of this thesis does not contain turbidites in its lowermost part. However, marine shales grade upwards into H.C.S. and swaley cross-stratified sandstones as in other sequences of the Alberta basin reflecting a shoaling upwards and a similarity of depositional conditions. Also, the uppermost part of the sequence in this study lacks a well developed beach compared with other sequences of the Alberta basin. This difference is due to the the fact that the shoreline in this study was protected by offshore bars that prevented high energy storm waves from reaching it. This allowed fine-grained sediment to be deposited in a restricted marine environment (see Chapter 3.3.2).

Despite these differences, the sequence observed in the Moosebar Tongue of this thesis grossly resembles other storm-dominated sequences of the Alberta basin.

4.3 Fluvial Paleohyraulics

An estimate of some stream characteristics for paleochannels in the Gladstone and Beaver Mines Formations was attempted in this thesis to determine the approximate size, morphology, and mean annual discharge of rivers occupying the foreland basin during Blairmore time. The stream characteristics used are given in Table 4.1, based on the methodology of Ethridge and Schumm (1978). Both methods of Ethridge and Schumm (1978) were used in the calculations for comparative purposes. The results are summarized in Table 4.2.

Bankfull depths of paleochannels were determined from the thicknesses of lateral accretion sets (if

STREAM CHARACTERISTIC	METHOD I	METHOD II
Silt-clay in channel perimeter (M)	$M = \frac{(Sc \times W) + (Sb \times 2D)}{W + 2D}$	
Width-depth ratio (F)	$F = 255M^{-1.08}$	$F = \frac{W}{D}$
Sinuosity (P)	$P = 0.94M^{+0.25}$	$P = 3.5F^{-0.27}$
Mean annual discharge (Qm)	$Qm^{+0.38} = \frac{WM^{+0.39}}{37}$	$Qm = \frac{W^{+2.43}}{18F^{+1.13}}$
Meander wavelength (L)	$L = \frac{1890\ Qm^{+0.34}}{M^{+0.74}}$	$L = 18\ (F^{+0.53}W^{+0.69})$

Table 4.1 Stream characteristics and equations used for paleohydraulic reconstructions in this thesis. Methodology is based on that of Ethridge and Schumm (1978). (Note: W = bankfull channel width; D = bankfull channel depth; Sc = percent silt-clay in channel perimeter; Sb = percent silt-clay in channel banks.)

Table 4.2. Results of paleohydraulic reconstructions. (Note: In the calculations, S_c was estimated from thin sections and was found to be 12% for fluvial sandstones of the Gladstone Formation and 5% for those of the Beaver Mines Formation. S_b was 100% in both formations.)

A). Gladstone Formation

Stream	Section 4: D=3.8m; W=24.7m		Section 1: D=8.0m; W=93.3m	
Characteristic	Method I	Method II	Method I	Method II
M (%)	32.7		24.7	
F	5.9	6.5	7.92	11.7
P	2.25	2.11	2.1	1.8
Qm (m^3s^{-1})	12.5	16.2	309	211.1
L (m)	102.9	135.2	374.9	462.1

B). Beaver Mines Formation

Stream	Section 4: D=5.4m; W=90.8m		Section 5: D=25m; W=961.2m	
Characteristic	Method I	Method II	Method I	Method II
M (%)	15.1		9.7	
F	13.59	16.8	21.9	38.4
P	1.85	1.63	1.66	1.31
Qm (m^3s^{-1})	173	131.3	54,390	15,946.7
L (m)	445.6	548.1	4,070.9	4,327.9

present) or the thicknesses of fining-upward coarse-members when lateral accretion sets were absent. Bankfull channel widths were estimated from lateral accretion sets by multiplying the horizontal width of the set by 1.5 (Ethridge and Schumm, 1978, p. 708).. When lateral accretion sets were absent, bankfull channel widths were estimated using the methodology of Leeder (1973):

$$\log W = 1.54 \log D + 0.83$$

where

W = bankfull channel width

D = bankfull channel depth.

Stream characteristics calculated for paleochannels of the Gladstone Formation are shown in Table 4.2A. Paleochannel widths range from 24.7 m to 93.3 m. The percent silt-clay in the channels (M), width-depth ratios (F), and sinuosities (P) indicate that rivers occupying the foreland basin during Gladstone time were highly sinuous and had a suspended sediment load (Schumm, 1968, Table 5). Mean annual discharges (Qm) ranged from about 12-16 m^3s^{-1} to 200-300 m^3s^{-1}.

Rivers present in the study area of this thesis during Gladstone time are of comparable size and morphology to the modern Guadalupe River of Texas (Morton and Donaldson, 1978a, 1978b). The Guadalupe is a high sinuosity (P = 2.24) suspended load stream that has a bankfull depth and width of 7 m and 57 m, respectively. The width-depth ratio of the Guadalupe River is 8.1 and the mean annual discharge is 45.8 m^3s^{-1} (measurements were taken 81.6 km above the mouth of the river; Morton and Donaldson, 1978a, Table 2). All of these stream characteristics are of the same order of magnitude as those calculated for paleochannels in the Gladstone Formation (cf. Table 4.2A).

Stream characteristics calculated for paleochannels in the Beaver Mines Formation are given in Table 4.2B. Paleochannel widths range from 90.8 to 961.2 m, indicating that rivers occupying the foreland basin during Beaver Mines time were larger on average than those that occupied the foreland basin during Gladstone time. The percent silt-clay in the channels (M), width-depth ratios (F), and sinuosities (P) suggest that lower sinuosity mixed load channels were present during Beaver Mines time. Mean annual discharges ranged from about 450-550 m^3s^{-1} to 16,000-55,000 m^3s^{-1}.

The smallest paleochannel present in the study area of this thesis during Beaver Mines time had channel dimensions (i.e. width, depth) and a mean annual discharge that were of the same order of magnitude as the modern Guadalupe River. The ancient river was of lower sinuosity and had a mixed sediment load, thus differing from the Guadalupe. The largest paleochannel in the Beaver Mines Formation had channel dimensions (i.e. width, depth) comparable to the modern Missouri River. The calcuated mean annual discharge of 54,390 $m^3 s^{-1}$ is greater than that of the modern Mississippi River at flood stage. This figure seems rather high and the smaller calculated mean annual discharge of 15,946 $m^3 s^{-1}$ (comparable to the average discharge of the modern Mississippi) may be a more realistic estimate.

4.4 Basin and Tectonic Implications

Deposition throughout Blairmore time took place in an elongate foreland basin created during the Columbian Orogeny (see Chapter 2.1). The Cadomin Formation represents a period of extensive pedimentation and coarse clastic deposition and indicates that major uplift occurred in the Canadian Cordillera during earliest Blairmore time. In the Spirit River Channel, deposition was controlled to the east by the Fox Creek Escarpment. A change from a pebbly braided to low sinuosity (braided?) sandy style of fluvial depositon occurs within the Spirit River Channel and is attributed to: 1) a cessation of uplift in the source area; and 2) a lowering of stream gradient within the depositional basin due to the southward transgression of the Clearwater Sea. As stream gradient continued to be lowered, fine-grained meandering fluvial sequences of the Gladstone Formation were deposited.

The southward transgression of the boreal sea and deposition of the Moosebar Tongue during early-middle Blairmore time reflects continued subsidence within the foreland basin combined with a low sediment input. The withdrawal of the Clearwater Sea and subsequent deposition of coarse feldspathic sandstones of the Beaver Mines Formation suggests renewed tectonic activity and uplift in the Cordillera during middle to late Blairmore time.

Paleocurrent data from sections of the Blairmore Group measured for this thesis indicate a generally north to northwesterly dipping paleoslope. Northerly flowing rivers during Blairmore time have been suggested by Eisbacher _et al_. (1974) who indicated that the rivers originated in the area of the Crowsnest re-entrant. The rivers flowed subparallel to the trend of the Cordillera reflecting strong basin control on deposition and a high rate of subsidence in the foredeep. The Fox Creek Escarpment which controlled deposition in the Spirit River Channel during Cadomin time was apparently active in controlling deposition in the basin throughout Blairmore time. Deposition parallel to the axis of the foreland basin in the Canadian Cordillera is similar to depositional trends observed in the Alpine molasse sequence (Van Houten, 1974).

During Blackstone time marine conditions prevailed within the western interior of North America. Paleocurrent measurements of sole marks and asymmetrical ripple crests from sandstones in the lower Blackstone Formation indicate flow towards south (Figure 3.49). This suggests a reversal of paleoslope from that of the underlying Blairmore Group. The sediment source was apparently to the north and changing paleoflow directions may reflect uplift in the north-central Cordillera or possibly renewed activity in the Peace River arch.

4.5 Source of Sediment

The conglomeratic Cadomin Formation and overlying fine-grained sandstones of the Gladstone Formation consist largely of quartz, chert, and non-volcanic rock fragments (see Appendix 2). The source area of this detritus has not clearly been resolved, and at the present time two sources have been proffered in the literature. A source area west of the present-day Rocky Mountain Trench is favoured by some workers (e.g. Norris, 1964; Rapson, 1965;

Mellon, 1967), with Proterozoic and Paleozoic carbonates and clastics having supplied detritus to the east.

More recently, Price and Mountjoy (1970), and Schultheis and Mountjoy (1971, 1978) have suggested that detritus of the Cadomin and Gladstone Formations was derived from thrust sheets of the eastern Main Ranges and Front Ranges of the Rocky Mountains. Microfossils within chert pebbles indicate that a large proportion of the clasts were derived from Carboniferous rocks (possibly the Livingstone Formation and laterally equivalent Pekisko and Turner Valley Formations). Quartzite pebbles are believed to have been derived from the Lower Cambrian Gog Group. The similarity of detritus comprising the Gladstone Formation and Moosebar Tongue to that of the Cadomin Formation suggests a common source area.

Sandstones comprising the Beaver Mines Formation differ markedly from those of the underlying Gladstone and Cadomin Formations. They consist largely of angular quartz, feldspar, and volcanic and non-volcanic rock fragments (see Appendix 2), indicating renewed tectonic activity in the southeastern Cordillera. Mellon (1967), and Price and Mountjoy (1970) have suggested that volcanic detritus in the Beaver Mines Formation was derived from correlatives of parts of the widespread suite of acid igneous rocks in the Omineca Crystalline Belt of the southern Cordillera.

The Mill Creek Formation was not examined in this thesis but consists of quartz, chert, and non-volcanic rock fragments, overlain by a thick wedge of pyroclastic detritus (i.e. the Crowsnest Member). Mellon (1967) believes that the lowermost part of the Mill Creek Formation (excluding the Crowsnest Member) was derived from a similar source as the Beaver Mines Formation; however, the absence of volcanic detritus suggests that the volcanic source was inactive and largely removed through erosion by late Blairmore time. The pyroclastic detritus of the Crowsnest Member is believed to have originated within the depositional basin itself and was deposited at the top of the Blairmore succession.

CHAPTER 5

Conclusions

The conclusions reached in this thesis for sedimentation in the Moosebar Tongue of the Lower Cretaceous Blairmore Group can be summarized as follows:

1) The Moosebar Tongue thins southward from 115 m in the vicinity of the North Saskatchewan River to approximately 10-40 m at the Elbow River southwest of Calgary. The recognition of this marine tongue at the Elbow River is presently the most southerly reported occurrence and represents the maximum southerly extent of the early Albian Clearwater Sea.

2) The Moosebar Tongue is interpreted as having been deposited in a storm influenced shallow marine environment. The shoreline was probably protected by nearshore subaqueous bars that prevented storm waves from reaching it. This allowed fine-grained muds and poorly sorted argillaceous sandstones to accumulate in a restricted marine environment. The shoreline of the early Albian Clearwater Sea was oriented ENE-WSW.

3) The depositional sequence observed in the Moosebar Tongue is as follows (from bottom to top): marine shales, H.C.S., swaley cross-stratified sandstone,

shoreline. This sequence grossly resembles other storm-dominated shallow marine sequences observed in the Alberta basin suggesting similar depositional conditions.

The following conclusions were reached for sedimentation in the formations bounding the Moosebar Tongue (i.e. Cadomin, Gladstone, and Beaver Mines Formations):

1) The Cadomin Formation is interpreted as having been deposited in pebbly braided and low sinuosity (braided?) sandy fluvial environments. The Cadomin Formation in this thesis lies near the axis of the proposed Spirit River Channel and confirms the existence of a northerly flowing trunk stream during Hauterivian-Barremian (?) time. Deposition in the Spirit River Channel was controlled to the east by the Fox Creek Escarpment. The change from pebbly braided to low sinuosity sandy fluvial deposition upwards in the section is attributed to a cessation of uplift in the source area and a lowering of stream gradient due to the gradual southward transgression of the Clearwater Sea.

2) The lowermost part of the Gladstone Formation is interpreted as having been deposited in a meandering fluvial-floodplain environment. Rivers were of high sinuosity and had a suspended sediment load. These rivers flowed N-NW in the study area, subparallel to the elongate

foreland basin.

3) The uppermost part of the Gladstone Formation (i.e. the Calcareous Member and equivalent strata) is interpreted as a brackish lacustrine deposit. This interpretation is based largely on the paleoecological interpretation of fauna within this part of the formation that are envisaged as having inhabited a coastal (fringing) lake that was intermittently connected to the sea (cf. Lake Maracaibo, Venezuela).

4) The Beaver Mines Formation is interpreted as having been deposited in a meandering fluvial-floodplain environment. Rivers were of lower sinuosity than those of the underlying Gladstone Formation and had a mixed sediment load. These rivers flowed generally northward, subparallel to the foreland basin, debouching into an Arctic embayment.

5) Paleocurrent measurements from sandstones in the marine Blackstone Formation indicate flow towards south. This differs from the generally northward flow directions in the underlying Blairmore Group and suggests a reversal of paleoslope during Blackstone time. This reversal may be attributed to uplift in the northern Cordillera or renewed activity in the Peace River arch.

The paleogeography in the study area of this thesis during deposition of the Blairmore Group can be briefly summarized as follows:

1) In earliest Blairmore time (i.e. during Cadomin deposition) a series of humid-climate alluvial fans to the west fed a NNW flowing braided trunk stream to the east.

2) During lower Gladstone time an alluvial plain environment prevailed within the depositional basin.

3) During Moosebar time a boreal sea transgressed from the north and occupied most of central Alberta and northeastern B.C. Bordering the sea to the south was a large brackish lake that moved southward ahead of the sea during its initial transgression, depositing the uppermost part of the underlying Gladstone Formation.

4) Upon regression of this boreal sea from the basin during Beaver Mines time, a major regressive sequence was deposited. In this sequence, a coastal plain environment initially prevailed which was subsequently overlain by deposits of an alluvial plain environment.

5) Marine conditions returned to the western interior of North America during Blackstone time. This sea transgressed slowly southward, eventually connecting with the northward advancing Gulf of Mexico sea for at least part of the Blackstone time.

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APPENDIX 1

Measured Sections

Detailed measured sections and an accompanying legend are located in the back pocket of this thesis. Paleocurrent data and fauna at particular stratigraphic intervals are found to the right of the measured sections. Arrows indicate paleoflow directions. Unit numbers and formation names are found to the left of the measured sections. The vertical scale for all measured sections is in metres. No relative scale is implied for the symbols representing sedimentary structures within individual beds. (Note: The 'Moosebar Member' on the drafted sections is equivalent to the 'Moosebar Tongue' in the text of this thesis.)

APPENDIX 2

Petrography

Analytical Techniques

From sandstone samples collected at the six sections measured for this thesis, 14 were selected for detailed petrographic analysis. Samples were selected so as to be representative of the different types of sandstones present within each formation of the Blairmore Group (excluding the Mill Creek Formation). The selection of these samples allowed comparison of petrographic data obtained in this thesis with detailed petrographic analyses of Mellon (1967).

Samples were thin sectioned perpendicular to bedding and stained for plagioclase and potassium feldspars using a standard staining technique outlined in Hutchinson (1974, p. 18). The mineral composition of each sandstone was then determined from counts of 200 points, arranged in four traverses of fifty points each taken parallel to bedding. The constituents used in determining the compostion of each analysed sample are given in Table A.1. The "others" column in this table includes accessory minerals, organic material, and void spaces. The percent fine-grained matrix per sample was difficult to distinguish from authigenic clay mineral cement therefore the matrix estimate is only approximate. Roundness was visually estimated using the scale of Powers (1953, p. 118). Sorting was visually estimated using sorting images found in Pettijohn et al. (1972, p. 585).

Results

The results of petrographic analyses of Blairmore Group sandstones are summarized in Tables A.1 and A.2. A brief discussion of the results for each formation follows.

Cadomin Formation. One sample from the Cadomin Formation (C-18-4) was thin sectioned and examined in detail. The main detrital mineral constituents present are quartz, chert, and non-volcanic rock fragments. The grains are sub-angular to sub-rounded; however, this was difficult to distinguish due to abundant quartz overgrowths. The grain size distribution is unimodal and the mean grain diameter is 0.35 mm. The sandstone is well sorted, and fine-grained matrix is present as a "dusting" around some detrital grains. Grain contacts observed included concavo-convex, long, and rare sutured grains. The sandstone is well cemented by silica.

sample	quartz	chert	vol. rock fragments	non-vol. rock fragments	plagioclase	detrital carbonates	clay minerals	others	carbonate cement	silica cement
C-18-4	42	29		22			1	1		5
G-10-1	31	10.5		22		12	16.5	8		
G-95-1	30.5	13		17		11.5	10	8	10	
G-55-3	22.5	10		16.5		22	20	9		
G-56-4	31	22		28		2	5	6		6
G-71-4	41	14		22		8	12	1		2
M-165-1	68.5	4		4			0.5	12.5	10.5	
M-185-1	53	24		15		0.5	0.5	3.5		3.5

Table A.1. Composition of Blairmore Group sandstones analysed in this thesis. The composition was determined from counts of 200 points arranged in four traverses of 50 points each taken parallel to bedding. C = Cadomin Formation; G = Gladstone Formation; M = Moosebar Tongue; BM = Beaver Mines Formation. The first number following each letter represents the stratigraphic level at which the sample was collected. The second number is the section number (e.g. C-18-4 means Cadomin Formation, 18.0 m, Section 4).

sample	quartz	chert	vol. rock fragments	non-vol. rock fragments	plagioclase	detrital carbonates	clay minerals	others	carbonate cement	silica cement
M-196-1	30	13		22		14	3	8	10	
47-2	25	15	6	12		2	27	13		
-200-3	24.5	21	22.5	13.5	4.5		11	3		
BM-150-4	23	7	26	14	12		14	4		
BM-76-5	23.5	13.5	37	8	10		6	2		
BM-120-6	13	10	33	13	18		8	5		
M (Mellon, 1967)	16.7	6.4	33.3	20.8	19.7			3.1		
(Mellon, 67)	39.2	20.7		21.3		9.3	7.7	1.8		

Table A.1 (continued)

sample	roundness	mean grain diameter (mm)	sorting	matrix (%)	cement
C-18-4	.35	.35	well	trace	silica
G-10-1	.35	.15	moderate	12	clay minerals
G-95-1	.30	.14	moderate	10	calcite
G-55-3	.30	.13	moderate	20	clay minerals
G-56-4	.35	.2	moderate	5	silica
G-71-4	.40	.25	well	12	silica
M-165-1	.50	.11	very well	trace	calcite
M-185-1	.35	.20	moderate-well	trace	silica
M-196-1	.40	.1	moderate-well	trace	calcite
M-47-2	.30	.13	poor-moderate	20	clay minerals
BM-200-3	.30	.25	moderate	10	clay minerals
BM-150-4	.30	.25	moderate	10	clay minerals
BM-76-5	.25	.35	moderate-well	5	clay minerals
BM-120-6	.30	.5	well	5	clay minerals

Table A.2. Petrographic characteristics of Blairmore Group sandstones analysed in this thesis.

<u>Gladstone Formation</u>. Sandstones analysed from the Gladstone Formation consist largely of quartz, chert, and non-volcanic rock fragments. Detrital carbonate grains were also present in all samples, with sample G-55-3 containing greater than 20 percent detrital carbonate. All grains are sub-angular to sub-rounded and sandstones are moderately to well sorted. The grain size distribution of all samples is unimodal with the exception of G-95-1 which is bimodal. The grand mean diameter for the unimodal samples is about 0.18 mm (means for each sample range from 0.13-0.25 mm), while in the bimodal sample the mean grain diameter for each mode is about 0.08 mm and 0.14 mm.

Fine-grained matrix is present in all samples, averaging about 12% (range 5% to 20%). Most grains are floating in the matrix but grains touching one another commonly display concavo-convex and long grain contacts. Samples G-10-1 and G-55-3 are cemented by authigenic clay minerals, G-56-4 and G-71-4 by silica, and G-95-1 by calcite.

Samples from the Gladstone Formation differ slightly from the sample analysed from the Cadomin Formation. Gladstone sandstones generally contain less quartz and chert but have a much higher matrix percentage and a smaller mean grain diameter than the Cadomin sample.

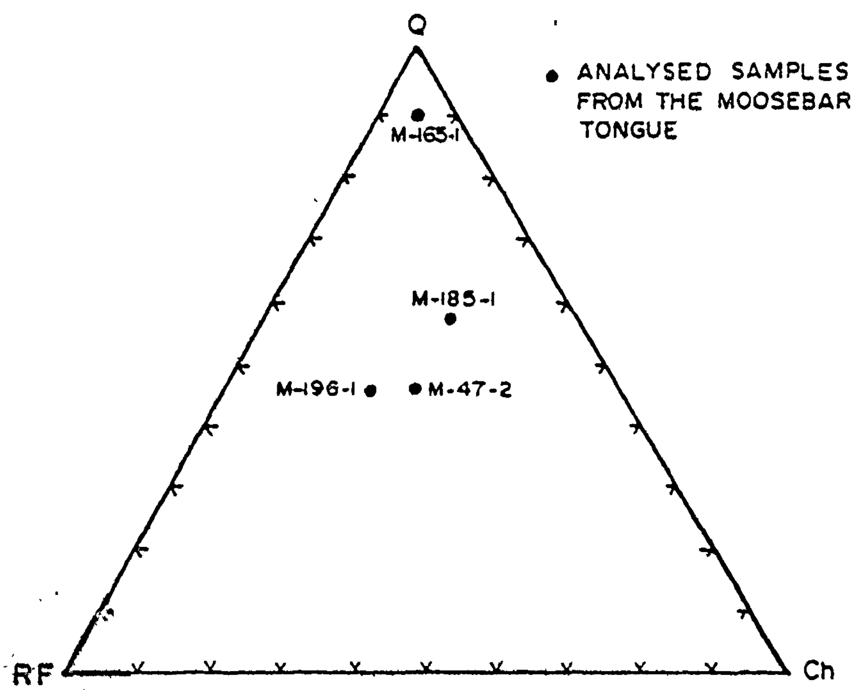
Moosebar Tongue. The main detrital mineral constituents of sandstones in the Moosebar Tongue are quartz, chert, and non-volcanic rock fragments. The proportion of each of these constituents varies from sample to sample (see Table A.1; Figure A.1).

Sample M-165-1 is a quartz arenite containing less than five percent rock fragments and very little matrix. Grains in this sample are sub-rounded to rounded and the sandstone is very well sorted. The grain size distribution is unimodal and the mean grain diameter is 0.11 mm. Observed grain contacts include concavo-convex, long, and rare sutured grains. The sandstone is well cemented by calcite. Rare glauconite grains were observed throughout the sample.

Sample M-185-1 contains less quartz than M-165-1 but has a higher percentage of chert and non-volcanic rock fragments. Grains are sub-angular to sub-rounded and the sandstone is moderately to well sorted. The grain size distribution is unimodal and the mean grain diameter is 0.2 mm. Grain contacts are concavo-convex and sutured, and the sandstone is well cemented by silica.

Sample M-196-1 contains less quartz and chert grains than M-185-1 but has a higher percentage of non-volcanic rock fragments. It also contains abundant detrital carbonate grains which are lacking in other

Figure A.1. Relative proportions of detrital mineral constituents in the Moosebar Tongue. Q=Quartz, Ch=Chert, RF= Non-volcanic rock fragments.


Q
ANALYSED SAMPLES FROM THE MOOSEBAR TONGUE
M-165-1
M-185-1
M-196-1
M-47-2
RF
Ch

samples from the Moosebar Tongue. Rare glauconite grains were observed throughout the sample. Grains are sub-rounded and the sandstone is moderately to well sorted. Concavo-convex and long grain contacts were observed within this sample and it is cemented by calcite.

Sample M-47-2 differs from other sandstone samples of the Moosebar Tongue. In addition to detrital grains of quartz, chert, and non-volcanic rock fragments, M-47-2 also contains detrital grains of volcanic rock fragments. All grains in this sample are sub-angular, and the sandstone is poorly sorted and contains about 20% fine-grained matrix. Sample M-47-2 is cemented by authigenic clay minerals.

Sandstones of the Moosebar Tongue contain similar detrital mineral constituents as those of the underlying Gladstone Formation, with the exception of some volcanic rock fragments present in M-47-2.

Beaver Mines Formation. The main detrital constituents of sandstones in the Beaver Mines Formation are quartz, chert, volcanic and non-volcanic rock fragments, and plagioclase. Grains are angular to sub-angular and the sandstones are moderately to well sorted. The grain size distributions of all samples are unimodal and the mean grain diameter is 0.34 mm (range 0.25-0.5 mm).

Fine-grained matrix is present in all samples, averaging 7.5% (range 5-10%), and many detrital grains float in this matrix. When grains are touching, concavo-convex and long grain contacts are most common. All samples are cemented by authigenic clay minerals.

One sample (BM-76-5) was x-rayed to determine the composition of the matrix and cement. The peaks obtained were found to be typical of chlorite (D.L. Thompson, pers. comm., 1981).

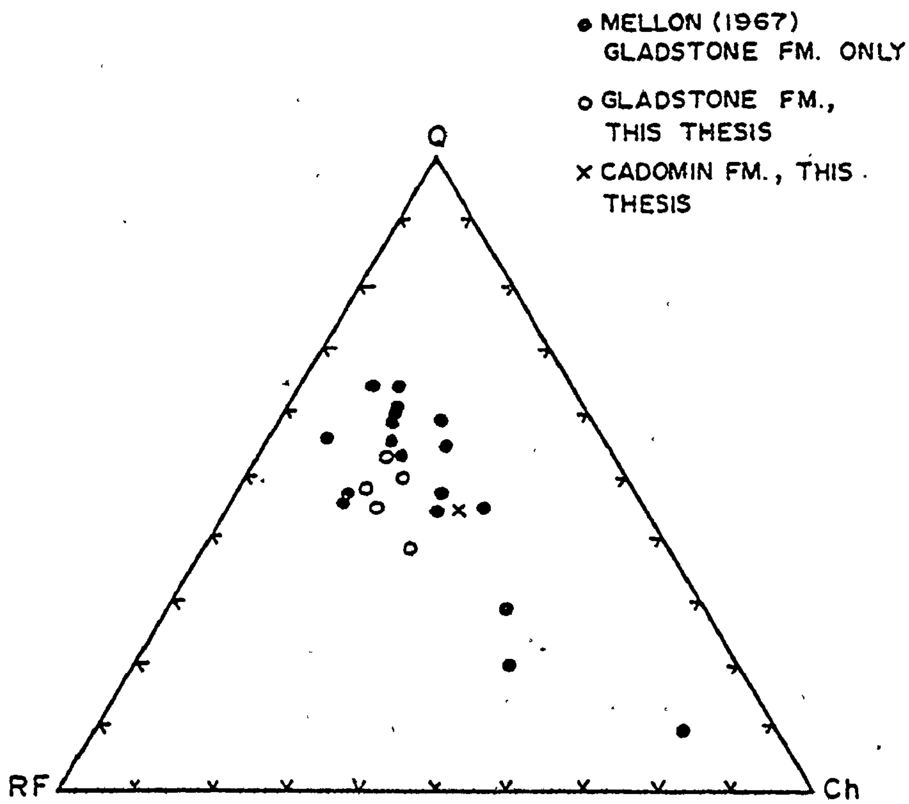
The occurrence of plagioclase feldspar and abundant volcanic rock fragments, plus the presence of chlorite cement and matrix distinguishes sandstones of the Beaver Mines Formation from other sandstones of the Blairmore Group.

Comparison

Detailed petrographic analyses of the Blairmore Group have previously been published by Mellon (1967). Mellon (1967, p. 135) noted that the rocks of the Gladstone Formation "are dominantly siliceous rocks composed of quartz, chert, and finely crystalline sedimentary rock fragments, with variable amounts of transported and authigenic carbonates. Quartz (as overgrowths) and kaolinite are the only common authigenic constituents in addition to calcite and dolomite." The average composition of rocks from the Gladstone Formation as determined by Mellon (1967) is given in Table A.1. On Figure A.2 Mellon's (1967) data were plotted for comparative purposes. Data obtained in this thesis plot on Figure A.2 within the range of Mellon's (1967) data.

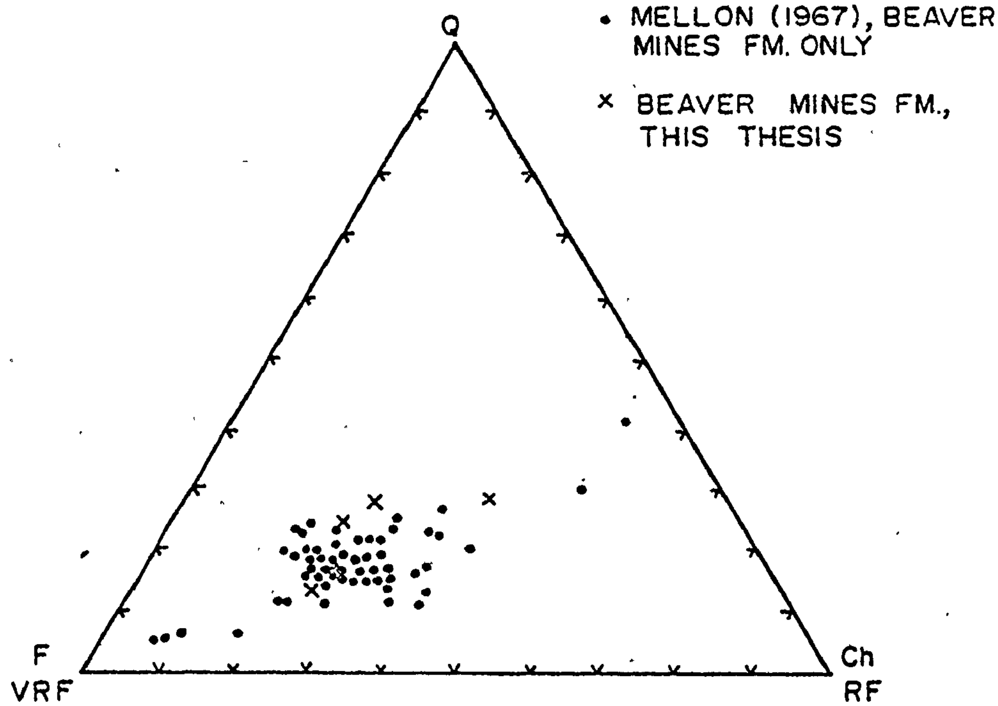
Rocks of the Beaver Mines Formation were described by Mellon (1967, p. 141) as "consisting of angular quartz, feldspars (largely plagioclase), and finely crystalline metasedimentary and volcanic rock fragments, with minor amounts of chert and accessory "heavy" minerals ...." Mellon (1967) also noted the presence of abundant chloritic matrix and authigenic cement in the sandstones of the Beaver Mines Formation. The relative proportions of the main detrital constituents as determined by Mellon (1967) were plotted on Figure A.3 for comparative purposes. Data obtained in this thesis plot within the range of Mellon's (1967) data.

Figure A.2. Relative proportions of detrital mineral constituents in the Gladstone Formation. Q=Quartz, Ch=Chert, RF=Non-volcanic rock fragments.



• MELLON (1967) GLADSTONE FM. ONLY
o GLADSTONE FM., THIS THESIS
x CADOMIN FM., THIS THESIS
Q
RF
Ch

Figure A.3. Relative proportions of detrital mineral constituents in the Beaver Mines Formation. Q=Quartz, Ch=Chert, RF=Non-volcanic rock fragments, F=Feldspar, VRF=Volcanic rock fragments.


• MELLON (1967), BEAVER MINES FM. ONLY
× BEAVER MINES FM., THIS THESIS
Q
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APPENDIX 3

Special Methods Utilized in this Thesis

Treatment of Paleocurrent Data. At all sections measured for this thesis, strata are tectonically deformed (see Chapter 2.2). Deformation involves folding around nearly horizontal axes, therefore, sedimentary structures measured to obtain paleoflow directions were rotated around regional strike to restore them to their original position at the time of deposition (Potter and Pettijohn, 1963, p. 259). Linear features (i.e. prod marks, scratches, ripple crests, etc.) were restored while in the field by measuring the rake (the angle between the linear feature and horizontal within the plane of the beds) and adding it to, or subtracting it from, the strike of the beds. Planar features (i.e. trough foresets, scour walls, a-b planes of pebbles, etc.) were restored using a stereonet after field work was completed.

Summary statistics for each group of data measured at a particular stratigraphic level were calculated using the computer program of Martini (1965), based on the methodology of Curray (1956). Summary statistics calculated include: 1) vector mean - a measure of the central tendency of the distribution ; 2) vector length -

the magnitude of the resultant vector in percent; 3) standard deviation; 4) chi-squared test of statistical significance. To determine if the vector mean calculated for a group of data was a true representation of paleoflow direction, rose diagrams were drawn. These are found throughout Chapter 3 and observed distributions are discussed along with sedimentological interpretations.

Picking of Microfossils. In this thesis, microfossils were used to aid in the interpretation of depositional environments within the Blairmore Group. Microfossils were picked from shale samples collected in the field and were later identified by R.J. Price (Amoco Canada). The steps involved in the picking of microfossils are outlined below (J. Terasmae, pers. comm., 1981).

1) Add 10 ml of "Quaternary 0" to 1.0 l of boiling water and allow it to dissolve.

2) Break shale samples into pieces roughly one inch in diameter and place them in the boiling water. The shale samples should be boiled for 6-9 hours until the "Quaternary 0" appears exhausted. (Note: caution should be used when breaking shale samples as microfossils are easily damaged.)

3) Allow solution to cool to room temperature so that residue and "Quaternary 0" will settle to the bottom of the container.

4) Place a 60 mesh sieve in a large tub and add enough water so that the sieve is half submerged.

5) Gently wash the residue from the container into the sieve and agitate the sieve.

6) Remove the sieve and repeat steps 4 and 5 until all the suds have disappeared.

7) Carefully wash the residue from the sieve into a petrie dish. Water should be directed through the sieve from underneath.

8) Pour off excess water from the petrie dish being careful not to lose any residue. Leave enough water in the residue to form a "slush".

9) Place the dish under a binocular microscope and remove microfossils with a camel-hair brush. Place microfossils on a pre-glued microfossil slide.

APPENDIX 4

Detailed Location Maps and Accessibility of Measured Sections

Section 1 (Tp. 39, Rg. 17, W of 5th meridian). Section 1 is located on the Bighorn River at Crescent Falls approximately 16 km west of Nordegg (Figure A.4). The section can be reached by regular automobile by following a dirt road that leads westward from Hwy. 11 to Crescent Falls. The section is best examined on the north side of the river.

Section 2 (Tp. 39, Rg. 17, W of 5th meridian). Section 2 is located on the Bighorn River 2.5 km west of Crescent Falls (Figure A.4). It can be reached by 4-wheel drive vehicle or by a short hike; however, the river must be crossed at a ford approximately 1 km upstream from Crescent Falls. This should only be attempted during low river stage. A pair of hip waders is recommended for examination of the section.

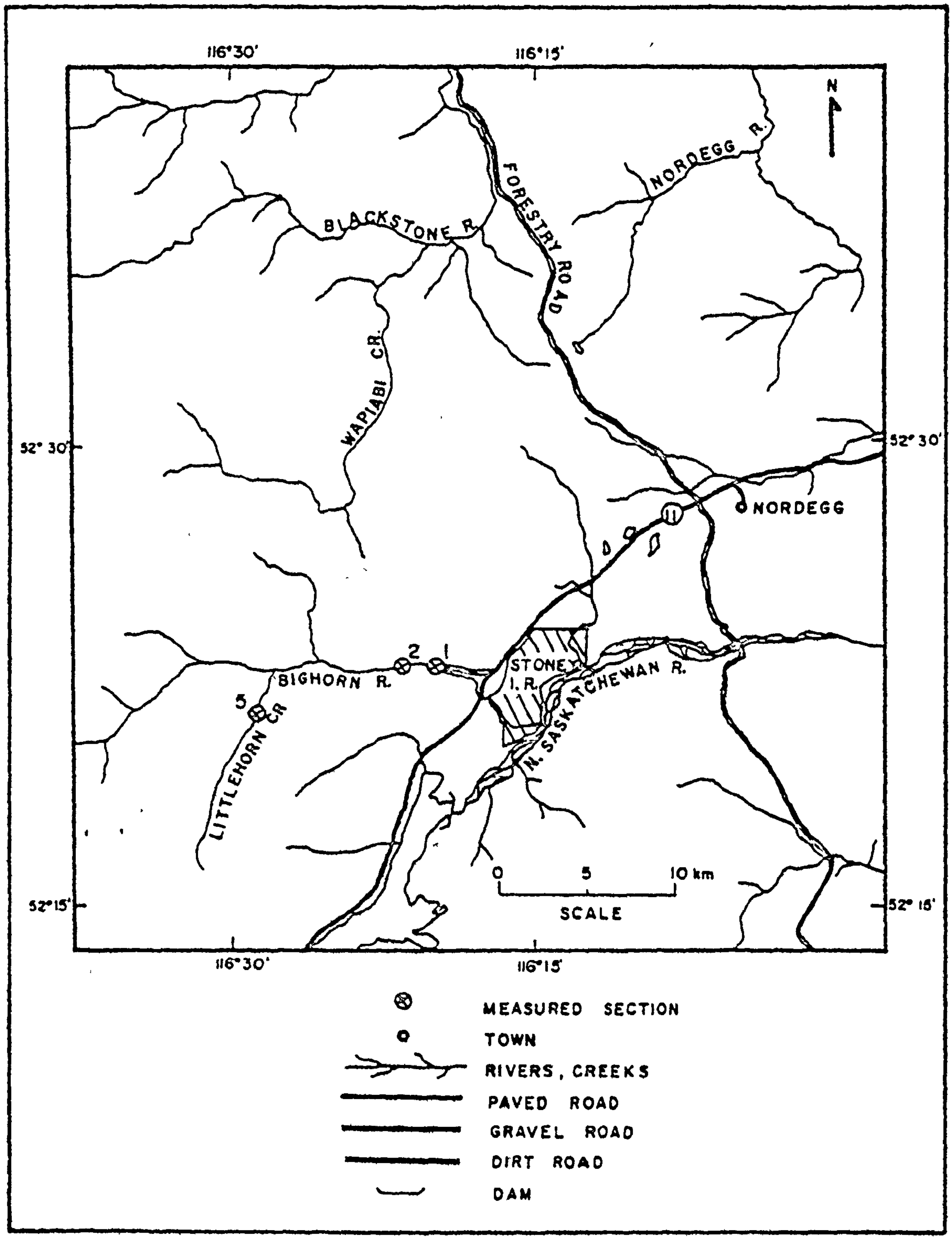
Section 3 (Tp. 47, Rg. 23, W of 5th meridian). Section 3 is located on the McLeod River at Cadomin (Figure A.5) and is accessible by regular automobile. It is exposed in a railroad cut on the east side of the river. It can be reached by crossing the bridge to a quarry located just south of the townsite.

Section 4 (Tp. 22, Rg. 6, W of 5th meridian). Section 4 is located on the Elbow River approximately 15 km southwest of Bragg Creek on Hwy. 768 (Figure A.6) and is accessible by regular automobile. Most of the section can be examined on the northwest side of the river, however, a pair of hip waders allows complete inspection. The section is best examined at low river stage.

Section 5 (Tp. 39, Rg. 18, W of 5th meridian). Section 5 is located on Littlehorn Creek (Figure A.4) and is accessible by helicopter, horseback, or a two day hike. The section is well exposed on both sides of the creek and hipwaders are recommended for complete inspection.

Section 6 (Tp. 30, Rg. 9, W of 5th meridian). Section 6 is located on Burnt Timber Creek approximately 100 km northwest of Calgary on the Forestry Road (Hwy. 940; Figure A.7). The section is about 1.5 km east of the road and can be reached with a short hike. It is exposed on both sides of the creek and hipwaders are recommended for complete inspection.

Figure A.4. Location map for Sections 1,2 and 5.



116°30'
116°15'
N
NORDEGG R.
FORESTRY ROAD
BLACKSTONE R.
WAPIABI CR.
52° 30'
NORDEGG
11
STONEY I.R.
N. SASKATCHEWAN R.
BIGHORN R.
LITTLEHORN CR.
1
2
5
0
5
10 km
SCALE
52°15'
MEASURED SECTION
TOWN
RIVERS, CREEKS
PAVED ROAD
GRAVEL ROAD
DIRT ROAD
DAM

Figure A.5. Location map for Section 3.

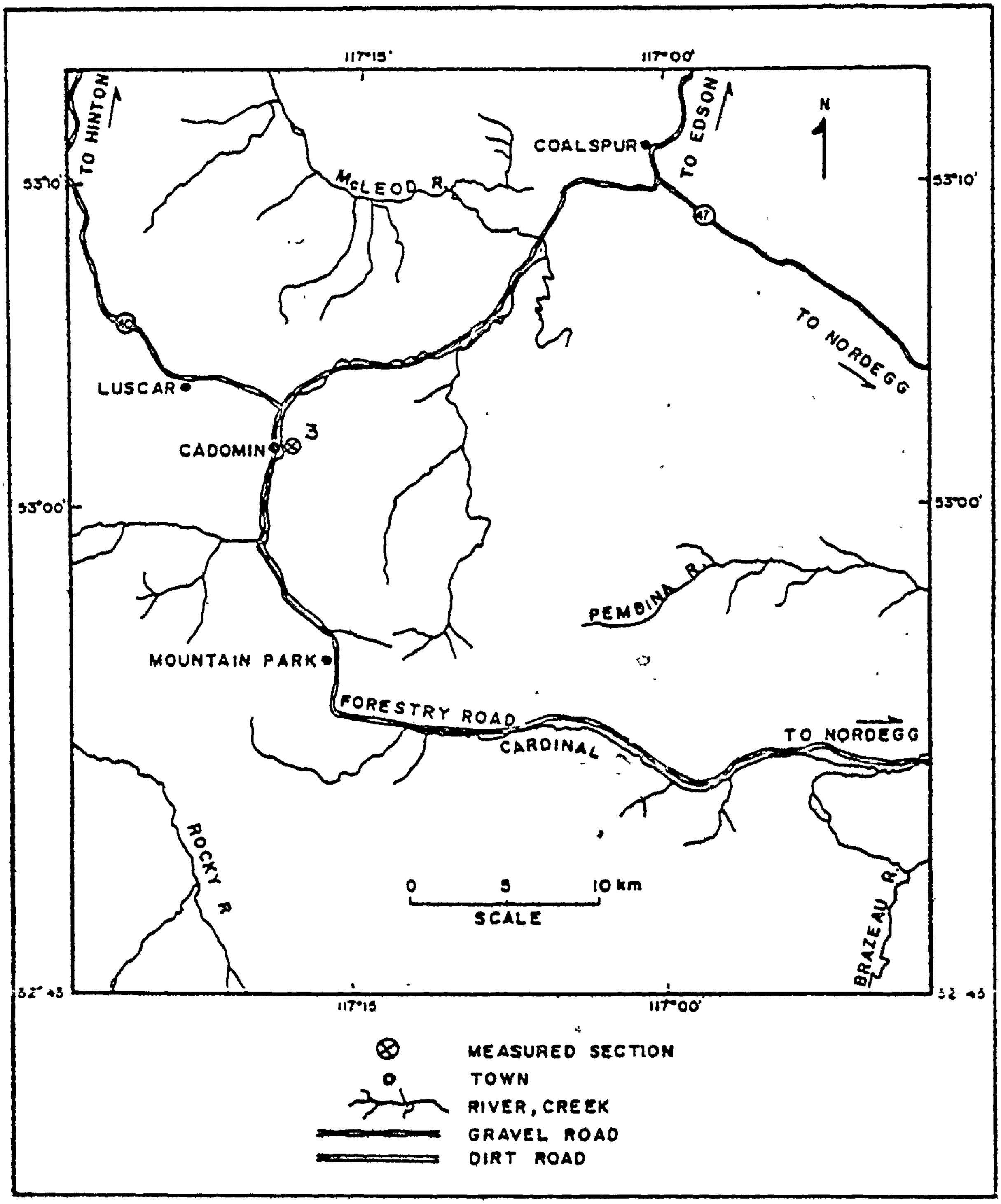
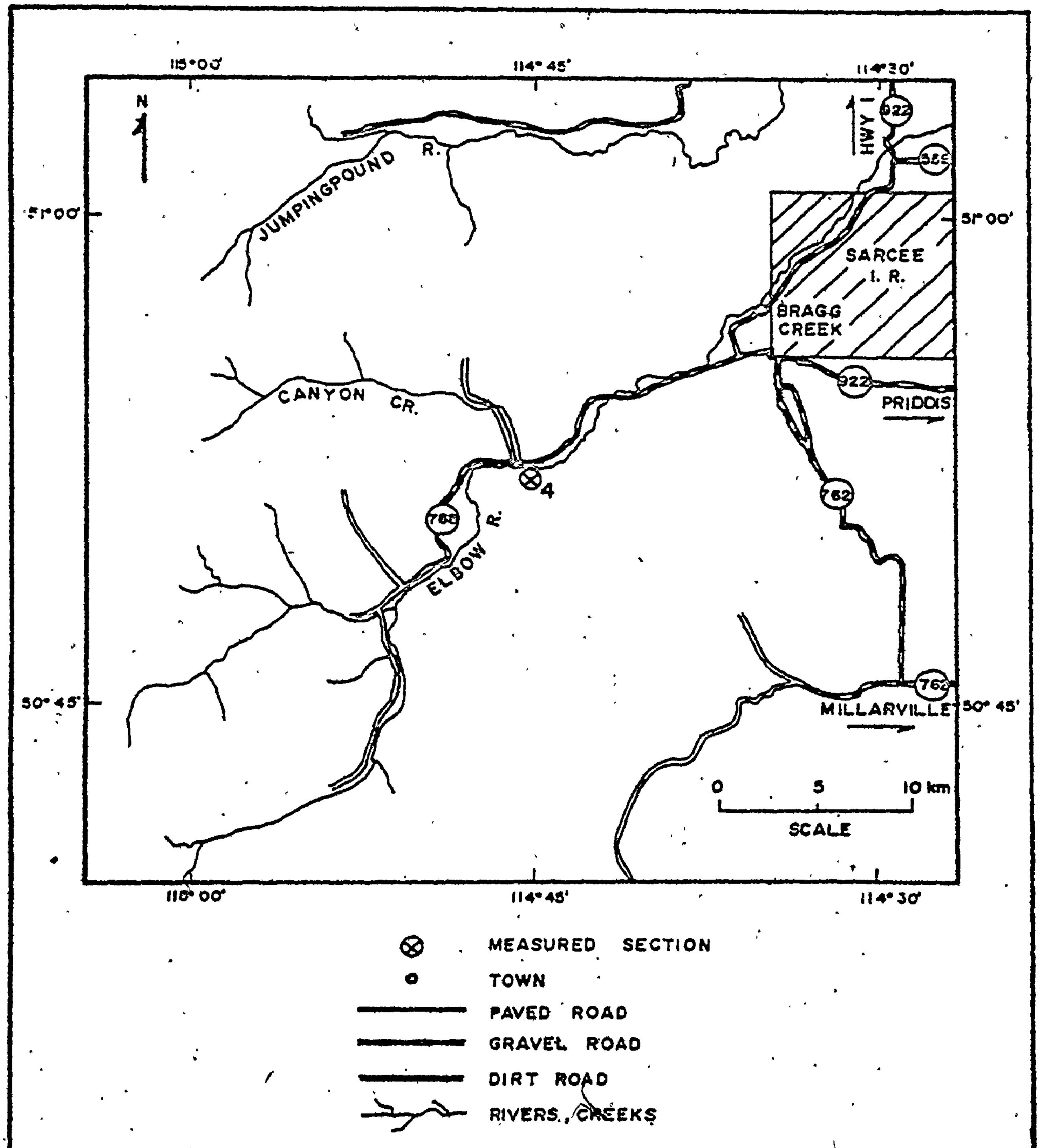
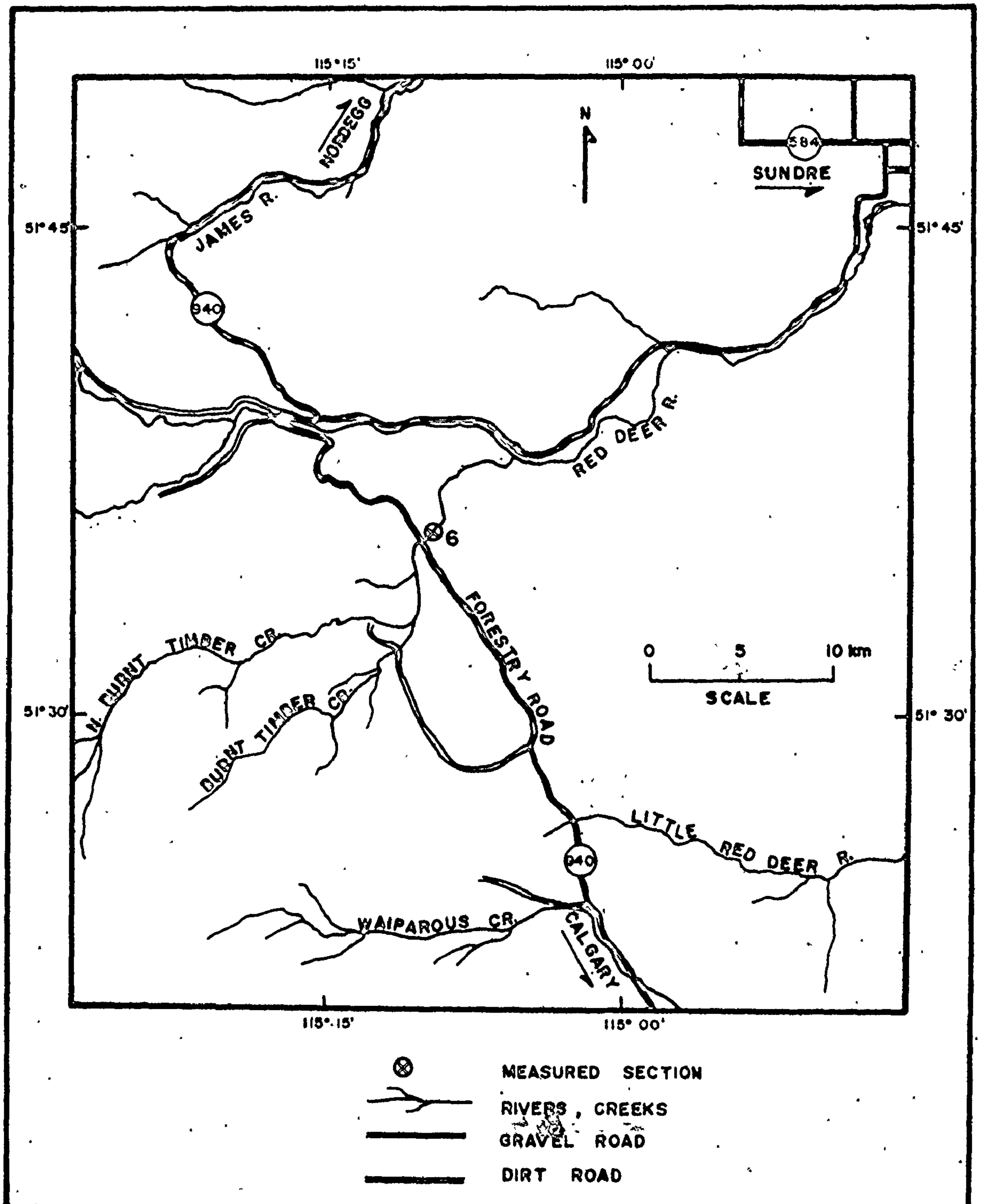

117°15'
117°00'
53°10'
53°00'
52°45
TO HINTON
TO EDSON
COALSPUR
McLEOD R.
47
40
TO NORDEGG
LUSCAR
CADOMIN
3
PEMBINA R.
MOUNTAIN PARK
FORESTRY ROAD
CARDINAL
TO NORDEGG
ROCKY R.
BRAZEAU R.
0 5 10 km
SCALE
MEASURED SECTION
TOWN
RIVER, CREEK
GRAVEL ROAD
DIRT ROAD

Figure A.6. Location map for Section 4.



115°00'
114°45'
114°30'
51°00'
50°45'
N
JUMPINGPOUND R.
HWY 1
922
SARCEE I. R.
BRAGG CREEK
CANYON CR.
922
PRIDDIS
4
ELBOW R.
762
762
MILLARVILLE
0
5
10 km
SCALE
MEASURED SECTION
TOWN
PAVED ROAD
GRAVEL ROAD
DIRT ROAD
RIVERS, CREEKS

Figure A.7. Location map for Section 6.


115°15'
115°00'
N
NORDEGG
584
SUNDRE
JAMES R.
51°45'
940
RED DEER R.
6
FORESTRY ROAD
0 5 10 km
SCALE
N. BURNT TIMBER CR.
BURNT TIMBER CR.
51°30'
LITTLE RED DEER R.
WAIPAROUS CR.
CALGARY
MEASURED SECTION
RIVERS, CREEKS
GRAVEL ROAD
DIRT ROAD

APPENDIX 5

Raw Paleocurrent Data

Data are arranged as follows: 1) by section, 2) by unit, 3) by stratigraphic level, and 4) by sedimentary structure. Summary statistics for each group of data are then presented in terms of: vector mean (θ, degrees), vector length (L, percent), standard deviation (SD, degrees), statistical significance (Pr, percent). Raw data follow the summary statistics of each group.

Section 1 (Bighorn River at Crescent Falls)

Unit 1

0.0 m channel wall strike:

321

scour wall strikes:

θ 328, L 99, SD 5, Pr > 99.5

325, 305, 315, 320, 335, 335

2.5 m lateral accretion surface strikes:

θ 307, L 95, SD 18, Pr > 99.5

328, 277, 328, 310, 310, 288

lineation, base of lateral accretion surface

322

10.0 m channel wall strike:

328

lateral accretion surface strikes:

θ 339, L 96, SD 16, Pr > 99.5

333, 331, 320, 015, 342, 339

Unit 2

25.0 m scour wall strike:

285

29.0 m **scour wall strikes:**

θ 295, L 79, SD 38, Pr > 75.0

300, 275, 340, 280, 244

ripple cross-laminations:

θ 255, L 94, SD 22, Pr >99.5

265, 235, 245 280, 260, 230, 300, 255, 280,

245, 225, 250, 255.

32.0 m scour wall strikes:

θ 341, L 69, SD 49, Pr >75.0

035, 345, 280

sole mark (scratch):

355

35.0 m scour wall strikes:

θ 092, L 72, SD 47, Pr > 97.5

095, 107, 062, 130, 040, 110, 029, 177

37.5 m planar cross-beds:

θ 132, L 60, SD 59, Pr > 90.0

148, 116

scour wall strikes:

θ 290, L 99, SD 5, Pr > 75.0

185, 195

41.5 m ripple cross-laminations:

θ 224, L 93, SD 23, Pr > 99.5

210, 220, 200, 225, 205, 250, 190, 260, 210,

250, 225

48.0 m scour wall strike:

010

37.5 m planar cross-beds:

θ 132, L 60, SD 59, Pr $>$ 90.0

148, 116

scour wall strikes:

θ 290, L 99, SD 5, Pr $>$ 75.0

185, 195

41.5 m ripple cross-laminations:

θ 224, L 93, SD 23, Pr $>$ 99.5

210, 220, 200, 225, 205, 250, 250, 190, 260,

210, 250, 225

48.0 m scour wall strike:

010

Unit 3

48.5 m channel wall strike:

326

55.0 m lateral accretion surface strike:

θ 336, L 77, SD 43, Pr $>$ 99.5

013, 325, 010, 308, 325, 267, 015, 340, 296,

325, 310, 348, 278

sole mark:

360

62.0 m <u>ripple cross-lamination</u>:

295

63.5 m <u>ripple cross-laminations</u>:

θ 072, L 98, SD 11, Pr > 97.5

080, 050, 060, 090, 080

<u>Unit 4</u>

67.5 m <u>lateral accretion surface strikes</u>:

θ 323, L 71, SD 47, Pr > 90.0

312, 325, 296, 335, 264, 298

71.0 m <u>scour wall strikes</u>:

θ 323, L 76, SD 44, Pr > 99.0

308, 352, 338, 282, 301, 250, 300, 320

77.5 m <u>scour wall strike</u>:

273

78.5 m <u>scour wall strike</u>:

310

79.0 m <u>scour wall strike</u>:

278

80.0 m <u>scour wall strikes</u>:

θ 307, L 98, SD 11, Pr > 75.0

320, 295

87.5 m <u>scour wall strike</u>:

340

88.2 m scour wall strike:

330

91.0 m scour wall strikes:

θ 305, L 91, SD 25, Pr > 95.0

285, 341, 315, 282

lateral accretion surface strikes:

θ 339, L 98, SD 11, Pr > 75.0

350, 328

95.0 m ripple cross-laminations:

θ 148, L 91, SD 25, Pr > 99.5

150, 145, 135, 130, 085, 155, 150, 110, 135,

175, 170, 170, 180, 165

Unit 5

124.0 m symmetrical ripple crest strikes:

θ 236, L 89, SD 27, Pr > 90.0

260, 240, 250, 190

124.2 m symmetrical ripple crest strike:

235

142.9 m symmetrical ripple crest strikes:

θ 235, L 89, SD 27, Pr > 95.0

225, 220, 250, 245

145.0 m symmetrical ripple crest strike:

255

147.0 m channel wall strikes:

θ 026, L 73, SD 46, Pr > 75.0

041, 309, 064, 012, 357, 084

147.5 m gutter cast axes:

θ 319, L 91, SD 25, Pr > 99.5

315, 330, 330, 310, 335, 295, 305, 010, 283

Unit 6

155.5 m scour wall strikes:

θ 327, L 82, SD 36, Pr > 99.5

274, 057, 340, 305, 310, 330 315, 345

161.1 m symmetrical ripple crest strike:

090

162.0 m scour wall strikes:

θ 344, L 75, SD 45, Pr > 97.5

047, 299, 323, 057, 322, 327

168.0 m symmetrical ripple crest strikes:

θ 229, L 92, SD 24, Pr > 95.0

205, 100, 235, 255, 250

Unit 8

182.0 m sole marks (scratches):

θ 096, L 74, SD 45, Pr > 75.0

045, 100, 085, 165

186.5 m <u>symmetrical ripple crest strikes</u>:

θ 255, L 99, SD 5, Pr > 75.0

260, 250

189.0 m <u>pebble orientations (direction of dip, a-b plane)</u>:

θ 047, L 40, SD 75, Pr > 99.5

016, 169, 039, 061, 053, 033, 028, 077, 333,
028, 338, 256, 057, 057, 044, 059, 324, 320,
047, 001, 109, 032, 052, 330, 001, 027, 094,
047, 016, 003, 106, 350, 062, 077, 162, 010,
039, 340, 293, 025, 318, 275, 360, 019, 030,
325, 288, 018, 014, 075, 166, 151, 026, 158,
128, 151, 092, 129, 160, 175, 020, 164, 087,
074, 005, 023, 305, 310, 270, 252, 023, 090,
095, 011, 272, 187, 004, 044, 122, 220, 088,
040, 046, 036, 025, 006, 037, 220, 211, 114,
121, 090, 017, 354, 017, 114, 101, 107, 030,
057, 145, 171, 190, 190, 150, 232, 030, 171,
025, 066, 051

Section 2 (Bighorn River West of Crescent Falls)

Unit 9

14.5 m symmetrical ripple crest strike:

210

Unit 10

16.2 m scour wall strike:

008

22.5 m symmetrical ripple crest strike:

257

26.0 m pebble orientations (direction of dip, a-b planes):

θ 173, L 12, SD 95, Pr $<$ 75.0

242, 306, 159, 338, 310, 200, 182, 189, 302,
310, 032, 130, 067, 310, 115, 142, 201, 107,
010, 015, 168, 236, 234, 355, 156, 208, 270,
221, 223, 103, 240, 204, 285, 139, 185, 163,
289, 316, 309, 293, 026, 048, 021, 281, 178,
176, 165, 256, 255, 244, 131, 191, 176, 096,
151, 189, 056, 254, 246, 130, 152, 280, 234,
168, 090, 148, 331, 176, 104, 010, 136, 074,

231, 112, 147, 283, 091, 045, 079, 350, 175,
353, 249, 012, 056, 079, 109, 333, 064, 236,
017, 106, 213, 100, 115, 311, 084, 330, 040,
111, 321

Unit 12

44.0 m channel wall strike:
310

45.0 m channel wall strikes:
θ 315, L 87, SD 31, Pr > 75.0
285, 345

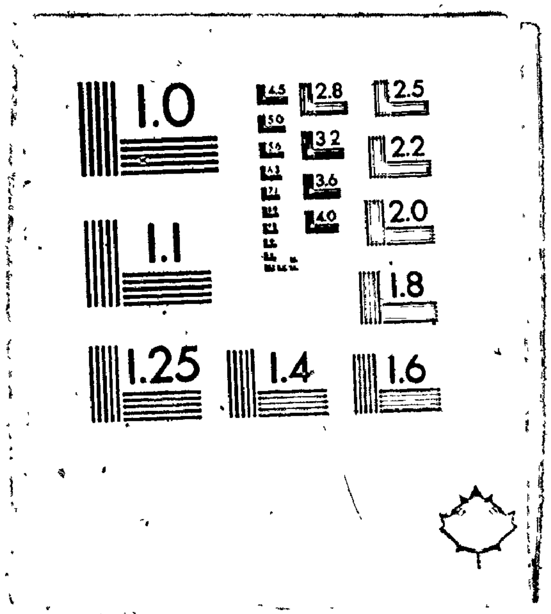
58.0 m ripple cross-laminations:
θ 030, L 92, SD 24, Pr > 99.5
055, 045, 015, 015, 010, 075, 012, 020

Unit 13

67.0 m channel wall strike:
061

ripple cross-laminations:
θ 037, L 99, SD 5, Pr > 99.5
045, 025, 040, 025, 045, 032, 036, 030, 043,
030, 032, 028, 035, 042, 056, 050

4 OF/DE 4



Section 3: (Cadomin Railroad Cut)

Unit 14

1.0 m <u>channel wall strikes:</u>

θ 168, L 83, SD 36, Pr > 99.5

179, 212, 140, 124, 198, 154, 126, 212

<u>linear sole mark:</u>

320

2.5 m <u>scour wall strikes:</u>

θ 035, L 91, SD 25, Pr < 75.0

200, 114

4.0 m <u>channel wall strikes:</u>

θ 189, L 65, SD 52, Pr > 95.0

128, 252, 212, 120, 180, 233

11.0 m <u>scour wall strikes:</u>

θ 076, L 72, SD 47, Pr < 75.0

032, 120

12.3 m <u>scour wall strikes:</u>

θ 278, L 99, SD 5, Pr > 75.0

270, 285

14.2 m <u>channel wall strike:</u>

071

19.0 m <u>scour wall strikes</u>:

θ 062, L 77, SD 43, Pr > 95.0

097, 101, 081, 003, 023

21.4 m <u>channel wall strikes</u>:

θ 092, L 79, SD 38, Pr > 97.5

071, 136, 027, 143, 066, 064, 122, 104

25.0 m <u>scour wall strikes</u>:

θ 204, L 91, SD 25, Pr > 97.5

166, 201, 232, 192, 229

28.0 m <u>scour wall strikes</u>:

θ 136, L 87, SD 31, Pr > 99.5

104, 164, 134, 084, 151, 177, 134, 158, 101

30.0 m <u>scour wall strikes</u>:

θ 106, L 87, SD 31, Pr > 75.0

070, 107, 142

32.0 m <u>scour wall strikes</u>:

θ 169, L 91, SD 25, Pr > 97.5

151, 181, 203, 177, 134

33.5 m <u>scour wall strikes</u>:

θ 074, L 98, SD 11, Pr >75.0

063, 085

38.0 m <u>scour wall strikes</u>:

θ 042, L 79, SD 38, Pr > 95.0

006, 021, 021, 122, 071, 033

47.0 m <u>scour wall strikes</u>:

θ 041, L 97, SD 15, Pr > 75.0

026, 041

49.2 m <u>channel wall strikes</u>:

θ 287, L 98, SD 11, Pr > 90.0

279, 281, 302

<u>ripple cross-lamination</u>:

259

55.0 m <u>channel wall strikes</u>:

θ 080, L 87, SD 31, Pr > 90.0

115, 041, 082

64.0 m <u>scour wall strikes</u>:

θ 023, L 80, SD 37, Pr > 99.0

007, 010, 004, 336, 075, 075

66.3 m <u>channel wall strikes</u>:

θ 060, L 94, SD 22, Pr > 99.0

019, 076, 067, 065, 071

<u>Unit 15</u>

75.0 m <u>scour wall strikes</u>:

θ 062, L 89, SD 27, Pr > 90.0

037, 032, 083, 095

80.7 m **scour wall strikes:**

θ 090, L 96, SD 16, Pr > 75.0

074, 105

82.5 m **scour wall strikes:**

θ 090, L 99, SD 5, Pr >95.0

093, 092, 086, 079

84.5 m **scour wall strikes:**

θ 056, L 93, SD 23, Pr > 90.0

072, 081, 036, 034

86.0 m **scour wall strikes:**

θ 222, L 93, SD 23, Pr > 75.0

068, 069, 179, 150, 093

88.5 m **scour wall strike:**

144

Section 4: (Elbow River)

Unit 18

1.0 m pebble orientations (direction of dip, a-b plane):

θ 205, L 40, SD 75, Pr > 99.5

239, 165, 063, 249, 242, 128, 222, 083, 154,

087, 190, 160, 177, 254, 101, 278, 155, 207,

241, 232, 212, 204, 077, 159, 230, 292, 314,
075, 253, 260, 163, 266, 270, 257, 265, 208,
122, 262, 211, 194, 214, 175, 234, 253, 253,
274, 116, 306, 348, 160, 143, 175, 108, 085,
162, 339, 258, 182, 050, 296, 087, 181, 240,
254, 074, 300, 245, 254, 345, 239, 126, 245,
159, 124, 172, 347, 065, 201, 183, 268, 168,
260, 121, 279, 141, 163, 209, 265, 184, 110,
273, 054, 195, 268, 066, 193, 190, 189

4.0 m pebble orientations (direction of dip, a-b plane):

θ 137, L 6, SD 100, Pr $<$ 75.0

163, 239, 226, 048, 205, 317, 228, 240, 182,
296, 168, 229, 222, 167, 035, 354, 299, 225,
051, 234, 085, 097, 203, 247, 043, 092, 052,
053, 088, 261, 119, 099, 079, 095, 222, 210,
267, 228, 238, 233, 273, 353, 238, 245, 201,
209, 279, 209, 224, 083, 083, 161, 086, 023,
337, 073, 052, 221, 001, 352, 349, 091, 004,
007, 196, 179, 171, 026, 010, 116, 071, 034,
321, 179, 163, 174, 352, 049, 207, 092, 055,
350, 061, 088, 049, 076, 343, 065, 064, 085,
085, 356, 166, 273, 229, 221, 269, 335, 054,
189

16.0 m trough foreset dip directions:

θ 310, L 93, SD 23, Pr > 99.5

277, 286, 303, 304, 307, 309, 315, 336, 356

Unit 19

22.0 m scour wall strikes:

θ 341, L 98, SD 11, Pr > 97.5

345, 350, 320, 350

28.0 m ripple cross-lamination:

240

36.0 m scour wall strike:

300

56.5 m channel wall strikes:

θ 015, L 74, SD 47, Pr > 90.0

055, 058, 331, 334

61.6 m channel wall strike:

013

62.0 m lateral accretion surface strikes:

θ 322, L 92, SD 24, Pr > 99.0

289, 352, 302, 339, 308, 345

Unit 20

69.0 m symmetrical ripple crest strike:

285

77.5 m scour wall strikes:

θ 009, L 97, SD 15, Pr > 90.0

030, 002, 355

82.0 m scour wall strike:

319

89.0 m sole mark (scratch):

350

98.5 m sole mark (scratch):

327

100.0 m oriented plant fragments:

310

Unit 21

122.5 m scour wall strike:

360

147.8 m trough foreset dip direction:

-151.0 m θ 087, L 89, SD 27, Pr > 99.5

023, 030, 030, 030, 030, 034, 044, 044, 044,

050, 050, 059, 059, 059, 064, 064, 066, 074,

078, 078, 079, 083, 083, 083, 086, 086, 086, 086, 086, 089, 089, 090, 090, 090, 092, 092, 092, 094, 094, 092, 092, 096, 096, 099, 102, 102, 104, 104, 104, 106, 110, 110, 110, 112, 112, 114, 116, 116, 116, 118, 118, 120, 120, 120, 122, 122, 125, 127

Section 5: (Littlehorn Creek)

Unit 22

0.0 m - 3.0 m trough foreset dip directions:

θ 358, L 73, SD 46, Pr > 99.5

240, 254, 255, 262, 269, 277, 277, 277, 292, 297, 297, 307, 314, 320, 320, 320, 323, 323, 326, 329, 332, 332, 332, 337, 337, 343, 343, 344, 346, 348, 350, 350, 354, 354, 354, 354, 359, 007, 007, 007, 007, 007, 007, 007, 008, 011, 014, 014, 014, 014, 017, 017, 017, 019, 024, 024, 027, 027, 027, 031, 032, 043, 043, 043, 043, 043, 043, 053, 055, 059, 062, 062, 072, 076, 081

3.0 m - 6.5 m trough foreset dip directions:

θ 022, L6, SD 100, Pr < 75.0

010, 010, 017, 052, 052, 065, 180, 190, 205, 210, 237, 294

16.0 m <u>ripple cross-laminations</u>:

θ 355, L 72, SD 47, Pr > 99.5

003, 355, 338, 331, 250, 358, 276, 345, 335, 014, 267, 358, 330, 315, 338, 325, 343, 308, 352, 298, 300, 270, 293, 238, 332, 010, 350, 021, 218, 005, 343, 338, 357, 017, 010, 027, 017, 008, 321, 220, 022, 310, 223, 023, 240, 240, 018, 357

Unit 23

29.5 m <u>ripple cross-laminations</u>:

θ 033, L 98, SD 11, Pr > 99.5

025, 040, 030, 040, 035, 020, 010, 050, 050, 035

30.3 m <u>ripple cross-laminations</u>:

θ 258, L 89, SD 27, Pr > 95.0

300, 265, 230, 240

52.0 m <u>ripple cross-lamination</u>:

331

54.0 m <u>ripple cross-lamination</u>:

012

<u>scour wall strike</u>:

336

59.0 m <u>ripple cross-laminations</u>:

θ 311, L 98, SD 11, Pr > 95.0

327, 296, 313, 310

<u>Unit 24</u>

64.3 m <u>channel wall strike</u>:

332

<u>pebble orientations (direction of dip, a-b plane)</u>:

θ 016, L 23, SD 89, Pr > 99.5

029, 039, 356, 021, 120, 341, 231, 116, 060,
267, 070, 052, 074, 106, 043, 148, 022, 064,
085, 293, 061, 251, 016, 002, 012, 015, 017,
020, 215, 360, 020, 018, 194, 103, 338, 032,
120, 350, 192, 115, 223, 316, 087, 074, 297,
158, 074, 038, 209, 068, 137, 253, 354, 286,
139, 230, 339, 352, 305, 012, 358, 230, 048,
206, 288, 318, 034, 271, 238, 356, 041, 004,
037, 062, 083, 226, 037, 220, 306, 177, 146,
230, 153, 207, 251, 231, 282, 356, 161, 183,
204, 281, 247, 073, 313, 283, 276, 046, 035,
028, 046, 033, 025, 025, 318, 079, 033, 348,
025, 213, 202, 208, 059, 349, 013, 313, 291,
028, 059, 025, 114, 247, 038, 283

67.0 m <u>trough axes orientations</u>:

θ 299, L 96, SD 16, Pr > 99.5

286, 295, 275, 300, 289, 310, 297, 280, 275, 300, 310, 335, 330, 277, 310, 298

75.0 m <u>trough foreset dip directions</u>:

-79.1 m θ 307, L 34, SD 79, Pr > 99.5

180, 182, 183, 226, 230, 230, 230, 247, 247, 248, 251, 253, 253, 253, 257, 257, 257, 261, 261, 266, 267, 267, 268, 269, 271, 272, 272, 285, 289, 289, 296, 298, 307, 307, 310, 001, 007, 018, 026, 026, 026, 028, 033, 035, 039, 039, 039, 040, 041, 041, 044, 044, 044, 052, 058, 058, 070, 070

87.0 m <u>ripple cross-laminations</u>:

θ 306, L 94, SD 22, Pr > 99.5

290, 325, 307, 325, 330, 270, 295, 304, 310, 275, 335

96.0 m <u>ripple cross-laminations</u>:

θ 308, L 89, SD 27, Pr > 75.0

335, 280

Unit 25

107.0 m <u>ripple cross-laminations</u>:

θ 020, L 97, SD 15, Pr > 99.5

350, 005, 025, 025, 021, 035, 350, 025, 025,
030, 010, 035, 040, 020, 022

110.0 m <u>ripple cross-laminations</u>:

θ 014, L 99, SD 5, Pr > 99.5

005, 006, 015, 015, 010, 033, 015

129.0 m <u>ripple cross-laminations</u>:

θ 014, L 98, SD 11, Pr > 99.5

360, 005, 010, 013, 020, 025, 015, 015, 010,
025, 358, 030, 030, 001, 355, 035

132.0 m <u>ripple cross-laminations</u>:

θ 324, L 93, SD 23, Pr > 99.5

330, 337, 015, 340, 333, 320, 320, 330, 290,
309, 298, 330, 305, 345, 345, 315, 298, 355,
345, 315, 298, 298

144.0 m <u>ripple cross-laminations</u>:

θ 005, L 96, SD 16, Pr > 99.0

020, 355, 030, 345, 015, 348

148.5 m <u>channel wall strike</u>:

300

151.0 m <u>ripple cross-laminations</u>:

θ 354, L 90, SD 26, Pr > 99.5

018, 015, 360, 030, 033, 333, 335, 330, 325, 328

160.0 m <u>ripple cross-laminations</u>:

θ 022, L 98, SD 11, Pr > 99.5

005, 040, 015, 015, 022, 017, 031, 020, 032, 034, 358, 030, 035, 035, 011, 026, 021, 023, 035, 027, 020, 025, 020, 027, 030, 008, 002

161.5 m <u>pebble orientations (direction of dip, a-b- plane)</u>:

θ 314, L 28, SD 83, Pr > 99.5

062, 030, 325, 344, 322, 323, 289, 006, 351, 051, 263, 006, 281, 328, 013, 008, 095, 327, 348, 330, 026, 341, 322, 342, 327, 341, 239, 344, 030, 070, 021, 057, 315, 054, 011, 044, 052, 051, 205, 281, 273, 354, 318, 318, 269, 276, 299, 354, 017, 209, 172, 348, 329, 322, 139, 287, 150, 191, 120, 021, 279, 170, 264, 201, 315, 227, 196, 236, 259, 218, 228, 207, 027, 125, 219, 156, 264, 150, 181, 359, 162, 270, 234, 144, 316, 141, 298, 084, 052, 298, 163, 163, 305, 304, 325, 272, 163, 229, 242

Unit 26

182.0 m asymmetrical ripple foreset dip directions:

θ 194, L 97, SD 15, Pr > 99.5

177, 188, 212, 212, 187, 187, 213, 179, 202, 197, 184

185.0 m asymmetrical ripple foreset dip directions:

θ 187, L 88, SD 29, Pr > 99.5

151, 188, 158, 199, 184, 255, 184, 155, 215, 188

193.0 m asymmetrical ripple foreset dip directions:

θ 183, L 98, SD 11, Pr > 99.5

184, 181, 172, 197, 193, 185, 159, 190, 189

Section 6: (Burnt Timber Creek)

Unit 27

1.0 m ripple cross-laminations:

θ 113, L 96, SD 16, Pr > 90.0

101, 104, 137

2.6 m ripple cross-laminations:

θ 095, L 88, SD 29, Pr > 99.5

140, 130, 110, 090, 115, 108, 070, 047, 115, 063, 065, 110, 070

4.5 m <u>ripple cross-laminations</u>:

θ 049, L 96, SD 16, Pr > 99.0

040, 040, 050, 080, 040

7.0 m <u>ripple cross-lamination</u>:

090

15.0 m <u>ripple cross-laminations</u>:

θ 049, L99, SD 5, Pr > 99.5

050, 055, 057, 044, 040, 056, 040, 055, 044, 045

24.0 m <u>ripple cross-laminations</u>:

θ 324, L 84, SD 34, Pr > 99.5

298, 295, 283, 015, 355, 005, 318, 310

29.0 m <u>ripple cross-laminations</u>:

θ 019, L 92, SD 24, Pr > 75.0

345, 025, 040, 045, 360

33.5 m <u>ripple cross-laminations</u>:

θ 071, L 91, SD 25, Pr > 99.5

128, 070, 060, 065, 085, 045, 055

35.5 m <u>ripple cross-laminations</u>:

θ 060, L 100, SD 1, Pr > 75

062, 057

37.0 m <u>ripple cross-laminations</u>:

θ 170, L97, SD 15, Pr > 99.5

200, 173, 169, 170, 175, 146, 159, 170

38.0 m <u>ripple cross-laminations</u>:

θ 046, L 90, SD 26, Pr > 99.5

016, 023, 050, 030, 080, 053, 092, 025

40.5 m <u>trough foreset dip directions</u>:

θ 242, L 42, SD 76, Pr > 90.0

354, 351, 328, 317, 221, 214, 212, 212, 210, 194, 190, 179

50.5 m <u>trough foreset dip directions</u>:

θ 245, L 61, SD 59, Pr > 99.5

087, 123, 137, 155, 173, 210, 217, 231, 232, 234, 238, 239, 243, 243, 243, 243, 246, 249, 251, 254, 257, 260, 260, 266, 271, 286, 315, 325, 337

58.0 m <u>ripple cross-laminations</u>:

θ 237, L 99, SD 5, Pr > 97.5

245, 250, 230, 235, 225

59.0 m <u>ripple cross-laminations</u>:

θ 232, L 84, SD 35, Pr > 99.5

235, 225, 223, 245, 178, 180, 250 286, 264

83.0 m <u>ripple cross-laminations</u>:

θ 055, L 65, SD 52, Pr > 99.5

160, 098, 030, 090, 070, 025, 002, 307, 325, 075, 060, 075, 070, 070

83.5 m scour walls:

θ 334, L 99, SD 5, Pr > 75.0

325, 343

85.0 m ripple cross-laminations:

θ 276, L 98, SD 11, Pr > 99.5

270, 295, 270, 265, 270, 290

86.0 m ripple cross-laminations:

θ 287, L98, SD 11, Pr > 90.0

300, 275, 285

Unit 28

103.0 pebble orientations (direction of dip, a-b plane):

θ 215, L 70, SD 48, Pr > 99.5

259, 314, 278, 214, 283, 244, 265, 088, 272, 232, 293, 247, 188, 176, 284, 223, 255, 135, 241, 237, 198, 193, 015, 202, 248, 216, 302, 233, 208, 230, 222, 203, 157, 171, 205, 241, 209, 184, 234, 264, 248, 205, 198, 213, 173, 194, 247, 157, 174, 234, 186, 242, 174, 229, 232, 262, 224, 244, 180, 279, 240, 204, 263, 220, 090, 255, 100, 210, 258, 244, 156, 131, 222, 225, 222, 297, 238, 195, 243, 181, 173, 234, 226, 233, 117, 192, 157, 147, 157, 201, 174, 170, 165, 185, 279, 169, 164, 210, 275, 136

180.0 m -111.5 m <u>trough foreset dip directions</u>:

θ 048, L 82, SD 36, Pr > 99.5

323, 332, 021, 021, 022, 027, 030, 035, 035, 040, 045, 050, 056, 056, 064, 080, 080, 082, 082, 090, 100, 107

117.0 m <u>trough foreset dip directions</u>:

θ 316, L 19, SD 92, Pr > 75.0

010, 019, 019, 019, 019, 048, 069, 072, 076, 080, 164, 172, 177, 184, 190, 205, 208, 217, 219, 229, 249, 250, 300, 300, 300, 305, 323, 325, 325, 340, 350, 357

119.0 m <u>trough foreset dip directions</u>:

θ 051, L 92, SD 24, Pr > 99.5

011, 014, 020, 023, 028, 039, 043, 046, 047, 047, 050, 050, 052, 052, 055, 065, 065, 070, 070, 085, 095, 108

129.0 m -133.0 m <u>trough foreset dip directions</u>:

θ 360, L 39, SD 73, Pr > 97.5

009, 014, 021, 021, 033, 039, 043, 053, 053, 080, 080, 091, 102, 118, 118, 152, 214, 220, 278, 278, 283, 297, 299, 299, 302, 310, 315, 324, 324, 349, 349, 354

144.0 m <u>ripple cross-laminations</u>:

θ 032, L 93, SD 23, Pr > 99.5

017, 355, 005, 040, 035, 033, 057, 049, 020, 030, 025, 035, 057, 065, 025, 070, 353, 005, 030, 060

Unit 29

146.0 m <u>ripple cross-laminations</u>:

θ 048, L 88, SD 29, Pr > 99.5

065, 050, 059, 345, 052, 041, 042, 003, 013, 017 035, 100, 085, 100, 035, 050, 065, 062, 030, 045

161.0 m <u>trough foreset dip directions</u>:

θ 046, L 78, SD 41, Pr > 99.5

333, 357, 007, 016, 032, 046, 049, 070, 074, 077, 094, 108,

186.5 m <u>ripple cross-laminations</u>:

θ 050, L 99, SD 5, Pr > 97.5

052, 043, 057, 050

198.0 m <u>trough foreset dip directions</u>:

θ 039, L 76, SD 44, Pr > 99.5

290, 296, 318, 318, 334, 347, 360, 005, 010, 014, 014, 014, 017, 028, 040, 052, 052, 052, 055, 055, 061, 061, 061, 063, 068, 068, 068, 070, 072, 074, 076, 079, 079, 087

211.0 m <u>trough axes orientations</u>:

θ 046, L 100, SD 1, Pr > 95.0

043, 044, 050

Unit 30

246.5 m <u>prod marks</u>:

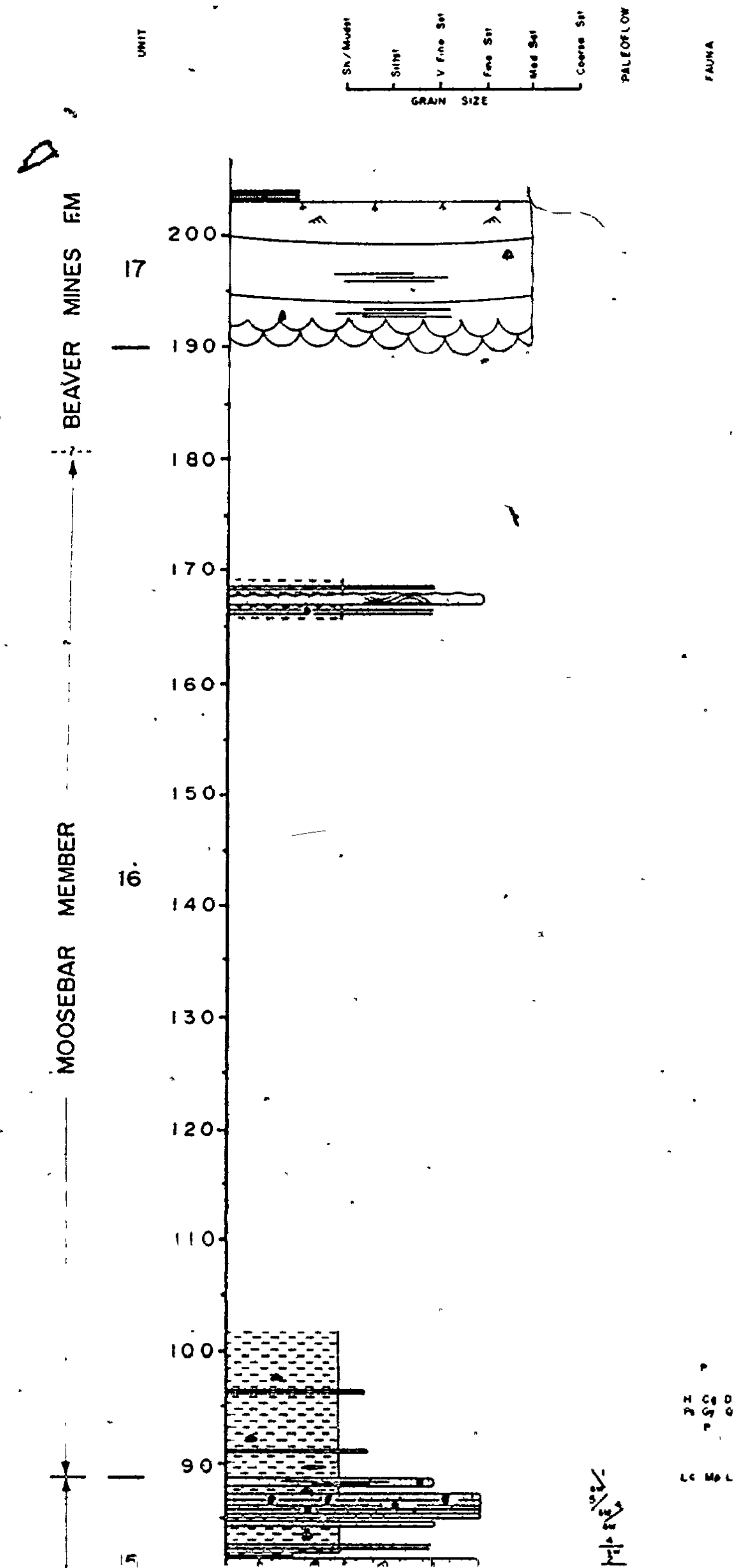
θ 192, L 93, SD 23, Pr >75.0

170, 213

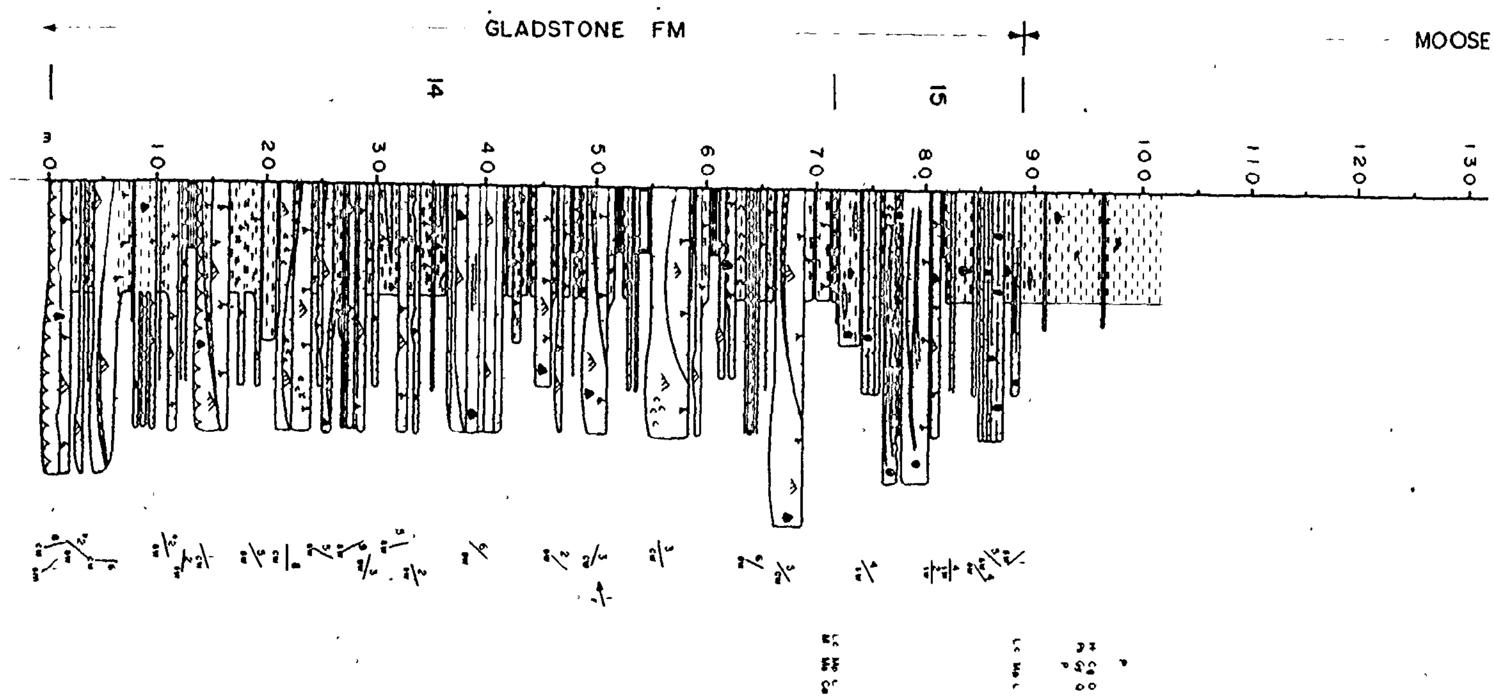
<u>sole mark (scratch)</u>:

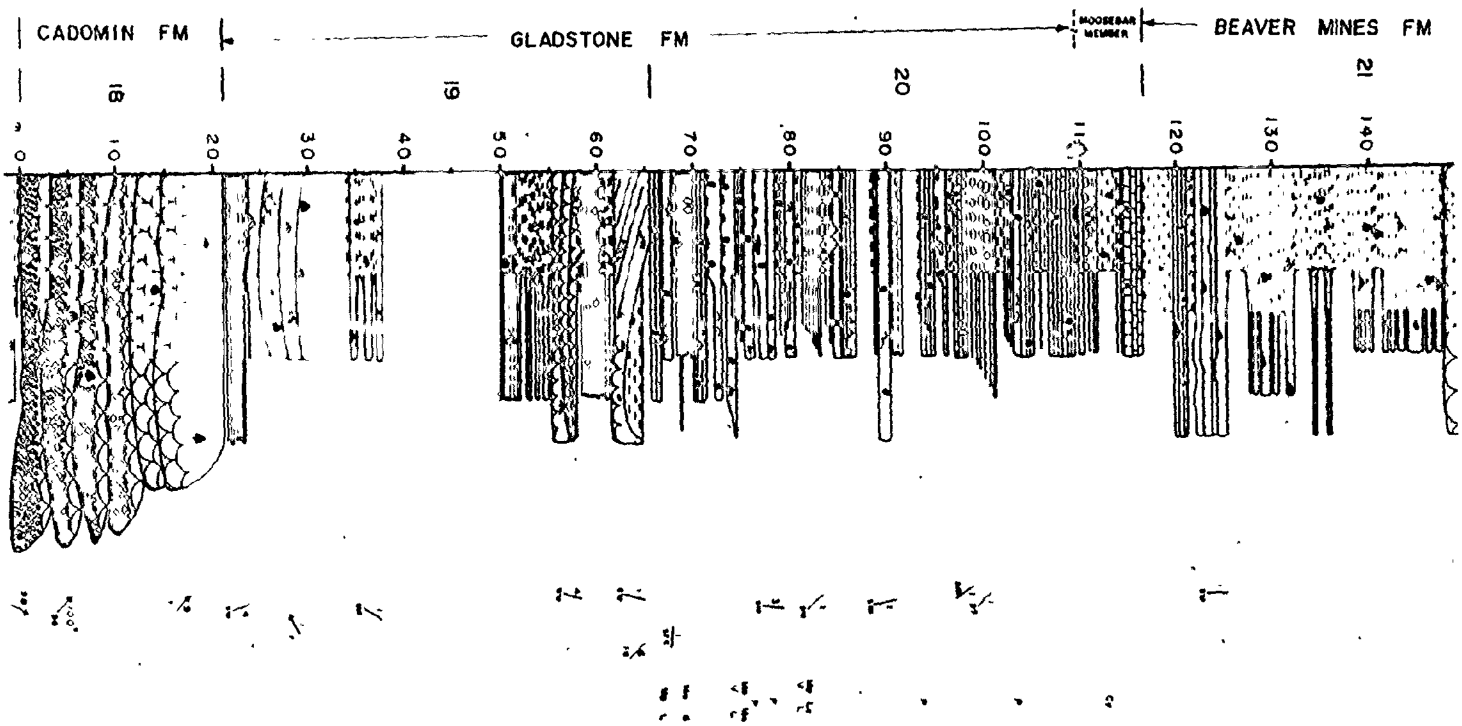
190

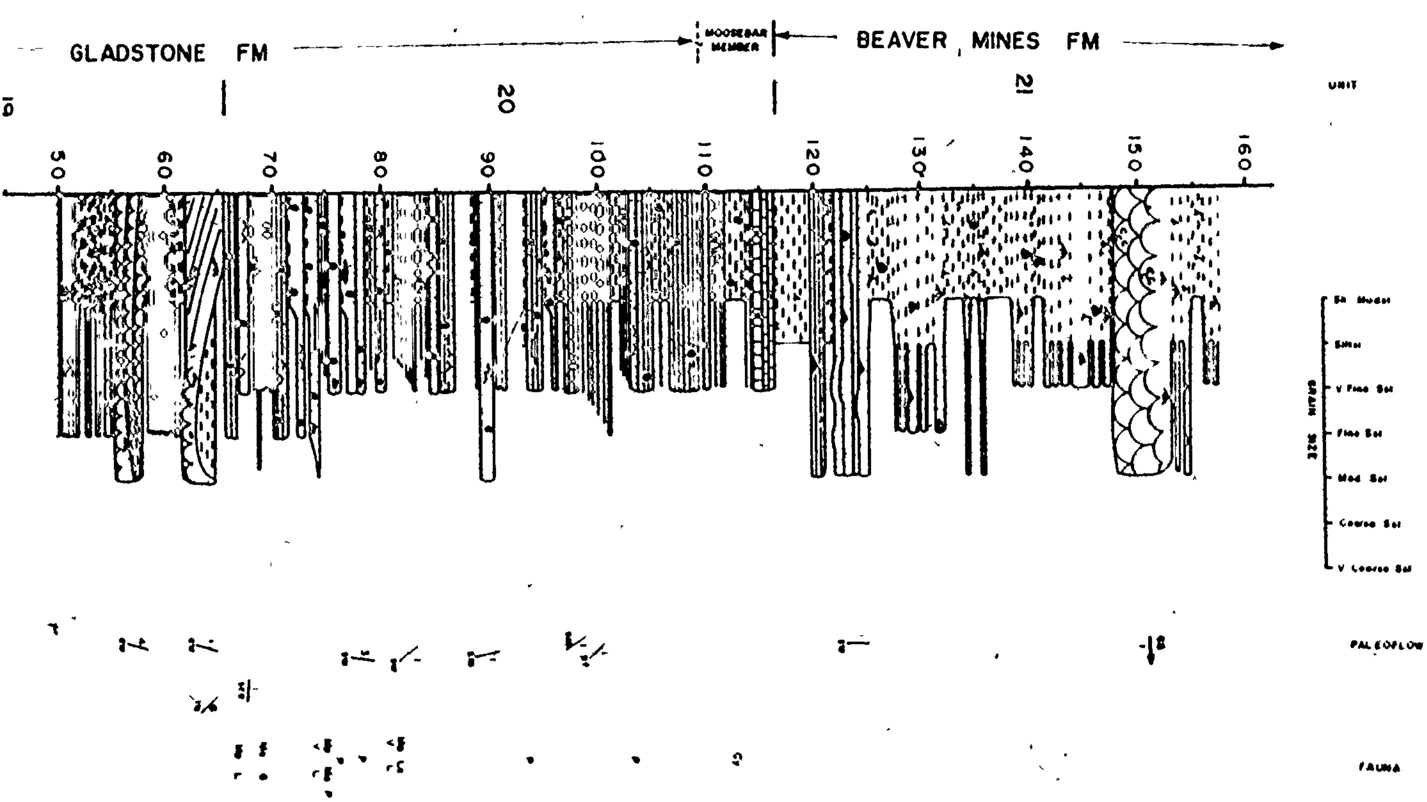
SECTION 3



UNIT
Sh/Mudst
Siltst
V Fine Sst
Fine Sst
Med Sst
Coarse Sst
GRAIN SIZE
PALEOFLOW
FAUNA
BEAVER MINES FM
MOOSEBAR MEMBER
17
16
15
200
190
180
170
160
150
140
130
120
110
100
90


GLADSTONE FM
MOOSE
14
15
m 0
10
20
30
40
50
60
70
80
90
100
110
120
130

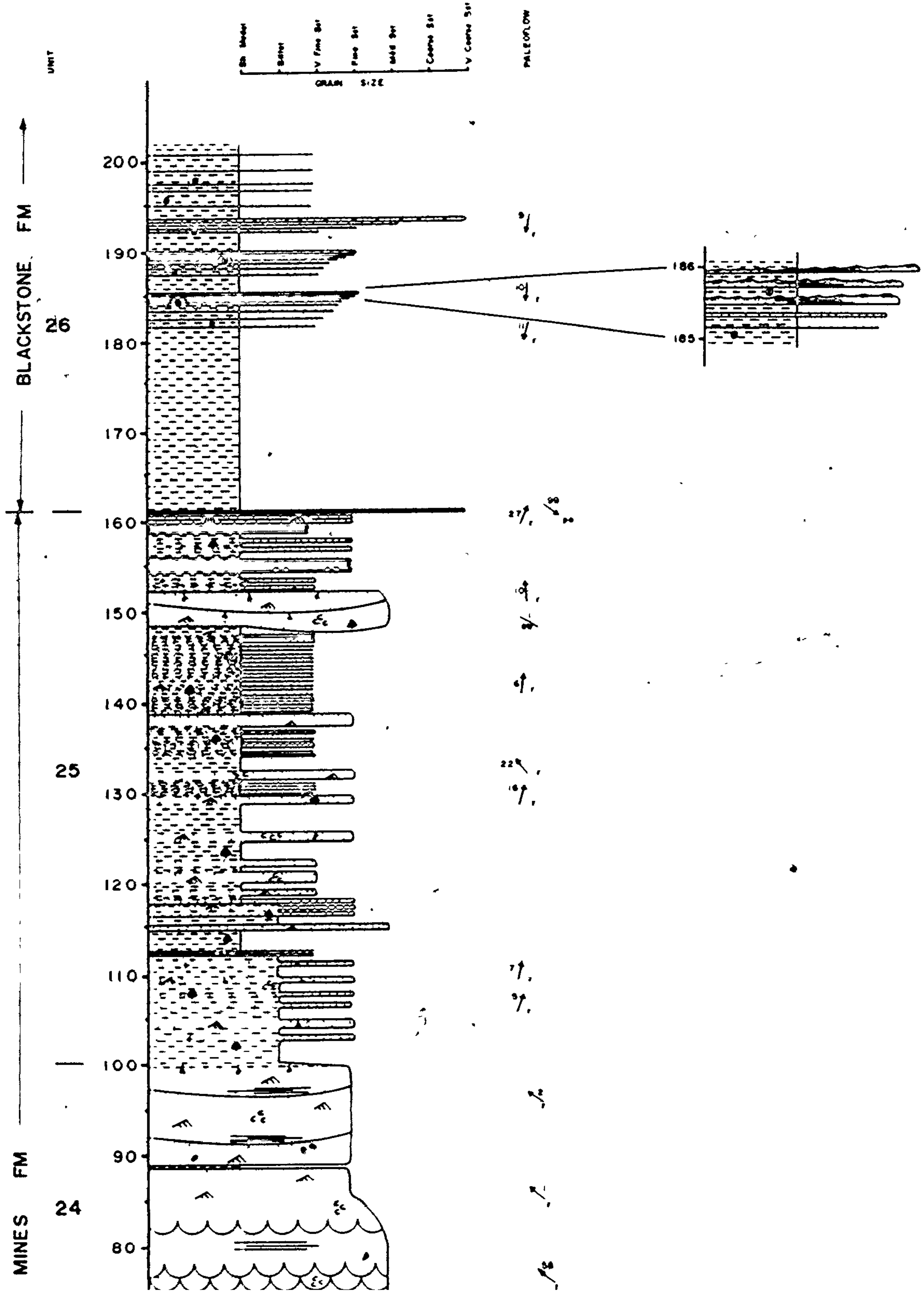

CADOMIN FM
GLADSTONE FM
MOOSEBAR MEMBER
BEAVER MINES FM
18
19
20
21
0
10
20
30
40
50
60
70
80
90
100
120
130
140



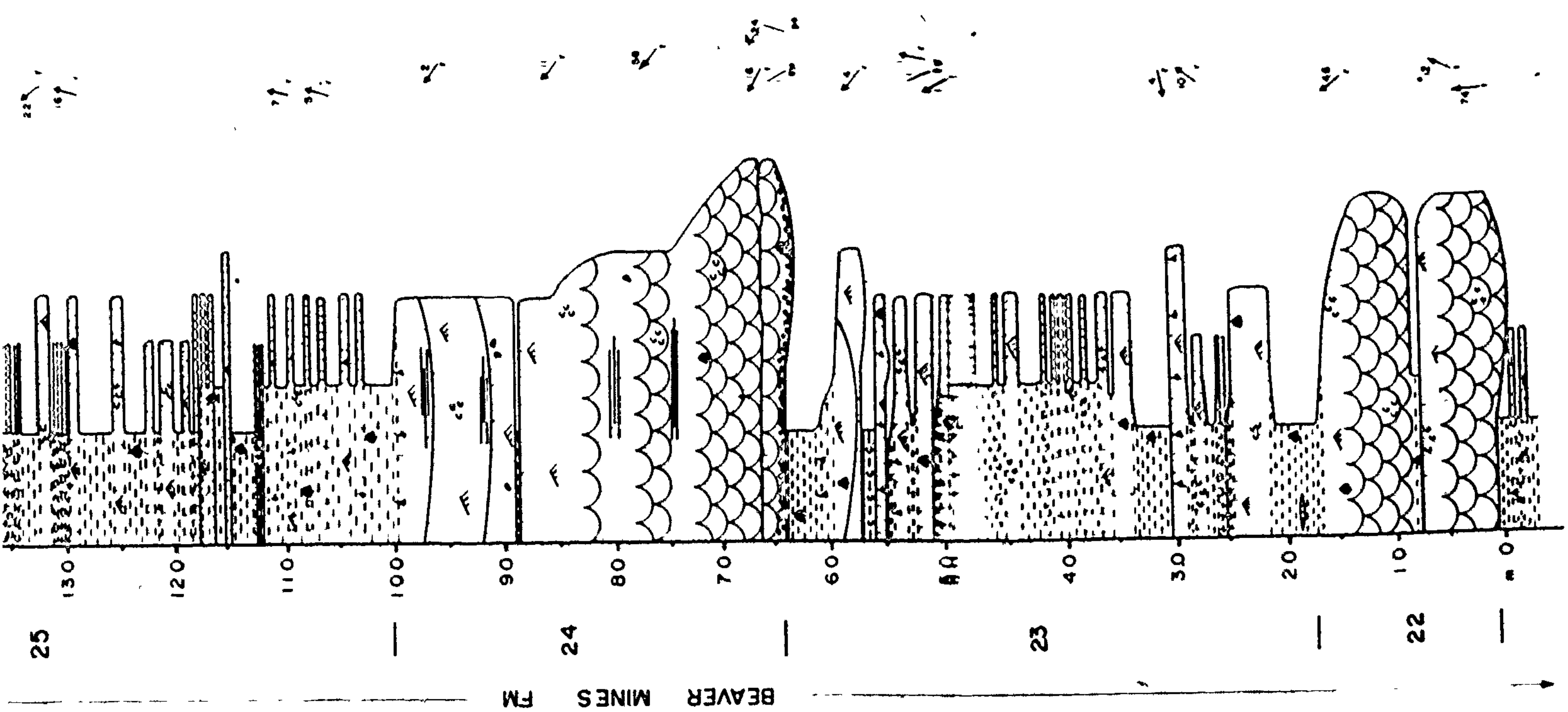
GLADSTONE FM
MOOSEBAR MEMBER
BEAVER MINES FM
UNIT
19
20
21
50
60
70
80
90
100
110
120
130
140
150
160
GRAIN SIZE
Sh Mudst
Siltst
V Fine Sst
Fine Sst
Med Sst
Coarse Sst
V Coarse Sst
PALEOFLOW
FAUNA

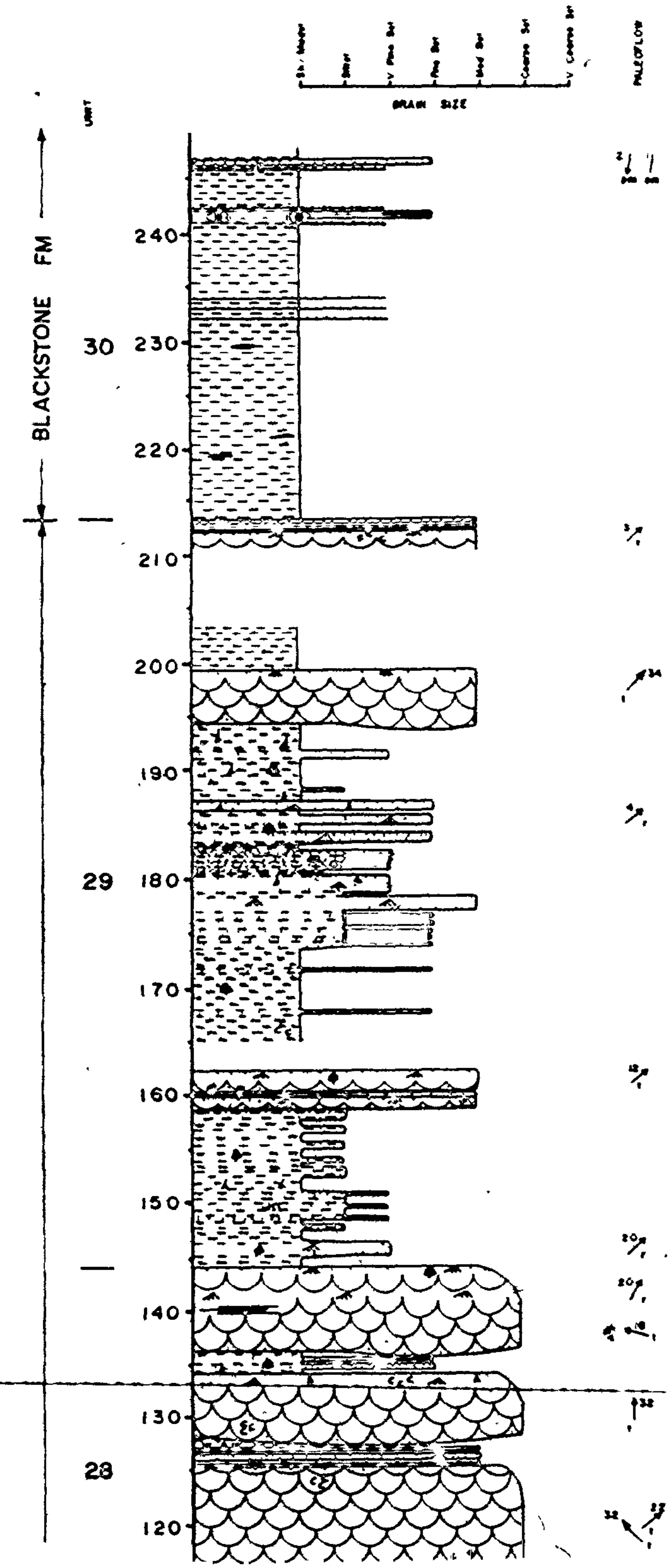
SECTION 4

SECTION 5



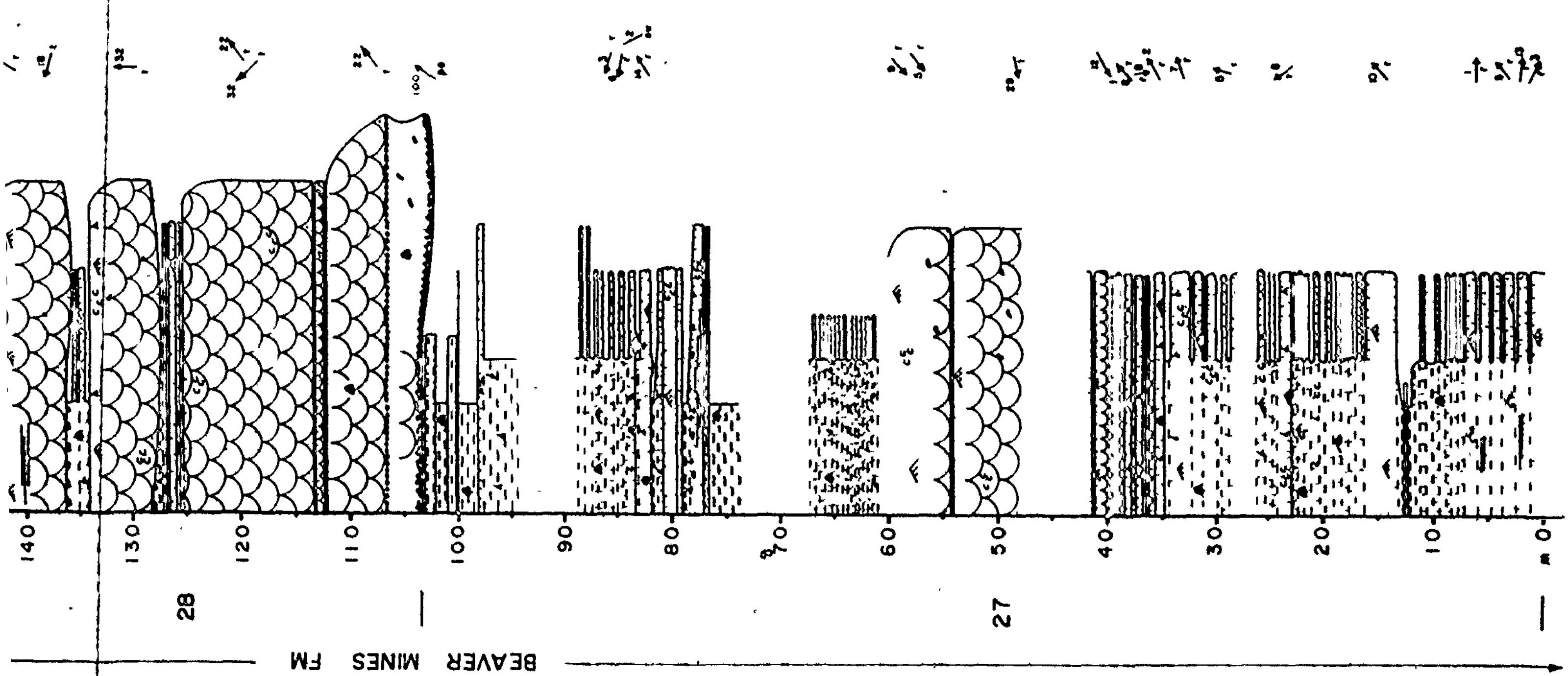
UNIT
GRAIN SIZE
PALEOFLOW
BLACKSTONE FM
MINES FM
26
25
24
200
190
180
170
160
150
140
130
120
110
100
90
80
186
185


BEAVER MINES FM
25
24
23
22
130
120
110
100
90
80
70
60
50
40
30
20
10
0



Slt/Mudst
Silt
V Fine Sst
Fine Sst
Med Sst
Coarse Sst
V Coarse Sst
GRAIN SIZE
PALEOFLOW
UNIT
BLACKSTONE FM
30
29
28
240
230
220
210
200
190
180
170
160
150
140
130
120

1 of


BEAVER MINES FM
27
28
m
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140

LEGEND

LITHOLOGIES

SHALE	CONGLOMERATE
MUDSTONE	LIMESTONE
SILTSTONE	COAL
SANDSTONE	SHELL HASH
PEBBLY SST	CONCRETIONS

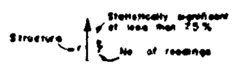
STRUCTURES

RIPPLE CROSS-LAMINATION	SYMM RIPPLE CROSS-LAMINATION
PARALLEL LAMINATION	LATERAL ACCRETION SURFACES
TROUGH CROSS-BEDS	BIOTURBATION
PLANAR CROSS-BEDS	ROOTS
H C S	PLANT FRAGMENTS, MACERATED
SWALEY CROSS-STRATIFICATION	SHELL REMAINS
SYMMETRICAL RIPPLES	MUDCLASTS

CONTACTS

SHARP EROSIONAL GRADATIONAL

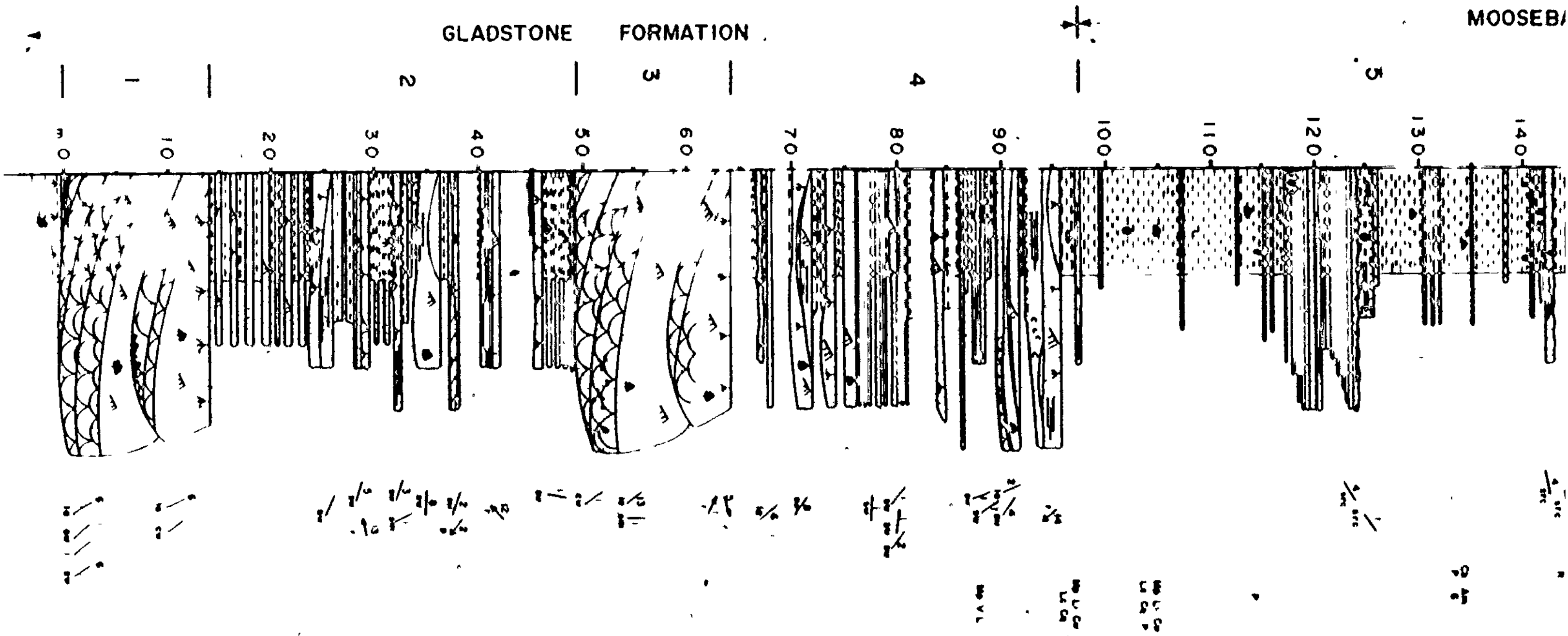
PALEOFLOW



cw	CHANNEL WALL	po	PEBBLE ORIENTATION
gc	GUTTER CAST	r	RIPPLE CROSS-LAMINATION
la	LATERAL ACCRETION SFCE	sm	SOLE MARK
p	PLANAR CROSS-BEDS	src	SYMMETRICAL RIPPLE CREST
pf	ORIENTED PLANT FRAGMENTS	sw	SCOUR WALL
pm	PROD MARK	t	TROUGH CROSS-BEDS
l	LINEATION		

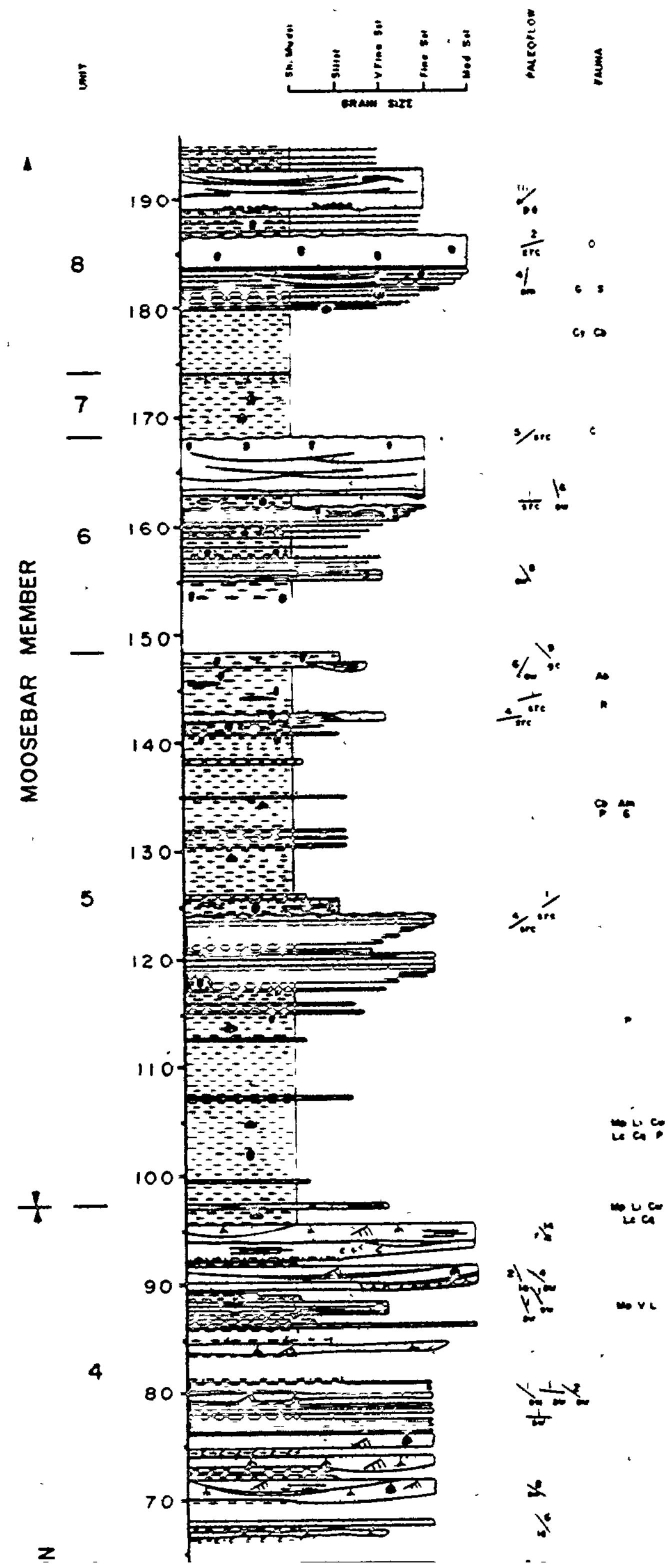
FAUNA

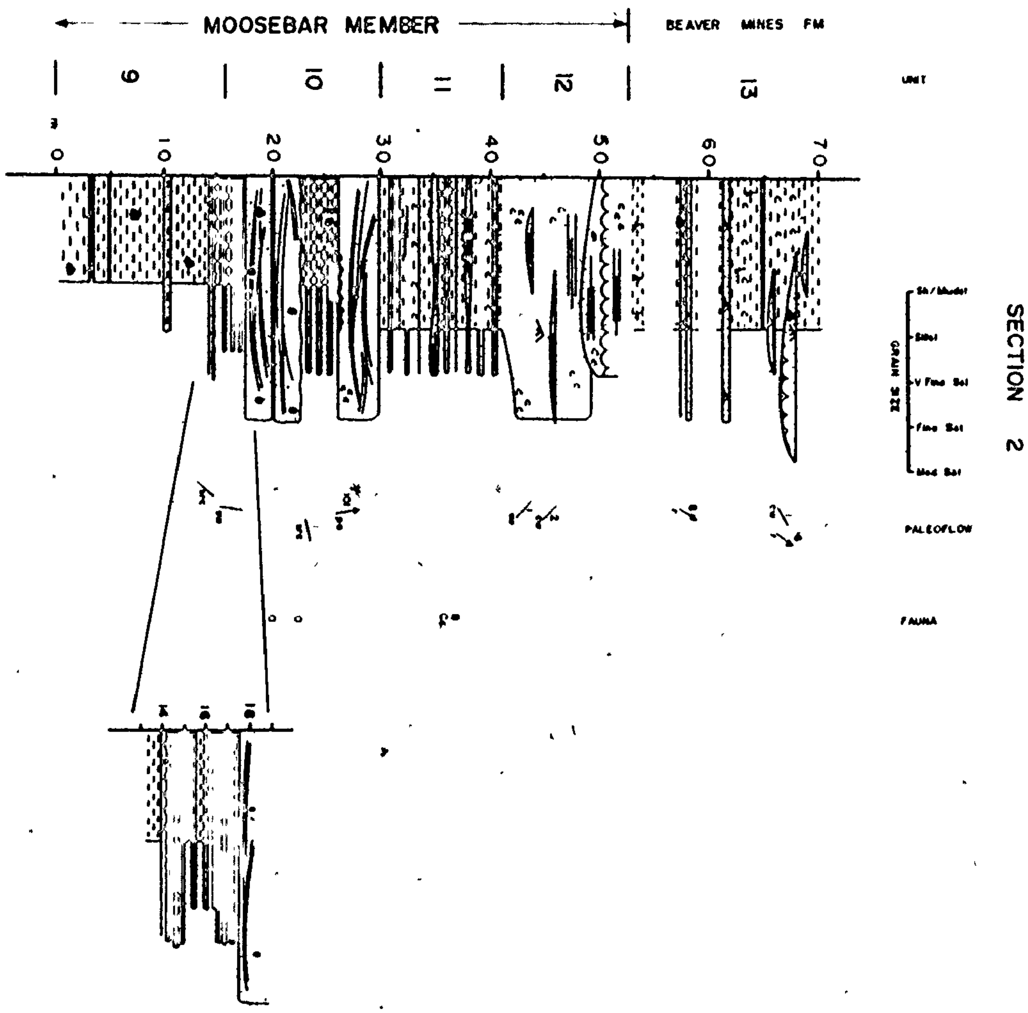
Ab	*Ammobaculites* ? sp	Lc	*Limnocythere calmontensis*
Am	*Ammomarginulina* ? sp	Li	*Limnocypridea* ? sp
B	*Bathysiphon* sp	M	*Murraia* sp
C	*Chondrites*	Ma	*Metacypris angularis*
Cb	*Cytheridea brevispinosa*	Me	*Metacypris* sp
Ca	*Campeloma* sp	Mp	*Metacypris persulcata*
Cg	*Cagena* ? sp	Ms	*Musculiopsis* sp cf *M. russelli*
Cq	*Cooneyella* cf *quadrispina*	O	*Ophiomorpha*
Cs	*Cosmorphaphae* ?	P	Pelecypods indet
Cw	*Cypridea* ? cf *wyomingensis*	Ps	*Psamminopelta* sp cf *P. bowsheri*
D	*Dentalina* ? sp	Q	*Quadrimorphina albertensis*
G	Gastropods indet	R	*Rhizocorallium*
Gp	*Globulina prisca*	S	*Saccammina lathrami*
Gy	*Gyroidina* sp cf *G. nitida*	V	*Viviparus* sp
H	*Haplophragmoides* sp	Cy	*Cytheridea bonaccordensis*
L	*Lingulacoides* ? sp		


GLADSTONE FORMATION
MOOSEBA
1
2
3
4
5
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140

1 of

SECTION 1


UNIT
Sh. Mudst
Siltst
V Fine Sst
Fine Sst
Med Sst
GRAIN SIZE
PALEOFLOW
FAUNA
MOOSEBAR MEMBER
4
5
6
7
8
70
80
90
100
110
120
130
140
150
160
170
180
190
N


SECTION 2
MOOSEBAR MEMBER
BEAVER MINES FM
UNIT
9
10
11
12
13
m
0
10
20
30
40
50
60
70
GRAIN SIZE
PALEOFLOW
FAUNA