TRIASSIC BRAIDED GRAVELLY RIVER

DEPOSITS AT PT. LEPREAU

NEW BRUNSWICK

By

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Abstract

A detailed section of the Duck Cove Member
(Nadon, 1981) of the Triassic Lepreau Formation of
Southern New Brunswick is measured.

The section consists of a complex sequence of
conglomerates and sandstones with a minor occurrence of
mudstones and breccia. A description of the facies is
provided and an interpretation is based on observations of
ancient and marine braided stream deposits of Miall (1978)
and Allen (1983). The Markov chain analysis is used to
describe the vertical succession of facies.

Paleoflow indicators suggest a flow towards the
south or southeast. However this conclusion is based
on limited availability of data.

Acknowledgements

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Chapter 1

Introduction

1.1 Purpose and Scope

The purpose of this study is to describe and
measure a detailed section of the Duck Cove Member of the
Lepreau Formation of southern New Brunswick. The goal is
to develop a facies description and to obtain paleocurrent
data in order to better understand the environment of
deposition.

1.2 Location

The measured section is located on Pt. Lepreau
near the Pt. Lepreau Nuclear Generating Station, at
approximately 66 27' longitude and 45 05' lattitude.
Outcropping on the northern shore of Duck Cove, the
section can be reached by turning south off of Highway 1,
50 km west of Saint John on Highway 790 for 23 km, and then
turning west following the sign for the Pt. Lepreau Nuclear
Generating Station Information Centre. The nature
trail leading from the information centre goes to Duck
Cove and the top of the section is on the west bank of
the small stream (Figure 1.1).

Figure 1.1. Outcrop of the Lepreau Formation based on

Alcock (1945).

Legend

Lepreau Fm.

Pre-Triassic

Section Location   A

Fault

N.B.

Saint John

Bay of Fundy

N.S.

45°N

65°W

Maces
Bay

Duck Cove

Bay of Fundy

Pt. Lepreau

N

1 km
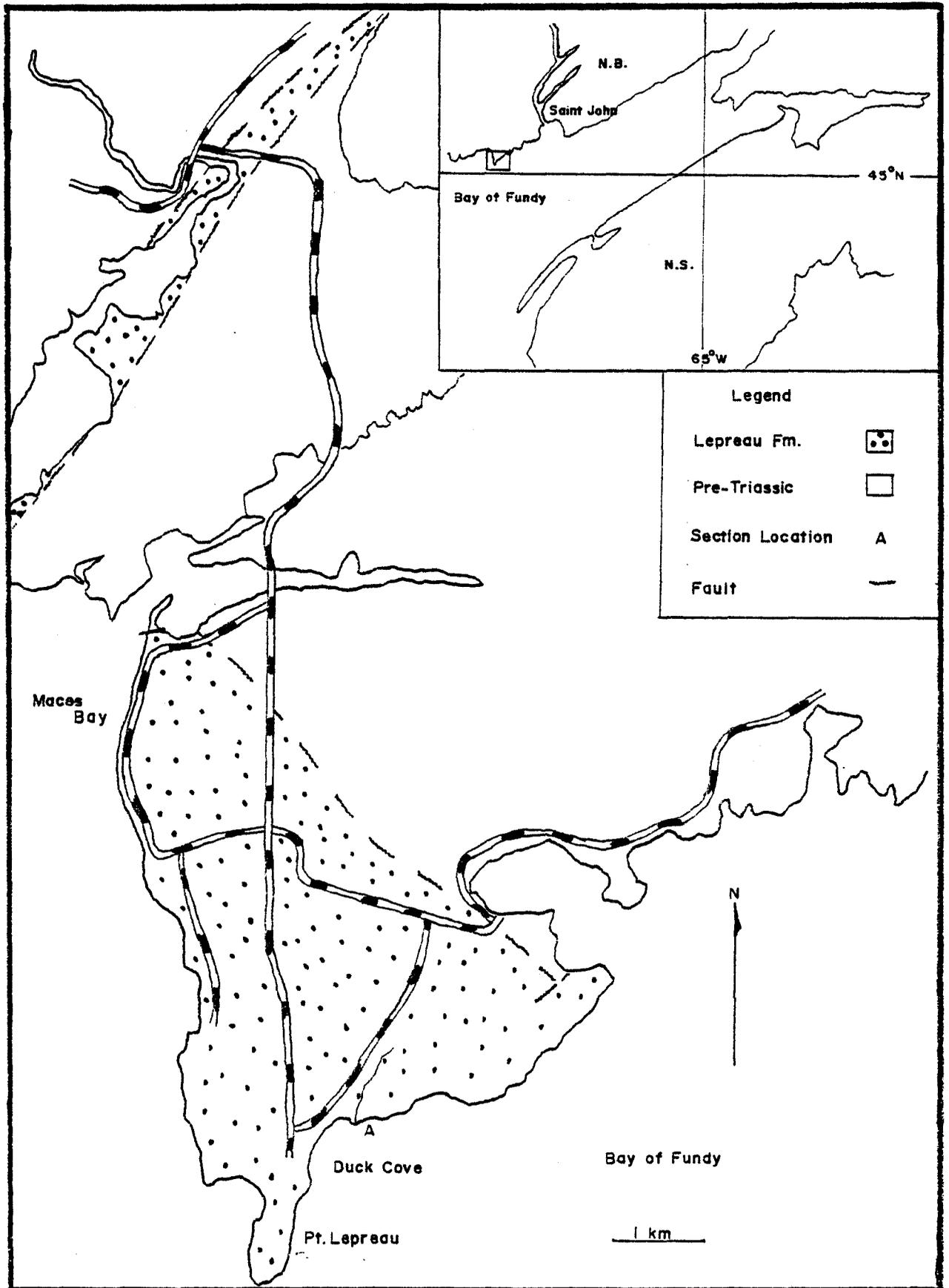
This particular section was chosen partly because of the ease of accessibility but more importantly, because its facies distribution typifies the lower part of the Duck Cove Member (Figure 1.2). Unfortunately, due to limited time for field work, a detailed section representing the top part of the member could not be measured and was only briefly examined.

Figure 1.2 Overview of the measured section at lowtide looking west. Trees for scale are approximately 5 m high.
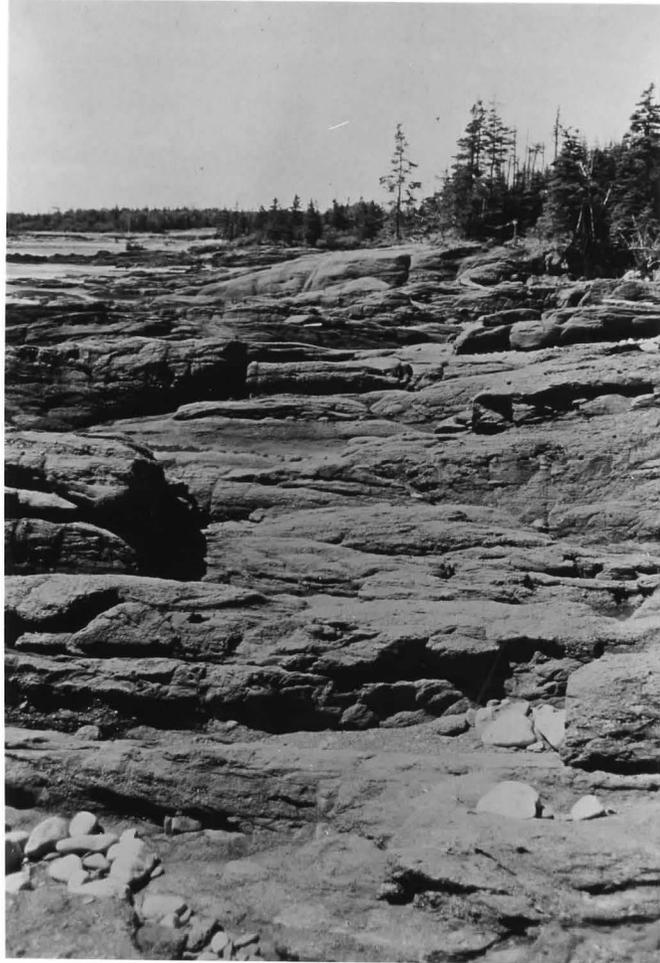
Chapter 2

Regional Geology and Stratigraphy

2.1 Regional Geology

The Fundy Basin, into which the Lepreau For-
mation was deposited, has been described as a half-graben
with the fault on the New Brunswick side of the basin
(Swift and Lyall,1968). In a half-graben basin, a greater
thickness of section would be expected nearest the fault
scarp, and a study by Klein(1962) confirmed this. The
minimum stratigraphic thickness on the Nova Scotia side
is reported as approximately 1060 m including the North
Mountain Basalt which may be Jurassic in age. This
measurement compares to the 2700 m thickness found at
Pt. Lepreau and the 2200 m found at St. Martins (Nadon 1981).

The Fundy Basin is one of a series of basins along
the eastern seaboard of the United States and Maritime
Canada. Each basin shows a similar sequence of alluvial
fan, fluvial and lacustrine sediments. There is however,
no connection between the northeastern United States basins
and the Fundy Basin because of doming of the crust between
them (Le Pichon and Fox 1971).

2.2 Stratigraphy

Early work by Bailey and Mathews (1872) and
Mathews (1896) indicated that the red beds outcropping
along the coastal reaches of Pt. Lepreau, were of
Carboniferous age. This conclusion was due to confusion
with the Carboniferous Lancaster Formation which also
contains abundant red beds and which outcrops near Pt.
Lepreau. Belyea (1939) recognized a difference between the
Pt. Lepreau rocks and the older Lancaster series and
first named the rocks the Pt. Lepreau Formation.

After a name change to the Lepreau Formation by
Wright and Clements (1943), Alcock (1945) mapped the
Musquash area for the Geological Survey of Canada and
included both the coastal section and a section out-
cropping along the Lepreau River as the Lepreau Formation.
Alcock indicated that both sections are bounded by faults of
unknown magnitude.

Klein (1962,1963) investigated both the lithology
and the paleocurrents of the coastal section and concluded
that it was a mixture of low and high-rank greywackes, as
well as arkoses. He determined that the formation had
been derived from the south and could be roughly correlated

to the Triassic Formations at St. Martins.

The Lepreau River section has been dated by
Sargeant and Stringer (1977) who have identified a
reptile track called <u>Isocampe lepreauense</u>.

This track dates this portion of the formation as
Middle to Upper Triassic. Unfortunately, the strati-
graphic position of the Lep reau River section has not been
determined with respect to the coastal section. Sargeant
and Stringer (1977) report that the Lepreau River section
consists of lithologies and structures similar to those of
the coastal section, however, it has undergone a slightly
different tectonic disturbance resulting in tighter folding.

Nadon (1981) briefly describes the Lepreau
formation in his study on Triassic sedimentology of New
Brunswick. He divided the coastal section into three
members. The members, from the base of the formation
upwards, are: the Fishing Point Member, the Duck Cove
Member and the Maces Bay Member. However, Nadon did
not examine the Lepreau River section.

The Fishing Point Member is composed of deep red
breccias comprising various types of granites derived
from a source to the east (Nadon 1981), interbedded with

rare, thin discontinuous fine sands and pebbly sandstones. The lower contact is not exposed, whereas the upper contact is erosional. The member is estimated from air photos to be approximately 350 m thick.

Nadon (1981) has interpreted this member to be a section deposited by debris flows on an alluvial fan, fining-upwards into the deposits of a playa-lake environment.

The Duck Cove Member, in which the measured section is located, consists of cross-bedded conglomerates inter-bedded with red shales and sandstones. The red colour is less strongly hued than in the lower Fishing Point Member, and the Duck Cove Member contains some grey-coloured beds. From air photos, the member is estimated to be approximately 1200 m thick and exhibits an overall fining-upward trend in grain size. The conglomerates are the dominant facies near the base of the member with little sandstone or shale. Further up, the shales and sandstones become more important in frequency and in quantity and, although still present, the conglomerates tend to be much sandier and have a much smaller clast size.

Near the top of the section, on the west side of the

point, the shales are very well-developed with moderately well-defined caliche horizons.

Nadon (1981) has interpreted the facies of this member to be representative of a braided river environment fining-upward into a floodplain sequence.

The lower contact of the Maces Bay Member has been set arbitraily at the initial appearance of a clast-supported breccia, although otherwise the lower facies of the member is identical to that of the upper facies of the Duck Cove Member (Nadon 1981). Breccia increases in frequency in the member until near the top, where the breccias become very coarse and contain large boulders up to 2 m in size. This has been interpreted by Nadon (1981) as the deposits of debris flows. The member is estimated from air photos to be about 1200 m thick.

2.3   The Measured Section

The measured section is located stratigraphically approximately 250 m from the base of the Duck Cove Member. Bedding dips towards the northeast at approximately $30°$ and is interrupted locally by a system of joints or minor faults with an orientation of 060°.

The measured interval broadly mimics the over-all fining-upward sequence exhibited by the member as a whole. Beginning with thick beds of clast-rich conglomerates at the base, there is an increase in frequency of sandstones and thinner, sandier conglomerates. Near the top of the section, the sandstones become finer and are thicker and more abundant than the conglomerates. Due to limited time, detailed work further up-section was not completed although a reconnaissance revealed a change to well-burrowed shales with occasional sandstones and rare conglomerates.

Accompanying this upward decrease in grain size, there is a change in scale and type of sedimentary structures. Near the base, the prominent structure is large-scale trough cross-bedded conglomerates with a high degree of lateral variability and erosional bases. Further up-section, the conglomerates are more abundantly planar bedded with smaller-scale trough cross-beds and planar cross-beds. The beds are generally thinner and show frequent lateral changes from planar-bedded to cross-bedded. Near the top, the prominent

structure is planar-bedding with cross-bedding being
rare.   The bedding is considerably more continuous
in nature and substantially thinner (Figure 2.1).

Figure 2.1   Detailed measured section.   Note the increase

in the amount of sandstones near the top and

the abundance of cross-bedding.

Lepreau Fm.
Duck Cove Member
Duck Cove

Legend

Planar tabular x-b	P ///
Trough x-b	T ///
Parallel bedding	=
Ripples	⌒
Low-angle x-b	L /
Current lineation	C
Burrows	'''
Mudclasts	---
Erosive	~
Abrupt contacts	—
Gradational	----

Clay·silt f.sand m.sand c.sand cgl.
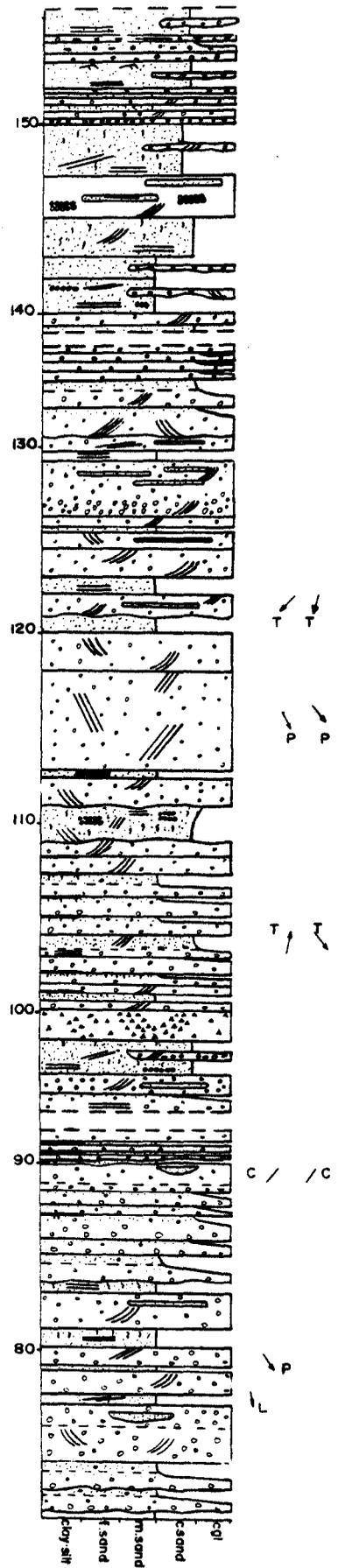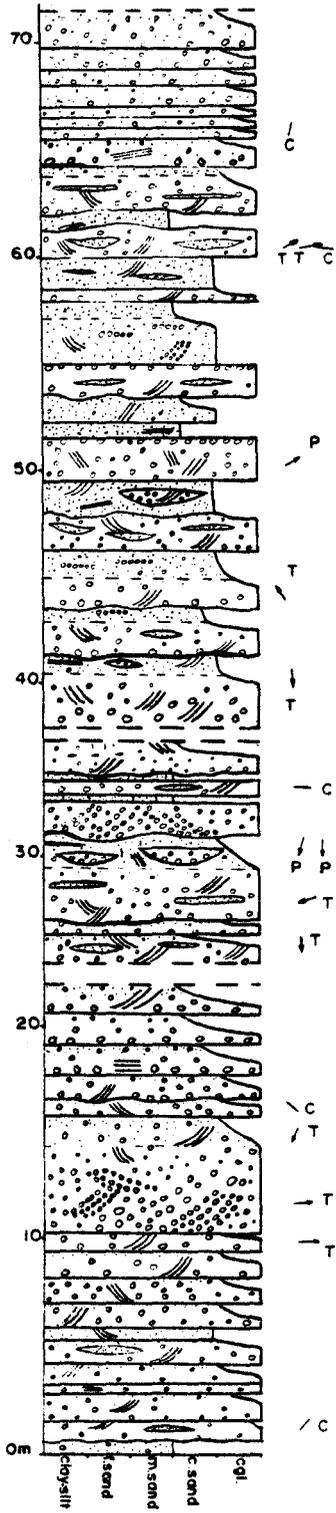
Chapter 3

Facies Description and Interpretation

3.1 Introduction

Within a stratigraphic section, individual facies
can be defined by field observations of its lithology,
sedimentary structures, and organic aspects (Walker,1979).
The key to defining a facies classification is to be totally
familiar with the rock body in question, a process that can
be completed only after all field work has been done.

In the measured section, four main facies have
been determined (Table 3.1), based primarily on gross
grain size and are given a letter designation. Each
facies is then subdivided into a subfacies with a numerical
designation, a classification relying on the relative
grain size and the difference in sedimentary structures.

3.2 Facies Description

3.2.1 Facies A

3.2.1.1 Introduction This facies is composed
of conglomerates with various types and sizes of clasts
which generally are rounded to well-rounded. The con-
glomerates are the dominant facies comprising roughly

Table 3.1

Main Facies Types

Facies A	Conglomerates
Facies B	Sandstones
Facies C	Mudstones
Facies D	Breccias

55 % to 65% of the measured section. They are charac-
teristically highly variable in grain size, matrix type,
and sedimentary structures, and in lateral and vertical
extent (Table 3.2). The conglomerates are red in colour
although not as strongly hued as the sandstones. Some
conglomerate beds have sharp, scoured bases and many
have gradational tops.

3.2.1.2 Facies A_1 This facies is comprised of
clast-supported conglomerates which characteristically
occur in laterally lenticular beds.

This conglomerate occurs as rare 20 cm thick
individual beds (Figure 3.1), or more commonly as local
clast-supported lenses in channels. The clasts are
rounded to well-rounded and range in size from 2 cm to 12 cm.
The dominant lithology of the clasts is a grey-green
aphanitic volcanic rock although quartzite clasts are
also present. The nature of the matrix of both the in-
dividual beds and lenses is comprised of fine to medium sand.

The local clast-supported areas in channels are
calcite cemented whereas, in the individual beds, cemen-
tation is not present (Figure 3,2).

Table 3.2

Facies A

Facies A_1 - Clast-supported conglomerate, well rounded clasts.

Facies A_2 - Massive to planar-bedded conglomerate with substantial lateral and vertical variability.

Facies A_3 - Planar tabular cross-bedded conglomerate. Distinctive grey-green aphanitic volcanic clasts Calcite cement.

Facies A_4 - Conglomerate similar to A_3, but with trough cross-bedding.

Figure 3.1   Clast-supported conglomerate of facies A_1

showing thin lenticular individual beds.

Scale is 1 m.

Figure 3.2   Clast-supported conglomerate of facies A_1.

Note grey-green aphanitic volcanic clast type.

Pen for scale is 15 cm long.

This facies is of relatively minor importance comprising less than 1-2% of the measured section.

3.2.1.3 Facies A_2

The conglomerates of this facies are matrix-supported, consisting of clasts of various sizes, shapes and types. The concentration of these clasts are extremely variable in extent both laterally and vertically. Rapid transitions between muddy matrix-supported and clast-supported, with clast size ranging from 1 cm to 12 cm, are not uncommon. In general this facies is the most variable of the conglomerates. Clasts average 3 cm in size and appear somewhat less rounded than in the other conglomerate facies.

The dominant sedimentary structure in this facies is planar bedding, although there is minor local cross-bedding. The bedding is usually defined by a concentration of clasts or as sandier laminae that have fewer pebbles. In many places, this facies is hard to distinquish from the sandstone facies B_1 and is gradational with it (Figure 3.3).

3.2.1.4 Facies A_3

The conglomerates of this facies are matrix-supported, consisting of clasts ranging

in size from 2 to 12 cm with an average of 6 cm. The clasts
are rounded to well-rounded and consist of grey-green
aphanitic volcanic rock, together with several types of
granites and sedimentary rocks. The size fraction less
then 2 cm in diameter is made up of angular quartz and
feldspar fragments.

Calcite is very abundant as a cement or as stringer
veins throughout the facies.

Individual beds are up to 1.5 m thick, commonly
with a sharp base and a gradational upper contact with a
sandstone facies. The dominant sedimentary structure is
planar tabular cross-bedding, with the structure being
defined by pebbles that lie on the foresets (Figure 3.4).

3.2.1.5. Facies A4   This facies is compositionally
similar to that of facies A3, having many lithologies of clasts
with the dominant grey-green aphanitic volcanic rock. This
facies, however, tends to have higher concentrations of
clasts which are rounded to well-rounded and range in
size from 4 to 15 cm, averaging 9 cm (Figure 3.5).

The matrix is similar to the matrix of facies A3,
comprising coarse angular fragments of quartz and

Figure 3.3 Planar-bedded matrix-supported conglomerate

of facies A_2 filling a channel. Scale is 1m.

Figure 3.4 The planar-tabular cross-bedded conglomerate

is at the top of the picture. Note the

foresets defined by grain size change. Scale

is 1 m.

Figure 3.5 Conglomerate is planar-bedded on the right

side of the picture and trough cross-bedded

filling a channel on the left side. Scale

is 1 m.

feldspar. There is, however, more abundant calcite, both as cement and as stringer veins.

Individual beds range in thickness from 0.2 m to 1.5 m and are dominated by trough cross-bedding. The lower contact is invariably sharp and may show channels with a relief of up to 0.5 m. The upper contacts are erosional, abrupt or gradational into a sandstone facies.

3.2.2. Facies B

3.2.2.1 Introduction This facies consists of sandstones of various grain sizes, sedimentary structures and composition (Table 3.3). The sandstones are less laterally extensive than the conglomerates, primarily due to the scouring of the conglomerates. A general trend in the section is an increase in sandiness of the conglomerates and also an increase in the frequency and thickness of sandstone beds.

3.2.2.2. Facies B_1 This facies is defined as a pebbly coarse sandstone, similar in characteristics to the conglomerate facies A_2 except for a lower percentage of clasts (Figure 3.6).

Table 3.3

Facies B

Facies B_1 –   Massive to planar-bedded pebbly sandstone
similar to facies A_2.

Facies B_2 –   Coarse pebbly sandstone which has planar
tabular cross-bedding.

Facies B_3 –   Coarse pebbly sandstone which has trough
cross-bedding.

Facies B_4 –   Medium-grained with well defined planar
bedding.

Facies B_5 –   Fine to medium-grained sandstone with low
angle cross stratification.

Facies B_6 –   Fine to medium-grained sandstone with
ripples.

Sandstones of this facies invariably have gradational bases from a conglomerate, and may be laterally gradational with conglomerates of facies A_2.

Sedimentary structures are not very well defined although stringers of pebbles may enhance the planar-bedding or trough cross-bedding. Locally the conglomerates can be clast-supported or, conversely, there can be many localized patches of planar-bedded medium-grained sand-stones. These localizations of different grain size material and sedimentary structures are not distinctly different beds but rather are laterally and vertically gradational from the pebbly coarse sandstone.

3.2.2.3 Facies B_2

This facies is defined as a coarse sandstone with rare localized patches of clasts and medium-grained sandstones. The dominant sedimentary structures are planar tabular cross-bedding and planar bedding which are, in general, well defined.

The basal contact is in most cases gradational, whereas the top contact is sharply defined usually by an erosive conglomerate unit. The beds may reach a thick-ness of 1.5 m and a lateral extent of 20 m.

3.2.2.4 Facies B$_3$ This facies is very similar
in characteristics to facies B$_2$ having localized patches
of pebbles and medium-grained sandstone. Beds within
this facies have gradational bases and sharp, erosive
tops and are also of similar size and thickness to
units within facies B$_2$. The main difference is that the
sandstones are trough cross-bedded to massive. Sand-
stones of this facies also have local patches of silts
and fine sands.

3.2.2.5 Facies B$_4$ This facies is a red, medium
sandstone that is characteristically planar bedded with
very well defined laminae. The basal contact is quite
sharp. The upper contact is also sharp primarily due to
scouring before deposition of the succeeding conglomerate
(Figure 3.7,3.8).

The beds average 30 cm in thickness and are less
than 5 m in lateral extent. This facies may be moderately
burrowed although not extensively enough to obscure
structure. Units of this facies may also be topped by
mud drapes that are rippled.

Figure 3.6   Coarse pebbly sandstone of facies B_1 with
             indistinct bedding near the 1m scale.

Figure 3.7   Planar bedded sandstone of facies B_4 forming
             small pool deposits.   Scale is 1m.

3.2.2.6 Facies B₅   This facies is defined as a
medium to coarse sandstone with very well defined low
angles cross-bedding (Figure 3.9). Both upper and lower
contacts are sharp, the upper contact being erosional.
Locally the foresets of the cross-beds have horizontal
burrows in them (Figure 3.10).

Units of this facies range up to 10 m in lateral
extent and reach 50 cm in thickness.

3.2.2.7 Facies B₆   This facies is a fine to
medium-grained sandstone that occurs as very thin beds,
usually less than 5 cm thick, and often with lenticular
habit due to scouring of overlying conglomerate (Figure 3.11).
This facies is found at the tops of a fining-upward cycles
and may be overlain by mud drapes.

These sandstones have indistinct bedding although
a few examples of current ripples can be found at the top.
Some units appear to be extensively bioturbated as no
structures were observed. Near the top of the section
some of the sandstones lose the red colour and become
distinctly grey in colour.

Figure 3.8 Planar bedded sandstone of facies B_4 with
minor channel. Scale is 1m.

Figure 3.9 Medium-grained sandstone of facies B_5 with
low angle cross stratification. Scale is 1m.
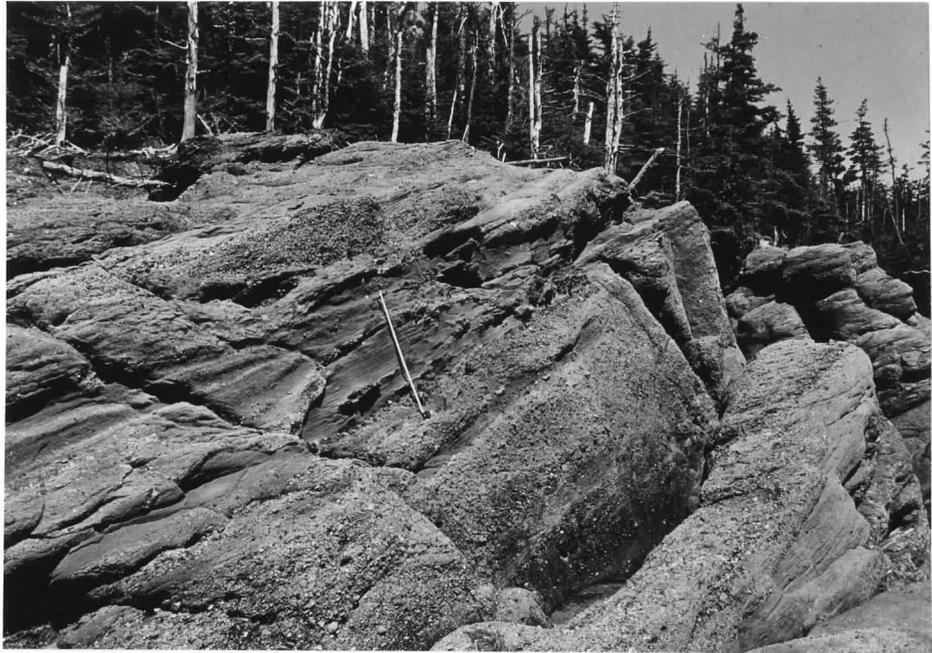
Figure 3.10 Burrowing on foresets of low angle cross

beds of facies B_5. Scale is 8 cm.

Figure 3.11 Fine-grained sandstone of facies B_6 with

ripples and burrowing. Scale is 1m.

3.2.3. Facies C

This facies is described as a mudstone with strong red colouring (Figure 3.12). Mudstones may occur as extensively burrowed or rippled mud drapes over sandstones or as thin distinct beds. The beds average approximately 15 cm in thickness and 2 m in lateral extent. Laminae cannot be seen in the beds, probably due to extensive bioturbation. The beds have abundant grey-green bleach spots which are probably remnant root systems.

The contacts of these beds are sharp and well-defined, the top contact being erosional. By frequency and volume this is a minor facies of the measured section.

3.2.4 Facies D

This facies is also a minor component in the measured section where only one unit was found. This unit is a 0.5 m thick breccia with well-defined cross-bedding. The breccia differs from the conblomerate facies in that it has dominantly angular to sub-angular clasts a very muddy matrix. Clasts are granitic in lithology, and average 3 cm in size, although the largest observed clast measured 40 cm by 34 cm (Figure 3.13).

Figure 3.12 Mudstone bed of facies C filling a channel.
            Note ripples.   Scale is 1m.

Figure 3.13 Cross-bedded breccia of facies D.
            Note the large clast.   Scale is 1m.

3.3 Facies Interpretation

3.3.1 Introduction

In evaluating a rock body, a key to the interpretation of a facies is to combine the observations of lithology and sedimentary structure, with an appreciation of the facies sequence or spatial relationship (Walker 1979). To test the relative validity of the interpretation, it is useful to compare it to well-studied stratigraphic units, as well as to observations of an analogous modern sedimentary environment.

Nadon (1981), in a brief study of the Lepreau Formation, determined that the Duck Cove Member is representative of a distal braided river like that of the Donjek type of Miall (1978), except deposited in a semi-arid environment. This conclusion was based on the lack of abundant clast-supported areas in the cross-bedded units, and also the lack of overbank deposits in association with the conglomerates. In addition, these deposits are spatially associated with the lower Fishing Point Member and the upper Maces Bay Member, which are interpreted to be debris flow deposits off a semi-arid alluvial fan.

The interpretation of each facies in this study will follow closely, the facies code and interpretation proposed by Miall (1978) for modern and ancient braided stream deposits and also to the facies code of Allen (1983).

3.3.2. Facies A

3.3.2.1 Facies A_1 This facies is described as a clast-supported conglomerate occurring as individual beds or as local concentrations in cross-bedded units. The individual beds are probably the result of lag deposits of flows of upper flow regime decreasing in velocity. The local concentration usually occur at the base of erosional trough cross-bedded units and can be up to 15 cm in length. These pebbles were also deposited when the fluid slowed and the flow was no longer capable of carrying them as bed load.

3.3.2.2 Facies A_2 This facies is a matrix-supported conglomerate that may be massive but predominately contains crudely defined planar bedding. This facies in conjunction with facies B_1, shows the greatest lateral and vertical variability. Facies A_2 corresponds

to facies Gm of Miall (1978), which he interprets as
being longitudinal bars or lag sieve deposits. Allen
(1983) classifies this facies as G_2 and finds that it
occurs in plane-bedded simple bars or as tops of compound
or composite-compound bars.

    3.3.2.3 <u>Facies A_3</u>   This facies is also a matrix-
supported conglomerate, but with dominantly planar
tabular cross-bedding. It corresponds to facies Gp of
Miall (1978), which he interprets as representing linquoid
bars or as deltaic growths from older bar remnants.
Allen (1983) classifies this facies as G_3, and finds it
is the primary structure in cross-bedded simple bars.
In the compound and composite-compound bars, the sediment
is deposited on the stoss-side of the bar producing
planar lamination of facies G_2, which then avalanches
down producing facies G_3. Other terms used in the liter-
ature for describing bars composed of this facies are
transverse, slipface or cross-channel.

    3.3.2.4 <u>Facies A_4</u>   This is a matrix-supported
conglomerates with dominantly trough cross-bedding. This

facies corresponds to facies Gt of Miall (1978) and is considered to represent in-channel deposition. Allen (1983) did not recognize this facies in his study.

3.3.3 Facies B

3.3.3.1 Facies B_1 Except for a decrease in the amount of pebble-size fraction, this facies has the same characteristics as facies A_2. Therefore, it may be also interpreted as a longitudinal bar, which corresponds to facies Gm of Miall (1978) and to facies G_2 of Allen (1983).

3.3.3.2 Facies B_2 This facies is a coarse pebbly sandstone with planar tabular cross-bedding and is recognized as facies Sp of Miall (1978) and facies S, of Allen (1983). Units of this facies have been interpreted to represent linguoid or transverse bars, or sandwaves of the lower flow regime.

3.3.3.3 Facies B_3 This facies is a coarse-grained, pebbly sandstone with trough cross-beds and is recognized as facies St of Miall (1978) and facies S_3 of Allen (1983). The trough cross-bedding is the result

of deposition of sinuous crested dunes in a lower flow regime.

3.3.3.4 Facies B_4

This facies is a medium-grained sandstone which has distinctive well-defined planar laminations and is recognized as facies Sh of Miall (1978) and facies S_4 or S_5 of Allen (1983). The planar bedding is the result of planar flow in the upper flow regime.

3.3.3.5 Facies B_5

This facies is fine to medium-grained sandstone which has low angle cross-bedding and is recognized as facies Sl of Miall (1978) and facies S_5 of Allen (1983). The low angle cross-bedding is the result of shallow, high velocity flow into low relief scours (Rust 1978).

3.3.3.6 Facies B_6

This facies is a fine to medium-grained sandstone with abundant ripples, and is recognized by Miall (1978) as facies Sr. The ripples are representative of lower flow regime.

3.3.4 Facies C

This facies occurs as finely laminated mudstones or as mud drapes, which may be rippled. It is equivalent to facies Fl or Fm of Miall (1978) and to facies M of Allen (1983). The finely laminated mudstone is interpreted as representing overbank deposits, whereas the mud drapes represent a waning flood deposit.

3.3.5 Facies D

This facies is defined as a breccia because of the sub-angular to angular nature of its clasts. Facies D has poorly defined cross-bedding and is equivalent to facies Gt or Gp of Miall (1978) and facies G_3 of Allen (1983). The facies might indicate the reworking of a debris flow.

A summary of the facies codes are given in Table 3.4.

3.4 Summary

3.4.1 Introduction

A discussion of facies descriptions and interpretations of a given measured section is incomplete with-

Table 3.4

Summary of Facies Code

Loosemore	Miall (1978)	Allen (1983)
A_1	–	–
A_2	Gm	G_2
A_3	Gp	G_3
A_4	Gt	–
B_1	Gm	G_3
B_2	Sp	S_1
B_3	St	S_3
B_4	Sh	S_4, S_5
B_5	Sl	S_5
B_6	Sr	–
C	Fm, Fl	M
D	Gt, Gp	G_3

out an idea of the vertical succession of these facies.
This study uses the statistical method of the Markov
chain analysis and observations of facies assemblages in
other braided stream deposits.

3.4.2 Markov Chain Analysis

The Markov chain analysis is a statistical
approach to determine the probability of one facies being
succeeded by another facies. The probability could be
defined as the relative frequency in the total popu-
lation of transitions from which the sample was drawn.

In order to simplify the analysis, the minor
facies have been incorporated into the major facies.
Therefore facies B_1, because of its similar characteristics
can be considered under facies A_2. The one unit of facies
D is considered to belong to facies A_4 and facies B_5 is
considered to belong to facies B_4. In addition a scour
surface indicated by SS has been incorporated into the
analysis.

The analysis used in this study is a first order
Markov chain (Miall 1973) which considers the relationship
between a given bed and the next bed immediately above it.

This method, however, does not consider the thicknesses of the beds nor does it account for the transition of a bed of one facies to another bed of the same facies.

The first step in a Markov analysis is to set up a transition count matrix which is designated T_{ij}. This matrix, given in Appendix A1 , is a two-dimensional array which tabulates the number of times all possible vertical facies transitions occur in the measured section. For example, facies A_2 is succeeded by facies B_2, 15 times.

From the transition count matrix, two probability matrices is derived. The first, given the designation P_{ij} and tabulated in Appendix A2 , represents the actual probability of the given facies transitions occurring in the measured section. For example, the transition of A_2 to B_2 occurs 15 times out of all 39 transitions from A_2 and therefore the probability of transition is 15/39=0.385.

The second probability matrix given the designation R_{ij} (Appendix A3), represents the probability of the given facies transition occurring randomly. For the example of the transition from A_2 to B_2, the total number of transitions of any facies to B_2 is 36. The total of transitions possible to a given facies but not itself, is the grand total number

of transitions (193) minus the number of transitions to
facies A_2 (39). Therefore the random probability of tran-
sition from facies A_2 to facies B_2 is 36/(193-39)=0.234.

To compare the actual observed probabilities to
the random probabilities, a new matrix is determined as
the actual minus the random probabilities. The matrix is
called the difference matrix and is designated as D_{ij}
(Appendix A4) where $D_{ij} = P_{ij} - R_{ij}$. For the example
from facies A_2 to B_2, $D(1,4) = 0.385 - 0.234 = 0.151$.

From the difference matrix a preferred facies
relationship diagram can be constructed (Walker,1979).
A simplified version of this diagram is give in Figure 3.14 .
This figure suggests five different sequences which are
listed below.

    (i)   SS -- A_2 -- B_2 -- C

    (ii) SS -- A_2 -- B4

  (iii) A4 -- B_2 -- C

    (iv) A4 -- B_3

    (v) A_3 -- B4

Sequence (i) suggests migration of a longitudinal
bar over a channel floor, succeeded by a linquoid bar with
waning flow mud drapes. The sequence may repeat with the

Figure 3.14 Preferred facies relationship diagram for

the measured section.

SS $\longrightarrow$ A2 $\longrightarrow$ B2

C $\longrightarrow$ A2

A2 $\longrightarrow$ B4

A4 $\longrightarrow$ B2

B4 $\longrightarrow$ A4

A3 $\longrightarrow$ SS

A3 $\longrightarrow$ B4

A4 $\longrightarrow$ B3
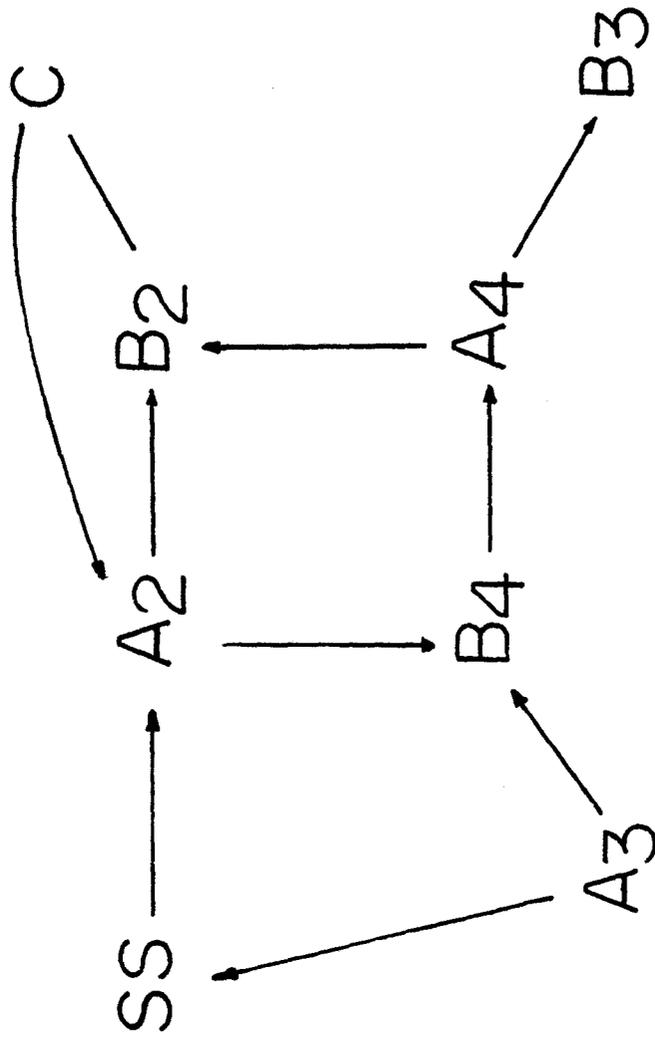
formation of a new longitudinal bar.

Sequence (ii) also suggests migration of a longi-
tudinal bar which is succeeded by planar bedded sandstone.

Sequence (iii) is only slightly more common than
random probability predicts. It represents channel-fill,
succeeded by growth of a linquoid bar into the channel.

Sequence (iv) represents channel fill followed by
the formation of sinuous crested dunes.

Sequence (v) probably represents the formation of
either a compound or composite-compound bar of Allen (1983).

It is necessary to determine whether or not the
observed probabilities differ from the random probabilities
simply by sampling variability. With a 5% level of
significance and one degree of freedom, the Chi square
value is 3.84. Where the Chi square is:

$$x^2 = \frac{(\text{observed freq} - \text{predicted freq})^2}{\text{predicted freq.}}$$

This is tabulated in Appendix   A5 .

For the example of the transition of facies A_2 to
B_2, the Chi square value is 3.78, or slightly below the
value of 3.84. This suggests that the null hypothesis
must be accepted, where the null hypothesis states that
the results could be achieved by random sampling of a

uniform distribution.

However for the purposes of this study this value is considered to be almost significant and therefore not rejected as random. The significant and almost significant transitions are listed in Table 3.5.

3.4.3   Facies Assemblages

The Markov chain analysis has suggested 5 succession cycles which, when applied to the vertical sequence, can help interpret the measured section. These succession cycles are imposed on the stratigraphy in Figure 3.15.

This figure shows predominantly channel fill succession at the base of the section, which corresponds to the thick coarse nature of the beds. This is succeeded by the growth of compound or composite-compound bars of Allen (1983), which are accompanied by minor channel fill. Near the top, these bars are succeeded by the growth of logitudinal bars, again with minor channel fills.

These observations, in combination with an upward decrease in grain size and thickness of beds, suggest an increase in the relative distance from the source. The area is assumed to be semi-arid (Nadon,1981) and an

Table 3.5

Significant and Almost Significant Transitions

Significant	Almost Significant
$SS-A_2$	A_2-B_2
B_2-C	B_3-A_4
A_4-A_4	

Figure 3.15   Succession Cycles determined from the

Markov chain analysis imposed on the

stratigraphy of the measured section.

Major Succession   Minor Succession

$SS-A_2-B_2-C$ A_4-B_2-C
$SS-A_2-B_4$

A_3-B_4 A_4-B_2-C

A_4-B_3
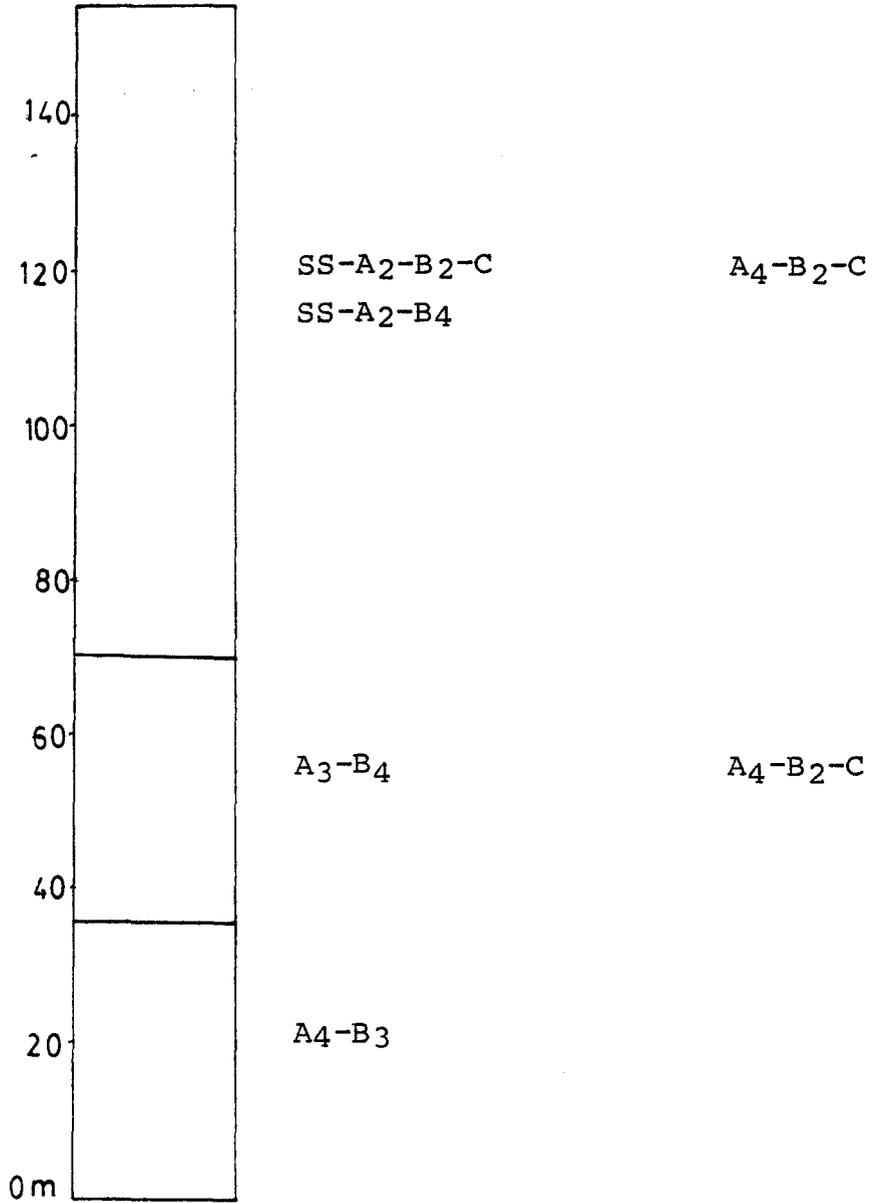
increase in aridity, which would reflect in a decrease in discharge, might produce this succession of facies.

Vertical profiles have been constructed by Miall (1978) to represent the different types of braided stream deposits. The measured section fits numerically into the Donjek type because it consists of 55 to 65% conglomerates. The Donjek type is considered to represent distal gravelly rivers with cyclic-type deposits (Miall 1978, Rust 1978). A comparison of the facies assemblages of the Donjek type to the measured section is give in Table 3.6 using the facies code after Miall (1978).

Because there are only slight differences between the two sections, the measured section can be considered to be of the Donjek type. This conclusion is justified, even though the two sections were deposited in different climatic zones, because the flashy discharge and ratio of sand to gravel are the actual controls on bar formation (Bluck,1979). The climatic effect is only reflected in the vertical accretion deposits which are rarely preserved in the rock record.

Table 3.6

Facies Assemblages

	Main facies	Minor facies
Donjek type	Gm,Gt,St	Gp,Sh,Sr, Sp,Fl,Fm
Measured section	Gm,Gt,Sh Sp	Gp,St,Sl, Fl,Fm,Sr

Chapter 4

Paleocurrent

4.1 Introduction

Although exposure of the measured section is
adequate and flow indicators such as cross-bedding are
abundant, the amount of paleocurrent data is relatively
meager. This lack of data is primarily due to the
faulting and jointing of the cliffs, which produce outcrops
that tend to have smooth, flush faces. This fact makes the
obtaining of paleocurrent data from cross-beds difficult
and often unreliable.

The nature of the cross-beds foresets also con-
tribute to the difficulty in obtaining reliable data.
The cross-beds foresets are of two types as recognized
by Eynon (1972): an openwork gravel type and a hetero-
geneous gravel type. The open-work gravel type consists
of a clast-rich foreset base and bed base which grade
outwards and upwards. The heterogeneous gravel type have
foresets defined only by a subtle change in grain size.
At a distance these foresets can be recognized by strings
of pebbles but identification becomes difficult when the
observer moves close to the outcrop to measure the

orientation of the structure.

Another difficulty encountered was an inability, in some instances, to determine whether the cross-beds were trough cross-beds or planar cross-beds. Some structures appear to be planar cross-beds but had very well-defined asymptotic toes. This may have been a reflection of either the shape of outcrop or alternatively, a transitional state between trough cross-beds and planar cross-beds in the depositional environment.

4.2 Method

Measurements were taken from three types of sedimentary structures: current lineation, planar cross-beds and trough cross-beds. The measurements were then rotated by using a stereonet to correct for tectonic dip which averages about 30 towards the northeast in the section.

The corrected data was then plotted on rose diagrams using the method proposed by Curray (1956). In this method, the vector mean, vector strength or magnitude and amount of dispersion are calculated.

The rose diagrams are plotted using the square root of the percentage of readings. This method is

employed because the area of the piece of the pie is

proportional to the square of the number of readings.

The result would be similar by plotting the percentage

of the number of readings but the area of the pie would

not correspond correctly to the number of readings.

A test of the null hypothesis was conducted by

using the Rayleigh method. This test determines if the

result was random sampling with uniform distribution.

4.3 Results

The measurement of trough cross-beds in the

section with n=13, reveals a mean of 145° (L=28%)

(Appendix B1) and these cross-beds are plotted on a

rose diagram in Figure 4.1. The results show essentially

a bimodal distribution to the east and south in addition

to a spurious mode to the north-northwest. An exami-

nation of modern braided gravelly rivers by Williams and

Rust (1969), suggests that trough cross-beds are not

always an accurate indicator of mean flow because the cross-

beds often form at a very high angle to the mean direction

of flow.

The measurement of planar cross-beds in the section

Figure 4.1 Rose diagram plot for trough cross-beds

n=13, L=28%, vector mean = 145°
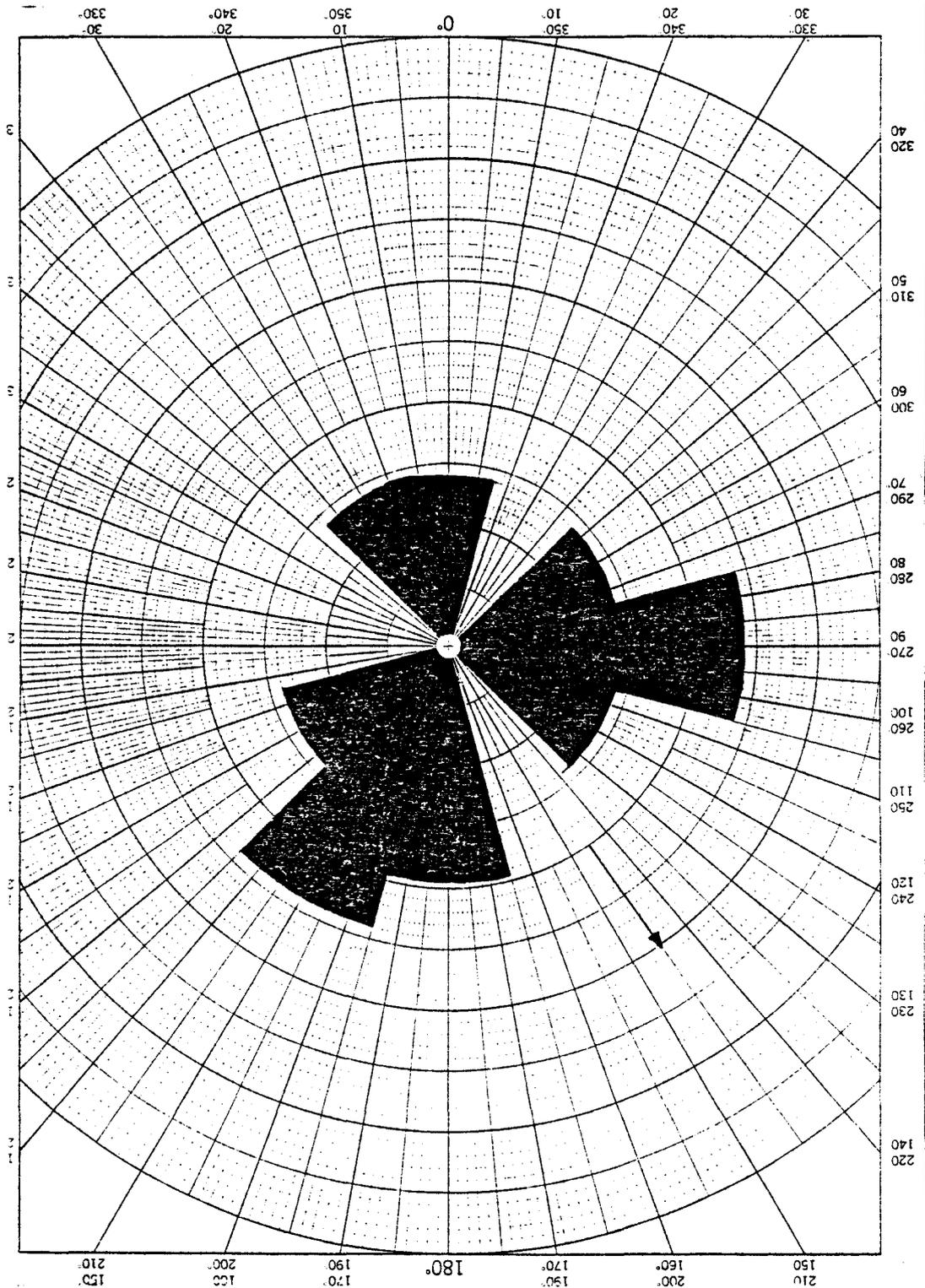
with n=6, reveals a mean of 152°(L-12%) (Appendix B2)

and these cross-beds are plotted on a rose diagram in

Figure 4.2. The results show a slight bimodal appear-

ance although with only six measurements, this is not a

statistically correct observation.

Williams and Rust (1969) suggest that to obtain

good reliable results, it is best to use small-scale

structures such as ripples or current lineations.

The current lineations are small channels or

grooves and since they are bidirectional, they imply

only an orientation of flow. A calculation of a grand

mean for all cross-bedding with n-13, reveals a value of

146°(L=23%) (Appendix B3). Therefore assuming that the

overall flow is to the south, a weighting of the current

lineation to the south reveals a vector mean with n=6 of

184°(L=11%). The rose diagram with weighting to the

south is plotted in Figure 4.3.

A grand mean calculated from all three sedi-

mentary structures gives a value of 151°where n=25 and

L=20%.

Work on the Platte River (Smith 1972) reveals

that with both active and exposed bars, the vector mean

Figure 4.2   Rose diagram plot for planar tabular cross-

beds   n=6, L=12%, vector mean = 152°
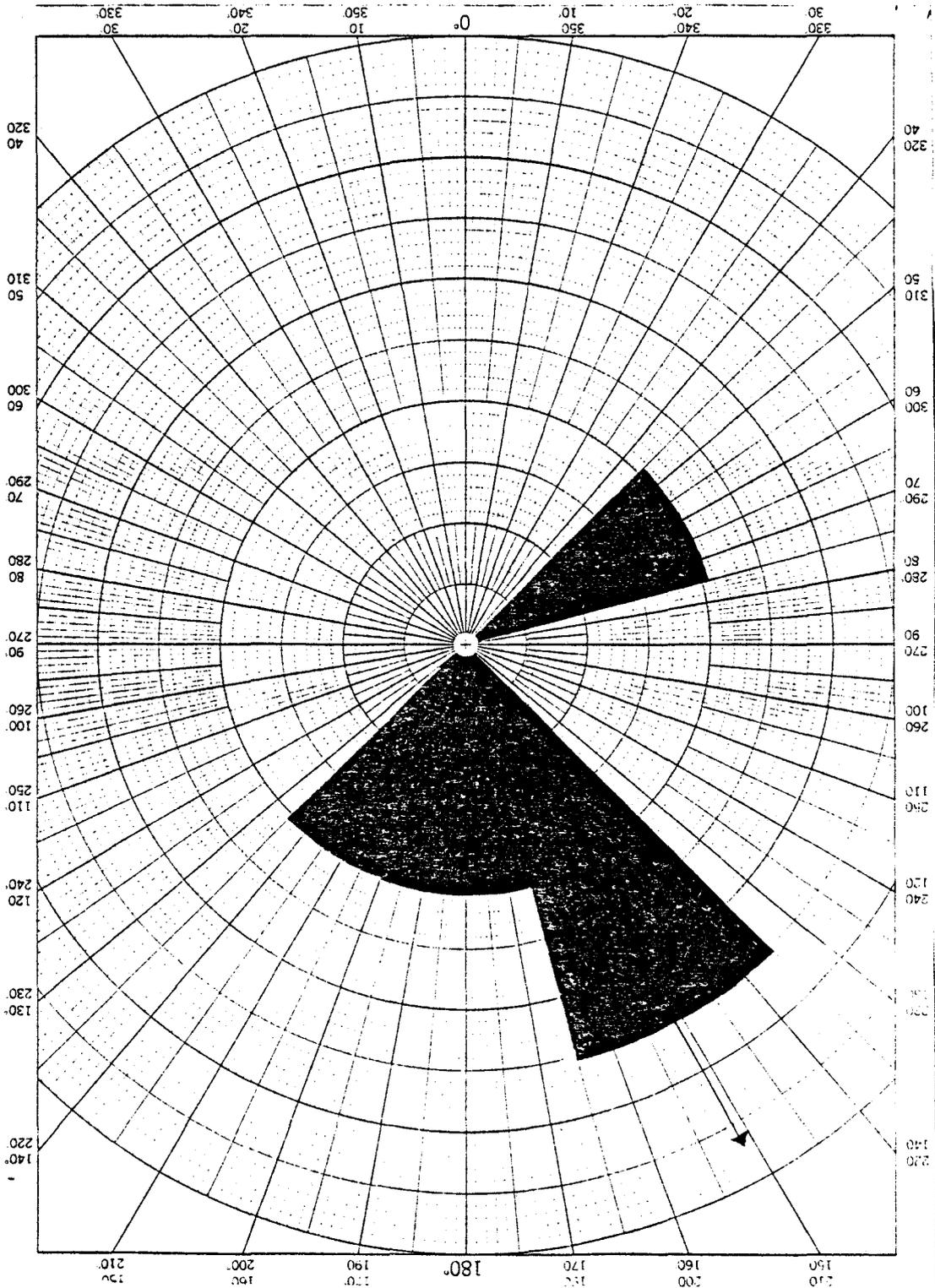
Figure 4.3   Rose diagram plot for current lineations

n=6, L=11%, vector mean = 184°

55
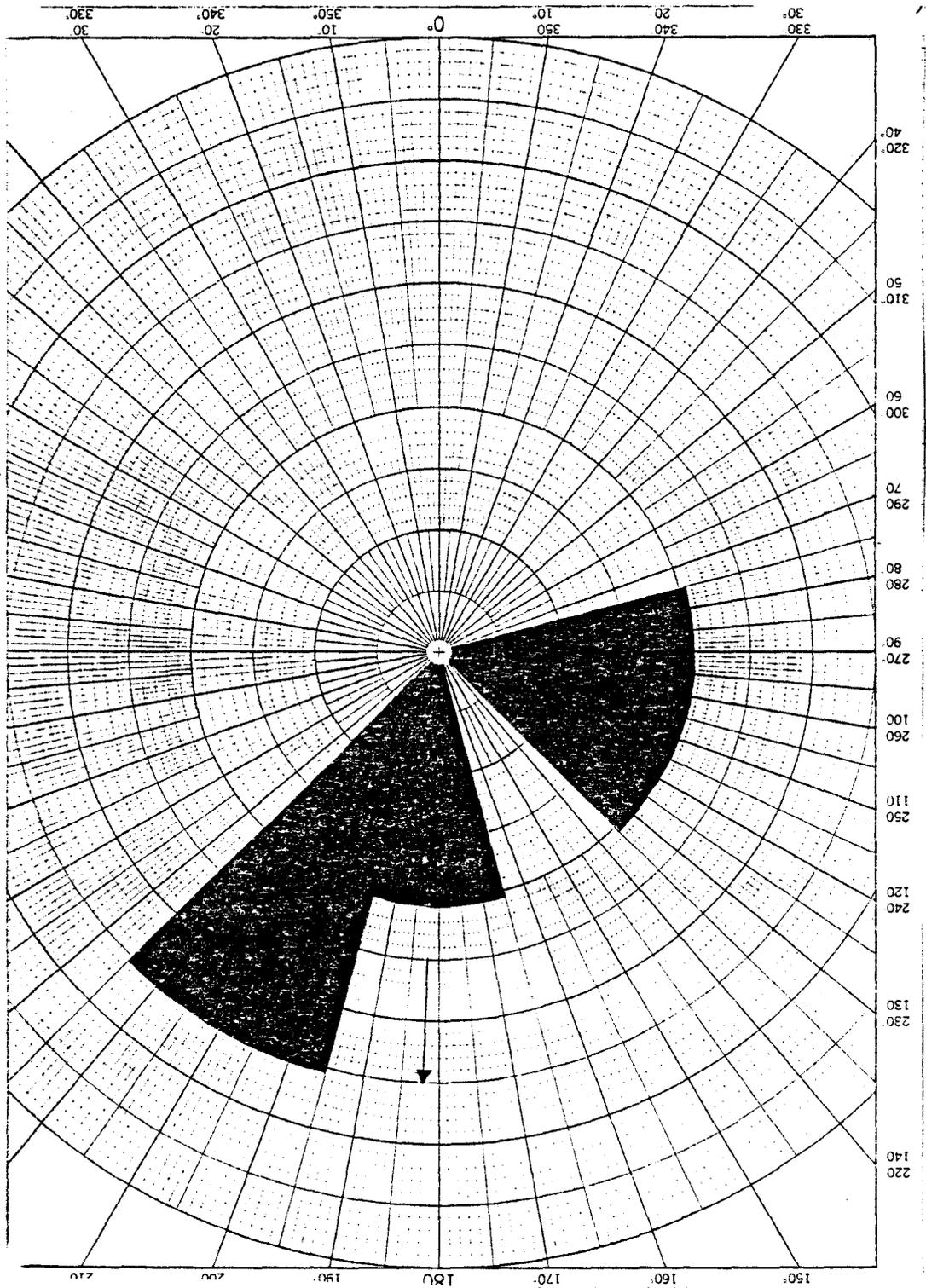
of planar cross-beds correspond closely to the trend

of the main channel althgouh the dispersion is considerable.

For low flood stage the variance is reported to be 3965

on active bars and 5650 on exposed bars. The variance

is simply the square of the standard deviation which

can be determined by using the method of Curry (1956).

Potter and Pettijohn (1963) report a general

range of variance between 4000 and 6000 for·fluvial-

deltaic deposits. However, Banks and Collinson (1973)

suggest that the calculation of variance on modern

deposits leads to an overestimated value when compared to

the value for ancient braided deposits. This overesti-

mation may result because the lowest variance occurs in the

portion of the bar that is most likely to be preserved.

Williams and Rust (1969) report a standard deviation about

the vector mean of 20° - 30° or a variance of less that 1000

for the gravelly braided Donjek River.

Calculations for planar cross-bedded units in

this study reveal a standard deviation of 48 or a variance

of approximately 2300. This would compare roughly with

that of the Donjek River. The difference in variance

is due to the complexities of each individual depositional

environment. Grain size and climatic differences would be expected to influence the sedimentary structures, thereby affecting the variance.

The value determined in this study for trough cross-beds is 77° for standard deviation and 5929 for variance. For current lineation the standard deviation is 49° or a variance of about 2400. Such a large variance value for trough cross-beds appear to support the need to use small-scale structures to determine an accurate paleoflow indication.

Chapter 5

Conclusions

The main contribution of this study is the detailed description of the facies and the facies succession, which complement the conclusion of Nadon (1981) that this member can be interpreted as a distal braided river of the Donjek type (Miall 1978).

This conclusion stands despite the Donjek River being deposited in a humid climatic environment, while the braided river forming the measured section was deposited in a semi-arid environment. A better modern analogue needs to be recognized for a semi-arid braided river system.

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Appendix A1

Transition Matrix

	A$_2$	A$_3$	A$_4$	B$_2$	B$_3$	B$_4$	C	SS	
A$_2$	0	2	6	15	2	13	0	1	39
A$_3$	2	0	1	2	0	4	0	2	11
A$_4$	6	2	0	13	9	9	0	2	41
B$_2$	10	1	10	0	2	2	7	4	36
B$_3$	0	2	7	2	0	0	0	3	15
B$_4$	7	3	11	2	1	0	1	3	28
C	6	0	2	0	0	0	0	0	8
SS	7	1	4	2	0	1	0	0	15
	38	11	41	36	14	29	8	14	193

Appendix A2

Actual Probability Matrix

0	0.051	0.154	0.385	0.051	0.333	0	0.026
0.182	0	0.091	0.182	0	0.364	0	0.182
0.146	0.049	0	0.317	0.220	0.220	0	0.049
0.278	0.028	0.278	0	0.056	0.056	0.194	0.111
0	0.133	0.467	0.133	0	0	0	0.120
0.250	0.107	0.393	0.071	0.036	0	0.036	0.107
0.750	0	0.250	0	0	0	0	0
0.467	0.067	0.267	0.133	0	0.067	0	0

Appendix A3

Random Probability Matrix

0	0.071	0.266	0.234	0.091	0.188	0.052	0.091
0.209	0	0.225	0.198	0.078	0.159	0.044	0.078
0.208	0.072	0	0.237	0.092	0.191	0.053	0.092
0.242	0.070	0.261	0	0.089	0.185	0.051	0.089
0.213	0.062	0.230	0.202	0	0.163	0.045	0.079
0.230	0.067	0.248	0.218	0.085	0	0.048	0.085
0.205	0.059	0.222	0.195	0.076	0.151	0	0.076
0.213	0.062	0.230	0.202	0.079	0.163	0.045	0

Appendix A4

Difference Matrix

0	-0.020	-0.112	0.151	-0.040	0.145	-0.052	-0.065
-0.027	0	-0.134	-0.016	-0.078	0.205	-0.044	0.104
-0.062	-0.023	0	0.086	0.128	0.029	-0.053	-0.043
0.036	-0.042	0.017	0	-0.033	-0.129	0.143	0.022
-0.213	0.071	0.287	-0.069	0	-0.163	-0.045	0.035
0.020	0.040	0.145	-0.147	-0.049	0	-0.012	0.022
0.545	-0.059	0.028	-0.195	-0.076	-0.151	0	-0.076
0.254	0.005	0.037	-0.069	-0.079	-0.096	-0.045	0

Appendix A5

Chi Square Matrix

0	–	–	3.78	–	0.77	–	–
–	0	–	–	–	2.89	–	1.52
–	–	0	1.11	7.25	0.17	–	–
0.19	–	0.04	0	–	–	14.52	0.20
–	1.23	3.65	–	0	–	–	2.86
0.05	0.67	2.37	–	–	0	–	0.16
11.59	–	0.03	–	–	–	0	–
4.53	0.01	0.09	–	–	–	–	0

Appendix Bl

Trough Cross-Beds

θ	n	%	$\sqrt{\%}$
345-15	1	7.7	2.8
045-075	1	7.7	2.8
075-105	3	23.1	4.8
105-135	1	7.7	2.8
165-195	2	15.4	3.9
195-225	3	23.1	4.8
225-255	1	7.7	2.8
315-345	1	7.7	2.8

V=-3.009

W= 2.084

θ=145°

R=3.66

L=28%

S=77°

variance = 5929

Rayleigh test = $1-e^{\left(\frac{R^2}{N}\right)}$
=0.65
$\therefore$ reject null hypothesis
(>0.05)

Appendix B2

Planar Cross-Beds

Θ	n	%	$\sqrt{\%}$
045-075	1	16.6	4.1
135-165	3	50.0	7.1
165-195	1	16.6	4.1
195-225	1	16.6	4.1

V=-0.655

W=0.355

Θ=152°

R=0.745

L=12%

S=48°

variance = 2304

Rayleigh test = $1-e^{-\left(\frac{R^2}{N}\right)}$

=0.09

∴ reject null hypothesis
(>0.05)

Appendix B3

Current Lineation (with assumed southerly direction)

Θ	n	%	$\sqrt{\%}$
075-105	1	16.6	4.1
105-135	1	16.6	4.1
165-195	1	16.6	4.1
195-225	3	50.0	7.1

V=-0.670

W=-0.049

$\Theta=184°$

R=0.672

L=11%

S=49°

variance = 2401

Rayleigh test = $1-e^{-(\frac{R^2}{N})}$
$ =0.07$
$\therefore$ reject null hypothesis
$ (>0.05)$