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SEDIMENTOLOGY OF THE WAPIABI-BELLY RIVER TRANSITION
AND THE BELLY RIVER FORMATION (UPPER CRETACEOUS)
NEAR GHOST DAM, ALBERTA.

SEDIMENTOLOGY OF THE WAPIABI-BELLY RIVER TRANSITION AND THE BELLY RIVER FORMATION (UPPER CRETACEOUS) NEAR GHOST DAM, ALBERTA.

By

DOUGLAS WAYNE HAYWICK

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AUTHOR: Douglas Wayne Haywick

SUPERVISORS: Dr. R. G. Walker and Dr. P. M. Clifford

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ABSTRACT

The Wapiabi-Belly River transition and the Belly River Formation was studied in detail in seven sections in the Ghost Dam spillway, near Ghost Dam,Alberta. Units in the lowest portion of the outcrop (Wapiabi) are characterized by sandy mudstones, often coarsening upwards. The mudstones are overlain by storm generated, hummocky cross-stratified sandstones and beach deposits. The vertical sequence represents a shallowing trend.

Above the beach deposits lie sandstone and interbedded mudstone-sandstone units (Belly River) deposited in a meandering river environment. Sandstones thicker than approximately two metres were deposited as point bars, show sedimentary structures representative of channels and often pinch out, or laterally interfinger with mudstone. Interbedded mudstone-sandstone units were formed during flood stages. These overbank deposits are classified as either proximal or distal components of the meandering river system.

Several marine trace fossils, (*Macaronichnus segregatis*, *Skolithos*, *Planolites*, *Chondrites*, *Teichichnus*, and *Ophiomorpha nodasa*), found in the Belly River rocks suggests a minor marine influence on the river system.

The river system is inferred to have been moderately

to highly sinuous and comparable in discharge to the Humber and Credit Rivers (Ontario).

Petrograghic studies show that point bar sandstones are often characterized by fining upward trends and an upward increase in the proportion of carbonate cement.

Distal overbank deposits are normally overlain by proximal overbank deposits which inturn are overlain by either point bars or distal overbank deposits. Point bar deposits may be overlain by either proximal or distal overbank.

ACKNOWLEDGEMENTS

The author wishes to thank Drs. R. G. Walker and P. M. Clifford who together provided expert advice and guidance throughout the project and yet at the same time, allowed him to tackle it in his own manner.

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CHAPTER ONE

INTRODUCTION

OBJECTIVES

The Belly River Formation consists of a series of sandstones, siltstones and mudstones ranging in thickness from 350 to 900 metres (Shawa, 1975) (Figure 1-1). It is thickest in the Alberta Foothills and thins to the south and east where it interfingers with the underlying Wapiabi Formation; a 450 to 600 metre thick sequence of dark bioturbated shales and thin interbedded fine grained sandstone with sharp bases and tops (Stott, 1963). The Upper Wapiabi Formation, composed of thin, grey, calcareous, fine grained, laminated sandstones interbedded with dark grey silty shale, grades upwards into a 30 $\pm$ 10 metre thick marine sandstone termed the Basal Belly River sandstone. Above this, Belly River sediments are dominantly non-marine.

Overlying the Belly River Formation is the marine Bearpaw Formation, 100 to 250 metres of mudstone very similar in nature to the Wapiabi Formation. The Bearpaw extends only as far north as the present Bow River, separating the Belly River from the continental sediments of the Edmonton and Saint Mary River Formation. Northward,

FIGURE 1-1: Cretaceous stratigraphic nomenclature of Southwestern Alberta. (Modified after Shawa 1975)

AGE		THICKNESS (m)	LITHOLOGY & ENVIRONMENT	STRATIGRAPHY		
U. CRETACEOUS	Maestrichtian	300–1000	Continental	Edmonton Fm. / St. Mary River Fm.		
U. CRETACEOUS	Maestrichtian / Campanion	300–1000	Continental	Blood Reserve Fm.		
U. CRETACEOUS	Campanion	100–250	Marine	Bearpaw Fm.		
U. CRETACEOUS	Campanion	350–900	Continental	Oldman Fm.		Belly River Gp.
U. CRETACEOUS	Campanion	350–900	Continental	Foremost Fm.		Belly River Gp.
U. CRETACEOUS	Campanion	350–900	Deltaic	Transition Zone		Belly River Gp.
U. CRETACEOUS	Santonian	450–600	Marine	Hanson	Wapiabi Fm.	Alberta Gp.
U. CRETACEOUS	Santonian	450–600	Marine	Thistle	Wapiabi Fm.	Alberta Gp.
U. CRETACEOUS	Santonian / Coniacian	450–600	Marine	Dowling	Wapiabi Fm.	Alberta Gp.
U. CRETACEOUS	Coniacian	450–600	Marine	Marshybank	Wapiabi Fm.	Alberta Gp.
U. CRETACEOUS	Coniacian	450–600	Marine	Muskiki	Wapiabi Fm.	Alberta Gp.
U. CRETACEOUS	Turonian	40–100	Littoral	Cardium Fm.		Alberta Gp.
U. CRETACEOUS	Cenomanian	250–300	Marine	Blackstone Fm.		Alberta Gp.
L. CRETACEOUS	Albian	450–800	Mainly Continental	Blairmore Gr.		
L. CRETACEOUS	Aptian	450–800	Mainly Continental	Blairmore Gr.		
L. CRETACEOUS	Neocomian	15–30	Mainly Continental	Cadomin Fm.		
L. CRETACEOUS	Neocomian	0–450		Kootenay Fm.		

beyond the Bow River, the Belly River and Edmonton Formations are inseparable and together are called Brazeau.

The objectives of this study are three fold; to examine the nature of the Wapiabi - Belly River transition at the Ghost Dam exposure with emphasis on the depositional history; to provide lithological and paleocurrent data concerning the Belly River Formation; and to determine and interpret the facies model best applicable to the Belly River Formation at this location.

PREVIOUS WORK

Mapping and interpretation of the Upper Cretaceous sediments of Alberta was first undertaken in 1883 by Dawson who was primarily concerned with the economic evaluation of coal resources. He applied the name "Belly River Series" to describe pale grey, arenaceous beds directly underlying the Pierre Shales along the Belly River in south-eastern Alberta. The following year, Dawson examined other outcrops along the Milk, Saint Mary, Upper Belly and Waterton Rivers and divided his series into an upper pale coloured, dominantly fresh water unit and a lower, yellow coloured marine unit. Dowling (1916, 1917) interpreted Dawson's pale beds to be of fresh water origin and renamed the yellow beds "Foremost".

Allan (1927, 1928, 1929), was commissioned to examine the geology of the Belly River exposure on the Bow River near Cochrane, Alberta (subject of this thesis), as a part of the construction of the Ghost Power Dam. He tentatively described the rocks of this exposure as a series of fresh water sandstones and mudstones overlying a marine sequence. His reports however, were primarily concerned with engineering problems and construction progress at the dam, rather than interpretation of the geology.

The sedimentary sequences of the Foremost were divided into three portions on the basis of depositional environments determined by Slipper and Hunter (1931). The lower unit was described as beach, the middle as lagoonal and the upper unit as deltaic. The interfingering of the Foremost with marine shales was interpreted to have been caused by a regressive Lee Park Sea.

Dawson's pale beds were renamed "Oldman" by Russell and Landes (1940) who also raised Oldman and Foremost to Formational status. Crockford (1949) interpreted the Oldman Formation as continental deposits and the Foremost Formation as fresh water in origin.

In 1963, Lerbekmo examined the petrography of the Drywood River exposure of Belly River Formation and concluded that the source region of the sediments probably lay to the south and west of that location. He further interpreted the depositional environment to be a low lying coastal plain with channels and overbank (flood) deposits.

Nelson and Glaister (1975) and Glaister and Nelson

(1978) interpreted the Belly River exposure at Trap Creek as prodelta, distributary mouth bar and delta plain deposits. The Chin Coulee exposure of the Oldman and Foremost Formations has been studied by Shawa and Lee (1975) who interpreted the Foremost to be of fresh water origin and the Oldman as large fluvial channel deposits. Ogunyomi and Hills (1977) examined eighteen stratigraphic sections in the Milk River area of southern Alberta. The Foremost was considered to contain depositional cycles, a complete cycle consisting of environments ranging from offshore transition at the base, through barrier island, lagoon and salt marsh, to fresh water marsh at the top. The Oldman was interpreted as fluvial.

Hunter (1980) examined the Wapiabi - Belly River transition at Highwood River, Alberta and determined that the transition contained storm generated density flow deposits. Recently Bullock (1981) has re-examined the Belly River outcrop near Lundbreck Falls that had been originally described as prograding delta by Lerand and Oliver (1975, 1980). He describes deep water Bouma type turbidites overlain by hummocky cross-stratification and beach deposits, (cf. Hunter, 1980). The beach facies in turn is overlain by nonmarine mudstones and fluvial sandstones. Bullock interpreted the sequence to be the result of a shallowing trend produced by the progadation of the Belly River shoreline.

Past studies have shown that in eastern Alberta, the Belly River Formation consists of alternating marine and nonmarine units overlain by nonmarine, dominantly fluvial sediments. Towards central and western Alberta, no alternations have been observed.

A more detailed summary of previous work can be found in McClean, (1971), and is summarized in Table 1-1.

STRATIGRAPHY

During Upper Cretaceous times, a broad epeiric sea (Colorado Sea) covered most of the western interior of North America, at times connecting the Arctic Ocean to the Gulf of Mexico. To the west, the sea was flanked by the rising mountains of the central cordillera, to the east by the Canadian Shield (Williams and Burk, 1966). Undoubtedly, both sources supplied sediments to the sea, but most material was probably derived from the higher topography in the west.

The gradual retreat of the Colorado Sea during the Upper Cretaceous, and subsequent increased sediment flow into the shallowing sea, resulted in a series of regressive coarsening upward sequences, the last of which becomes the Basal Belly River sandstone in the transition from marine to non-marine (Rosenthal, personal communication).

Although worldwide sea level changes occurred during the Upper Cretaceous, tectonism was probably the

TABLE 1-1: Summary of major studies concerning the Belly River Formation in Western Canada and Northern Montana. Note especially the confusion generated by the lack of a standardized nomenclature (After McClean, 1971).

AUTHOR	DATE	CONTRIBUTION
Hayden	1871	Formally proposed the name "Judith group" for strata exposed near the mouth of the Judith River.
Meek	1876	The name "Judith River Group" was employed.
Dawson	1883	The name "Belly River series" introduced for beds exposed along the Belly River (now Oldman River) from Lethbridge downstream.
Dawson	1884	More detailed geological work of southern Alberta. Dawson failed to recognize the presence of the Claggett (Pakowki) Shale, which gave rise to the subsequent nomenclatural confusion.
McConnell	1885	Introduced the name "Belly River series" in southern Saskatchewan.
Tyrrell	1887	Introduced the name "Belly River series" in east-central Alberta.
White	1891	Employed the name "Belly River" in preference to "Judith River" in his comprehensive report on the Upper Cretaceous rocks of North America.
Stanton and Hatcher	1903 1905	Established the succession Bearpaw, Judith River, Claggett, Eagle in Montana and correlated with Dawson's Belly River series along the Milk River.
Stebinger	1914	Introduced the name "Two Medicine Formation" on the west side of the Sweetgrass arch in Montana. Related it to Dawson's Belly River series and Stanton and Hatcher's Judith River Formation.
Bowen	1915	Confirmed Stanton and Hatcher's correlation of strata at the Judith River type area with Judith River beds in surrounding areas.
Dowling	1916 1917	Established four divisions of the Belly River series in southern Alberta: Pale beds, Foremost Formation, Claggett Formation, Milk River Sandstone. Employed the name "Bearpaw" proposed by Stanton and Hatcher.
Slipper	1919	Divided the Belly River series of east-central Alberta into five formations and made tentative correlations with Allan's succession.
Allan	1919	Divided the Belly River series along with the North Saskatchewan River into five formations and made tentative correlations with Slipper's succession.
Williams and Dyer	1930	Redefined the name "Belly River" to include only strata above the Pakowki Formation and below the Bearpaw Formation. Made tentative correlations between southern and east-central Alberta.
Russell	1940	Discontinued use of the name "Belly River" in the southern Alberta plains. Proposed the name "Oldman" as a substitute for "Pale beds". Oldman and Foremost employed as formation names.
Hume and Hage	1941	Discontinued use of the name "Belly River" in east-central Alberta and employed Slipper's (1919) divisions as formation names.
Nauss	1945	Re-introduced the name "Belly River" into east-central Alberta as a group name. Modified Slipper's (1919) succession and introduced two new names. Only sand tongues included in the Belly River Group. Intermediate clay tongues assigned to the Lea Park Shale.
Furnival	1946	Employed the names "Oldman" and "Foremost" in southwestern Saskatchewan to the exclusion of the name "Belly River".
Shaw and Harding	1949	Employed "Belly River" as a formation name. Revised and combined parts of Slipper's (1919) and Allan's (1919) successions. Included both sand and clay tongues as members of the Belly River Formation.
Caldwell	1968	Established an eleven member division of the Bearpaw Formation in west-central Saskatchewan.

dominant factor in the positioning of the paleoshore line of the Colorado Sea. Towards the east, the Lower Belly River has been observed in subsurface to interfinger with the marine Wapiabi (Lea Park) mudstones (Figures 1-2 and 1-3). Collectively, the Belly River sediments deposited in this fluctuating environment have been called "Foremost" and have been given individual member status. Continued uplift and erosion resulted in the deposition of continental sediments in the east, referred to as the Oldman Formation.

The overlying marine Bearpaw mudstones were deposited during a short transgressive phase when the sea advanced to the central foothills. Subsequent uplift and erosion produced the overlying continental clastics of the Edmonton and Saint Mary River Formations as the sea retreated for the last time.

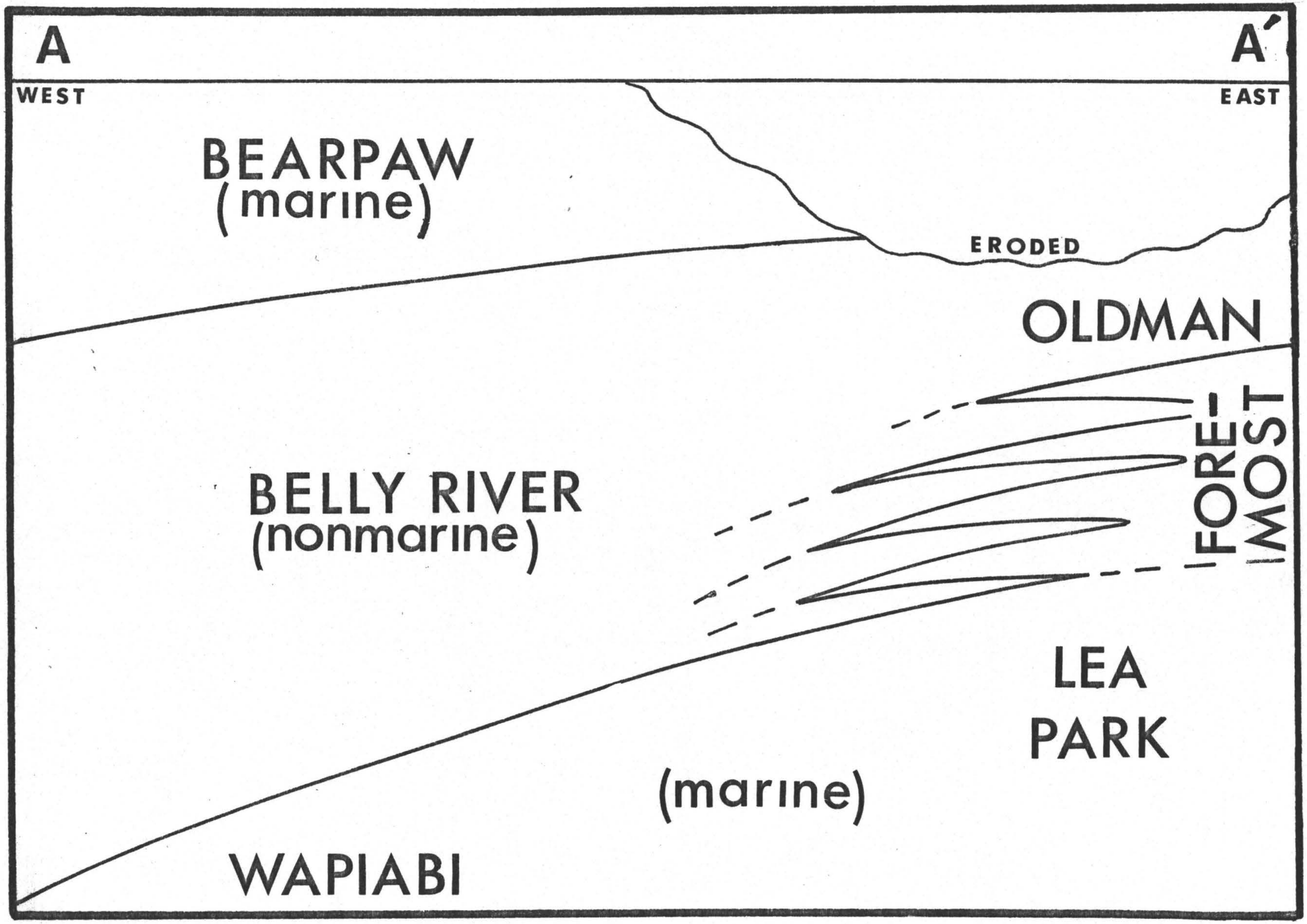
Throughout the many years of study of the Belly River Formation in Western Canada, the lack of a standardized nomenclature (refer to Table 1-1) has been a problem and the subject of considerable controversy. The interval between the Bearpaw and Pakowski (Wapiabi) in particular has been confusing being called Belly River in western and eastern Alberta, Oldman/ Foremost in southeastern Alberta and Judith River in southwestern Saskatchewan and northwestern Montana.

McClean (1971, 1977) after reviewing all past literature on the subject of nomenclature of the Belly

FIGURE 1-2: Map of Southern Alberta showing location of cross-section AA' a schematic cross-section showing the interfingering of the Belly River Formation (Foremost) in Eastern Alberta. (After Shouldice, 1979 and Hunter, 1980)


EDMONTON
ALBERTA
CALGARY
A
MEDICINE HAT
A′
0 20 60 100
(km.)

FIGURE 1-3: Diagrammatic cross-section A-A' (not to scale) showing interfingering of the Foremost Formation in the East. (After Shouldice, 1979)


A
A'
WEST
EAST
BEARPAW
(marine)
ERODED
OLDMAN
FORE-
MOST
BELLY RIVER
(nonmarine)
LEA
PARK
(marine)
WAPIABI

River Formation, suggests the elimination of the Formational names "Belly River", "Oldman" and "Foremost" in favor of "Judith River" which is older and used in Montana. Belly River would be retained specifically for the interval between the Wapiabi and Bearpaw Fromations in the southwestern Alberta foothills. Although for much of central Alberta and the southern Alberta planes, the Foremost and Oldman Formations can be recognized, (Russell and Landes, 1940, Oliver, 1966), McClean argues that they cannot always be distinguished from one another in eastern Alberta, nor can the distinction be made in western Alberta because the Foremost Formation does not extend that far. His argument for a change in nomenclature may be valid, but because the Formational name Belly River is so strongly established in the records of Alberta, the traditional nomenclature will be used in this study.

LOCATION

Field work was undertaken in the summer of 1981 at the Ghost Dam, approximately 5 km east of Ghost Lake, 15 km northwest of Cochrane and 38 km northwest of Calgary, Alberta along Highway 1A (Figure 1-4).

The outcrop is located in the Ghost Dam spillway approximately 275 metres southeast of the main dam (Figure 1-5). Thrusting in this region of Alberta (foothills) has caused the beds to dip at angles between 20 and 25° towards the west.

FIGURE 1-4: Location of Ghost Dam spillway outcrop near Ghost Lake, Alberta.

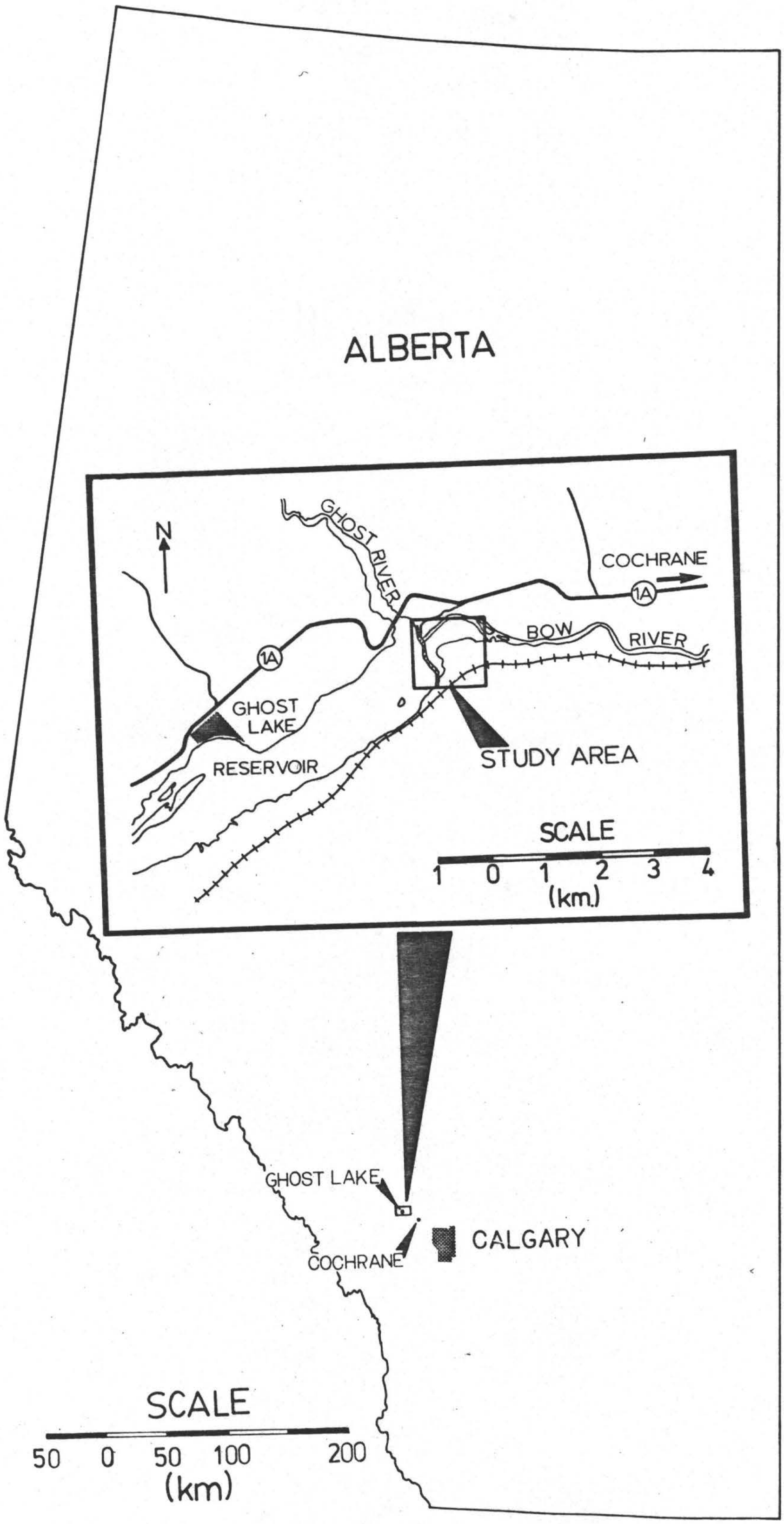
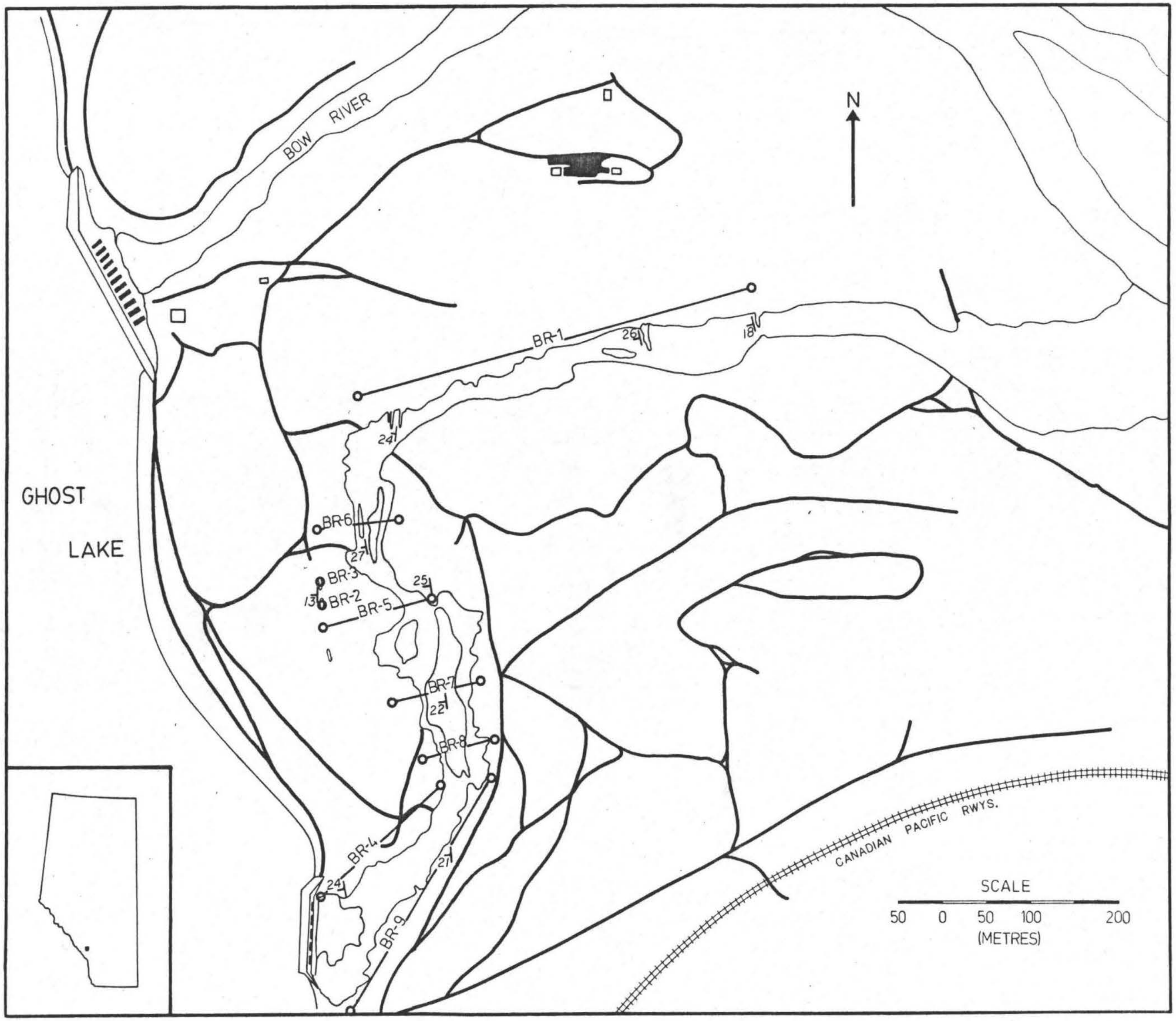

ALBERTA
N
GHOST RIVER
COCHRANE
1A
BOW
RIVER
1A
GHOST
LAKE
RESERVOIR
STUDY AREA
SCALE
1 0 1 2 3 4
(km.)
GHOST LAKE
COCHRANE
CALGARY
SCALE
50 0 50 100 200
(km)

FIGURE 1-5: Detailed map of study area showing location of stratigraphic sections (BR-1 to BR-9).


BOW RIVER
N
GHOST
LAKE
BR-1
BR-2
BR-3
BR-4
BR-5
BR-6
BR-7
BR-8
BR-9
CANADIAN PACIFIC RWYS.
SCALE
50 0 50 100 200
(METRES)

Much of the lower section is poorly exposed or covered but this gives way to excellent two and three dimensional exposures towards the middle of the outcrop. Above this point, the exposure is again irregularly covered.

Water levels in the spillway vary widely and the flood gates may be opened at anytime. Caution is advised when working in the spillway.

Seven sections labelled BR-1, BR-4, BR-5, BR-6/2/3, BR-7, BR-8 and BR-9 (refer to Figure 1-5), have been measured across the outcrop area in an attempt to record lateral variations in the exposure, especially with respect to sandstones. The total vertical measured thickness of the section is 220 metres.

CHAPTER TWO

UNIT DESCRIPTIONS AND INTERPRETATIONS

The sediments of the Wapiabi Formation (Nomad, Chungo and Hanson members) and the Belly River Formation in the Ghost Dam spillway have been divided into twenty three units which can be differentiated from one another on the basis of lithology, sedimentary structures and biogenic content.

Sandstones greater than approximately 2.0 metres in thickness are rare in the exposure and therefore each substantial sandstone or sandstone sequence, has been described as an individual unit. There are twelve such sandstone units. It became evident after describing the units that two of the sandstones differ drastically for a number of reasons from the other ten and could be explained by a different interpretation. As a result the twelve sandstone units have been grouped together into two facies; Facies B consisting of Units B1 and B2 and Facies C, consisting of Units C1 to C10.

Figures 2-1 to 2-7 are stratigraphic sections showing the positions of the sandstones in the various sections and Table 2-1 is a legend for them. Figure 2-8

TABLE 2-1: Legend for stratrigraphic sections (Figures 2-1 to 2-7) and fold out (Figure 2-8).

LEGEND

LITHOLOGIES

- Sandstone
- Siltstone
- Mudstone

SEDIMENTARY STRUCTURES

- Ripple Cross-bedding
- Trough Cross-bedding
- Low Angle Planar Cross-bedding
- Planar Tabular Cross-bedding
- Hummocky Cross-stratification
- Accretionary Surface
- Undulatory Top
- Loading
- Mudstone Drape
- Chute

CONSTITUENTS

- Bioturbation
- Rootlets
- Comminuted Coal Fragments
- Concretions
- Mud Rip-up Clasts
- Pebbles

PALEO-FLOW

- RF — Rib & Furrow Cross-bedding
- X BED — Planar Tabular Cross-bedding
- R — Asymmetric Ripples
- T — Trough Cross-bedding
- C — Chutes
- S F — Sole/Flute Markings

FIGURES 2-1 to 2-7: Stratigraphic sections of the Ghost Dam spillway outcrop. Refer to Figure 1-5 for the locations of the sections in the outcrop and Table 2-1 for a legend as to the various symbols used. Figure 2-8 (fold out) relates the seven sections to one another.

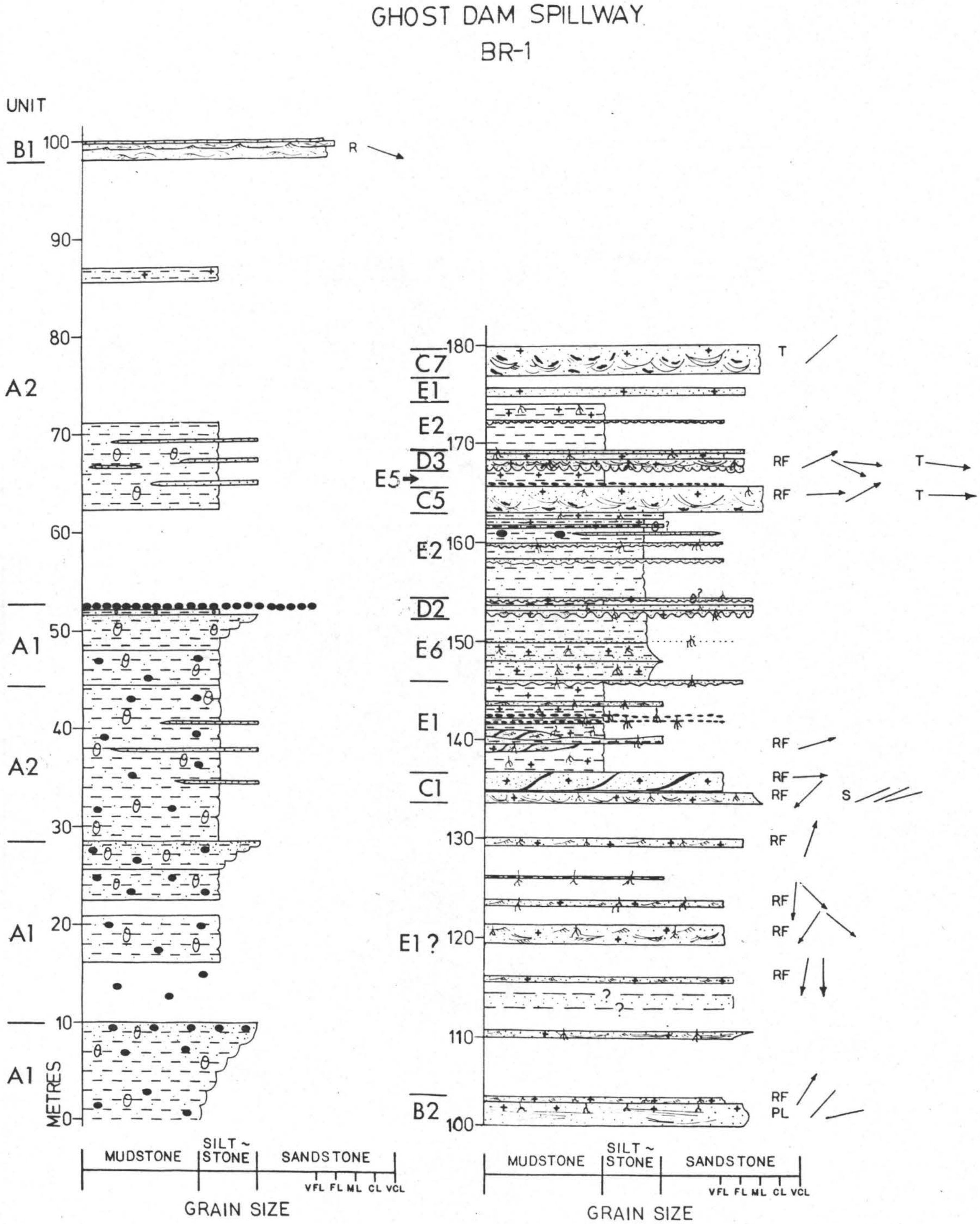

GHOST DAM SPILLWAY
BR-1
UNIT
B1
A2
A1
A2
A1
A1
METRES
R
MUDSTONE
SILT ~ STONE
SANDSTONE
VFL FL ML CL VCL
GRAIN SIZE
C7
E1
E2
D3
E5
C5
E2
D2
E6
E1
C1
E1 ?
B2
T
RF
PL
S

Figure 2-1

GHOST DAM SPILLWAY.
BR-6 & BR-2/3

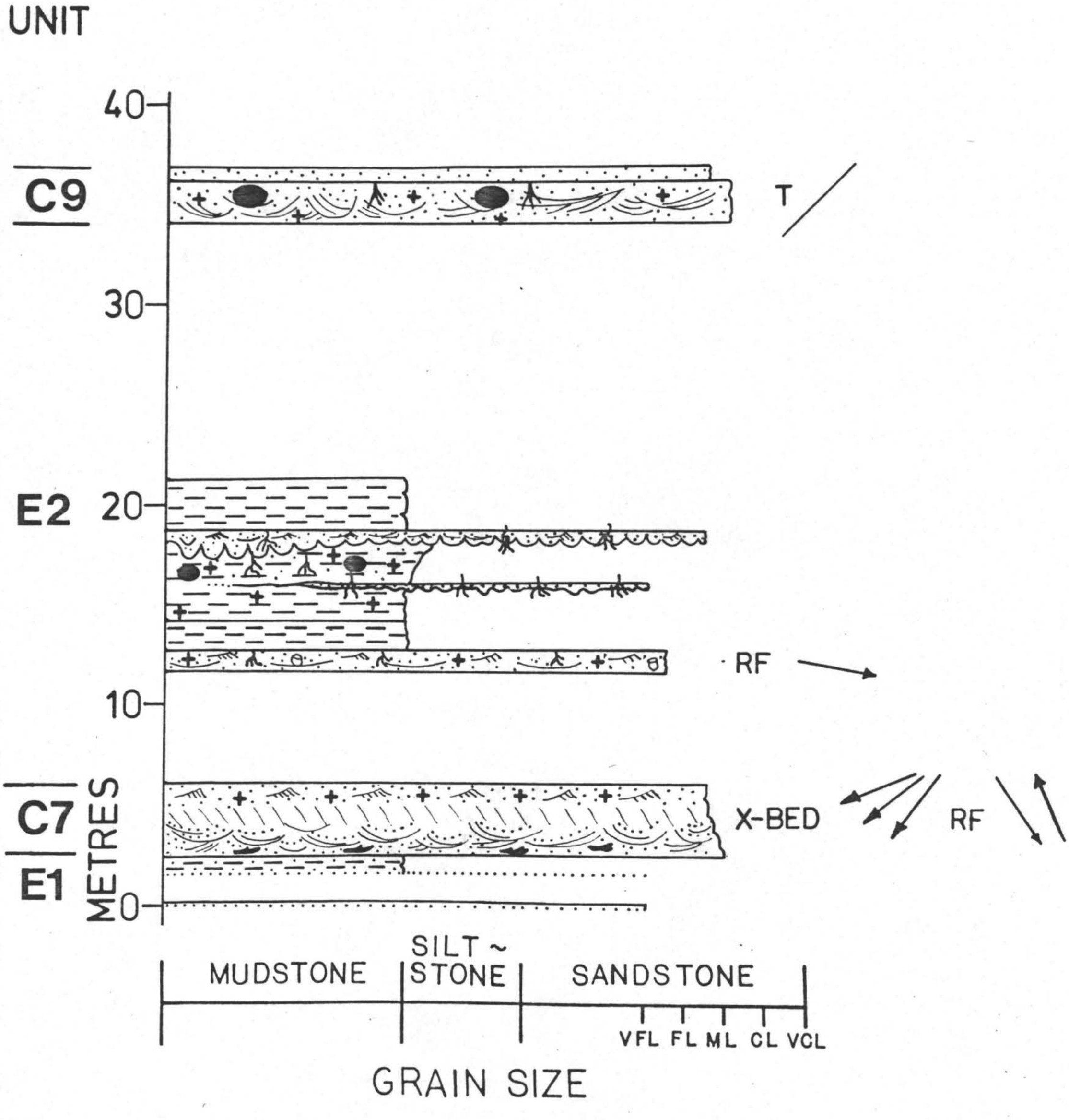


Figure 2-2

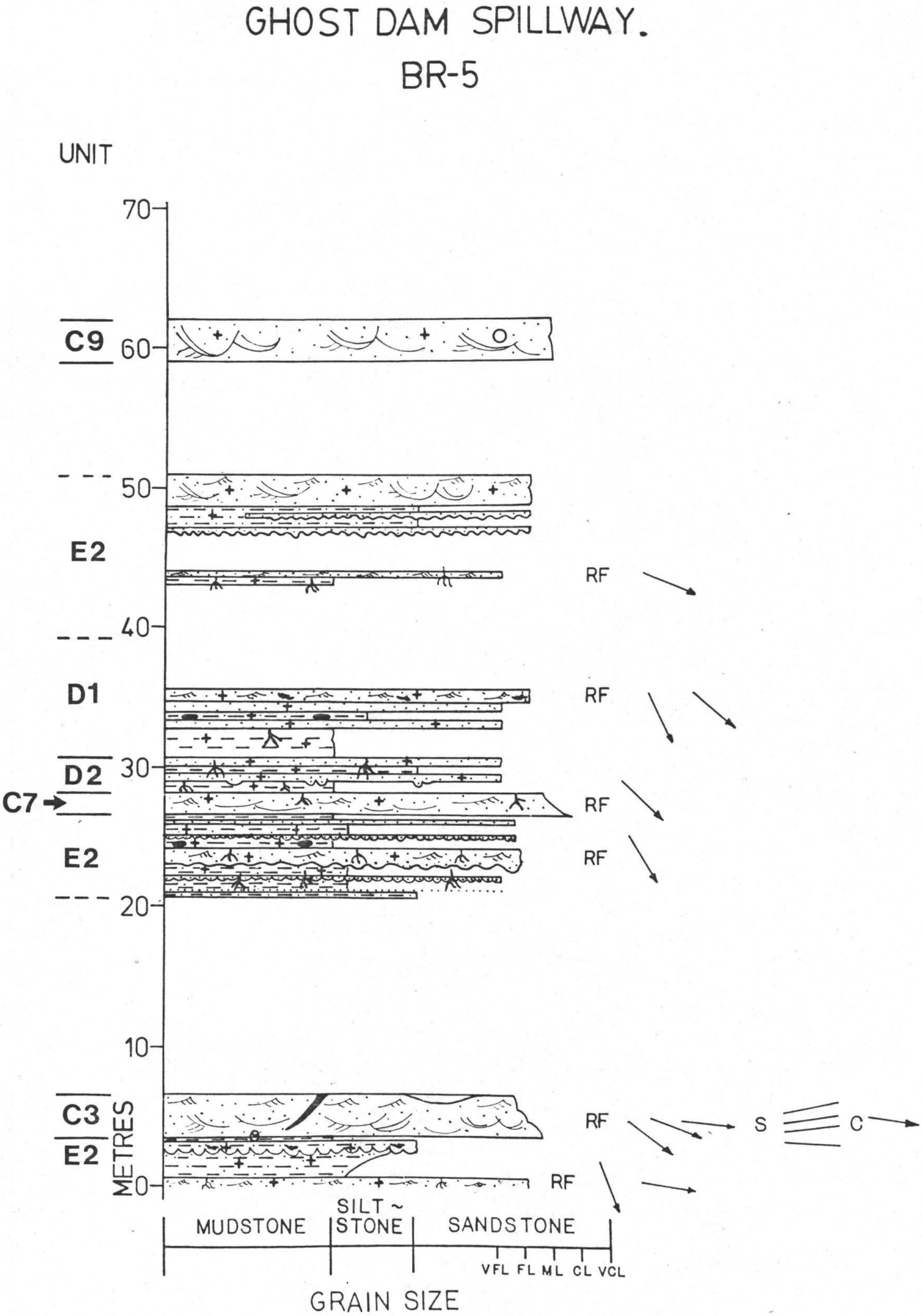

GHOST DAM SPILLWAY.
BR-5
UNIT
70
C9
60
50
E2
RF
40
D1
RF
D2
30
C7
RF
E2
RF
20
10
C3
RF
S
C
E2
METRES
0
RF
MUDSTONE
SILT ~ STONE
SANDSTONE
VFL FL ML CL VCL
GRAIN SIZE

Figure 2-3

GHOST DAM SPILLWAY. BR-7

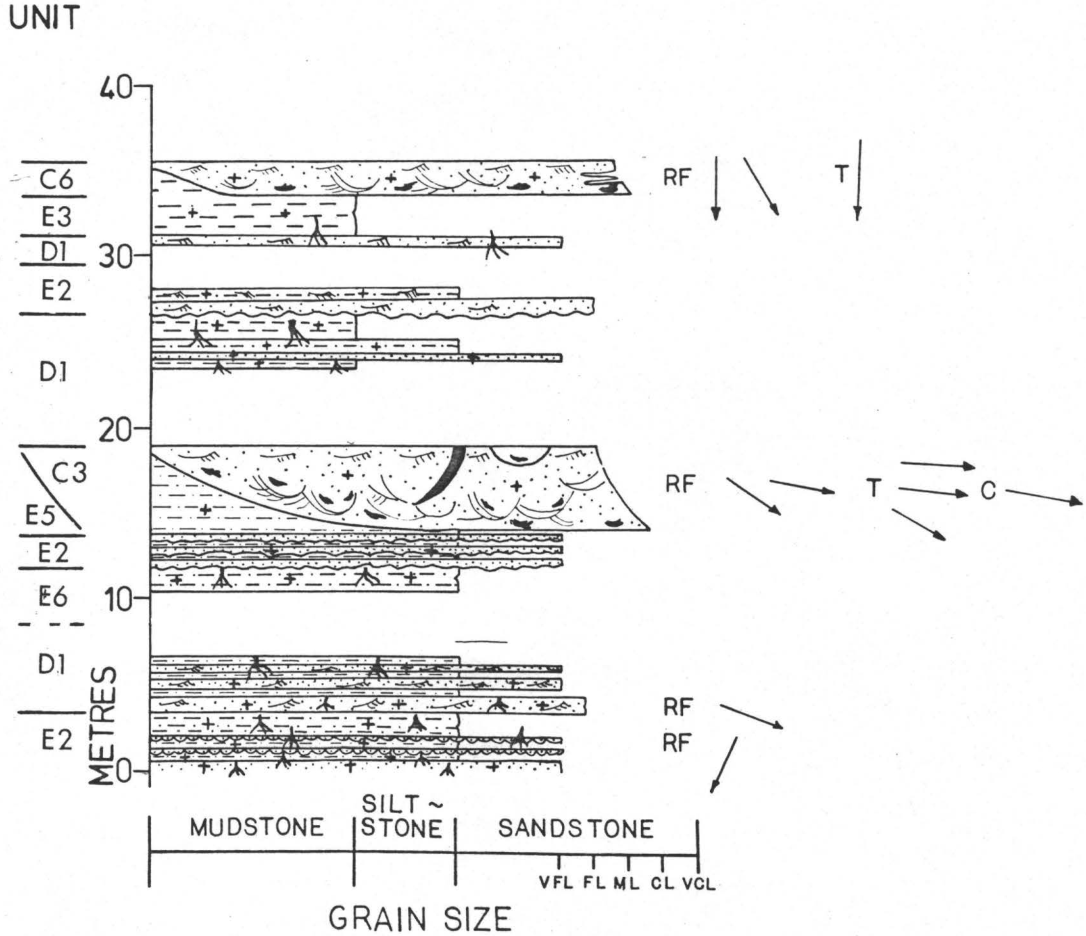


Figure 2-4

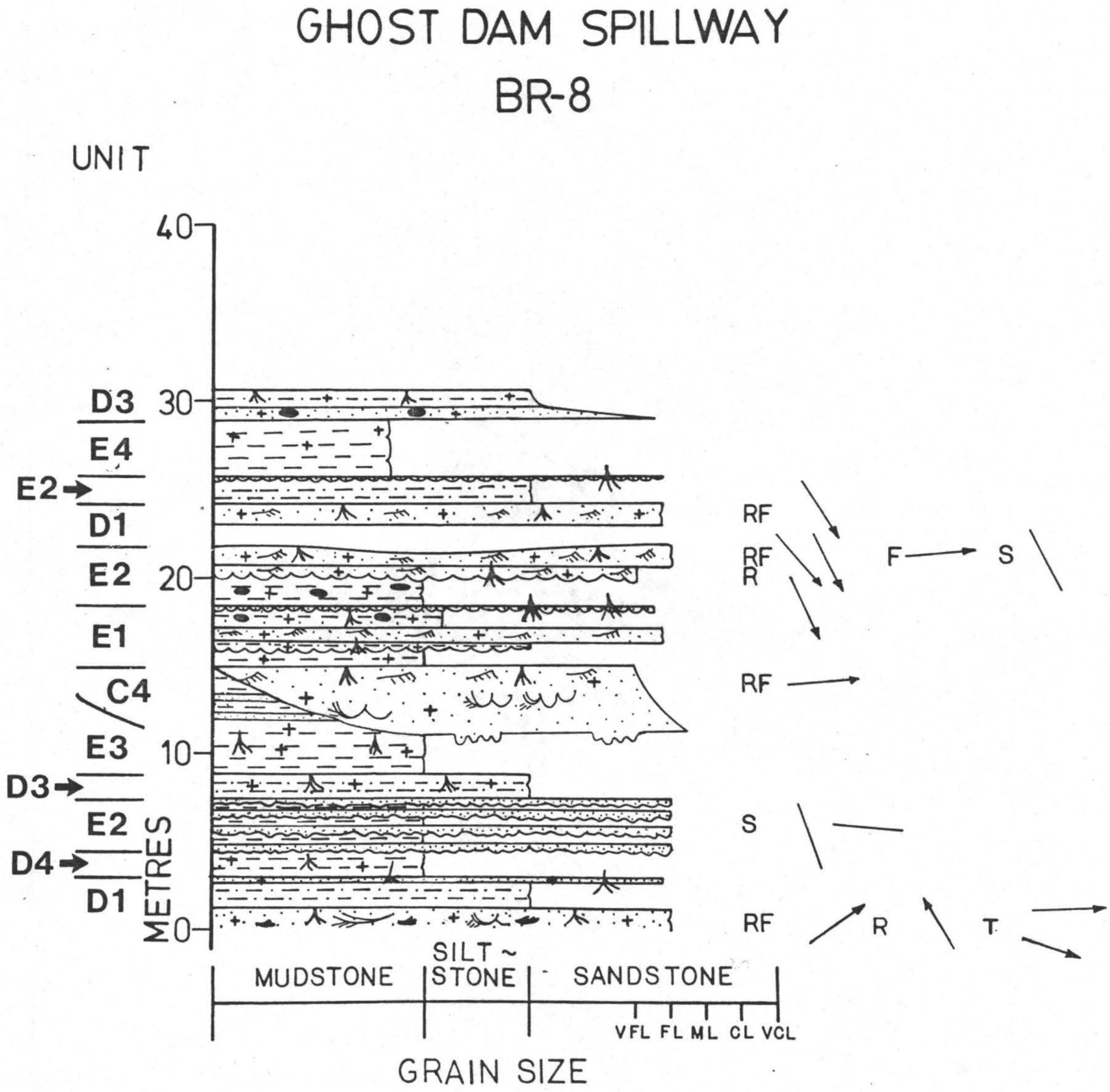

GHOST DAM SPILLWAY
BR-8
UNIT
D3
E4
E2
D1
E2
E1
C4
E3
D3
E2
D4
D1
40
30
20
10
0
METRES
RF
RF
R
F
S
RF
S
RF
R
T
MUDSTONE
SILT ~ STONE
SANDSTONE
VFL FL ML CL VCL
GRAIN SIZE

Figure 2-5

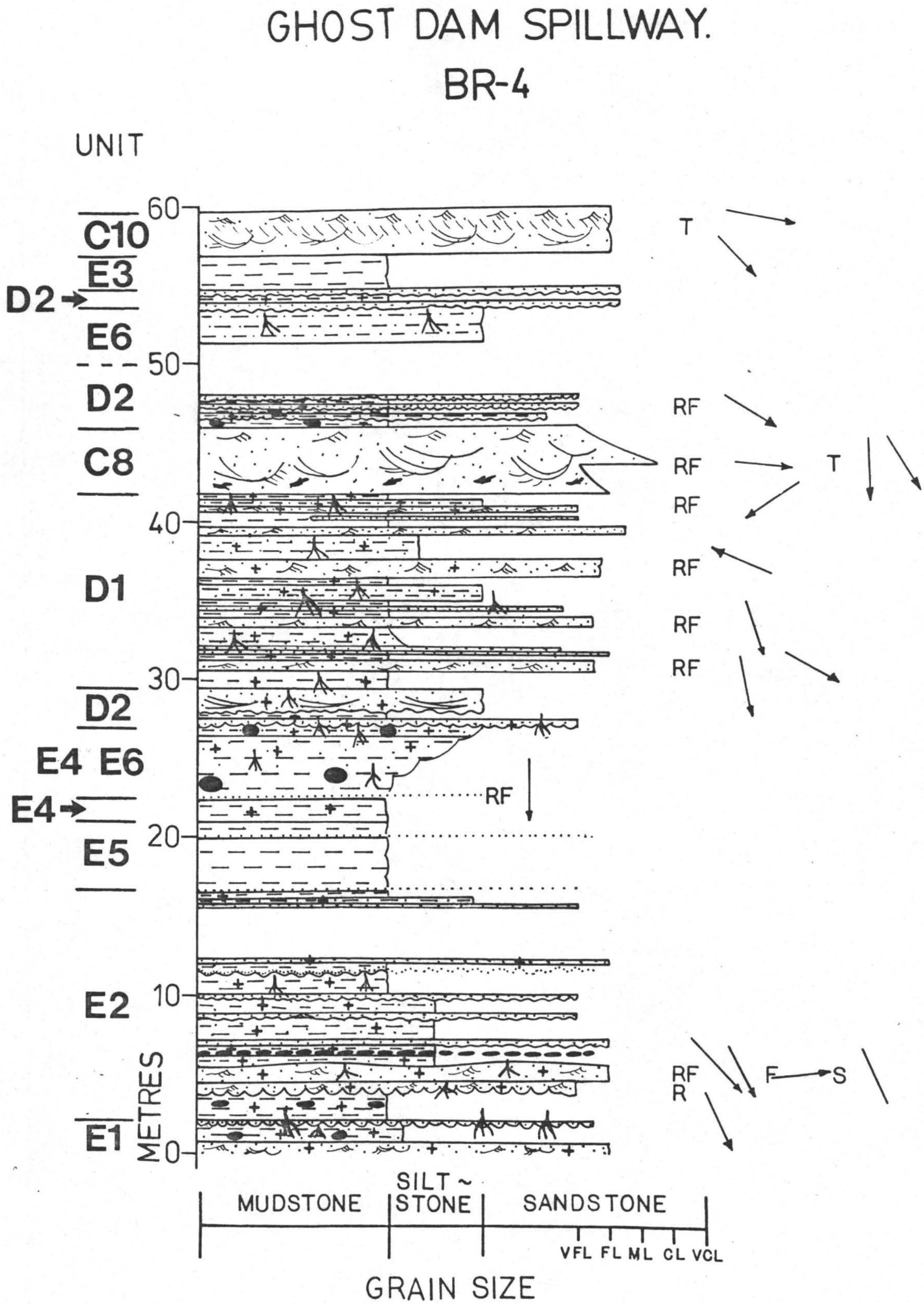

GHOST DAM SPILLWAY.
BR-4
UNIT
C10
E3
D2
E6
D2
C8
D1
D2
E4 E6
E4
E5
E2
E1
METRES
60
50
40
30
20
10
0
T
RF
RF
T
RF
RF
RF
RF
RF
RF
R
F
S
MUDSTONE
SILT ~ STONE
SANDSTONE
VFL
FL
ML
CL
VCL
GRAIN SIZE

Figure 2-6

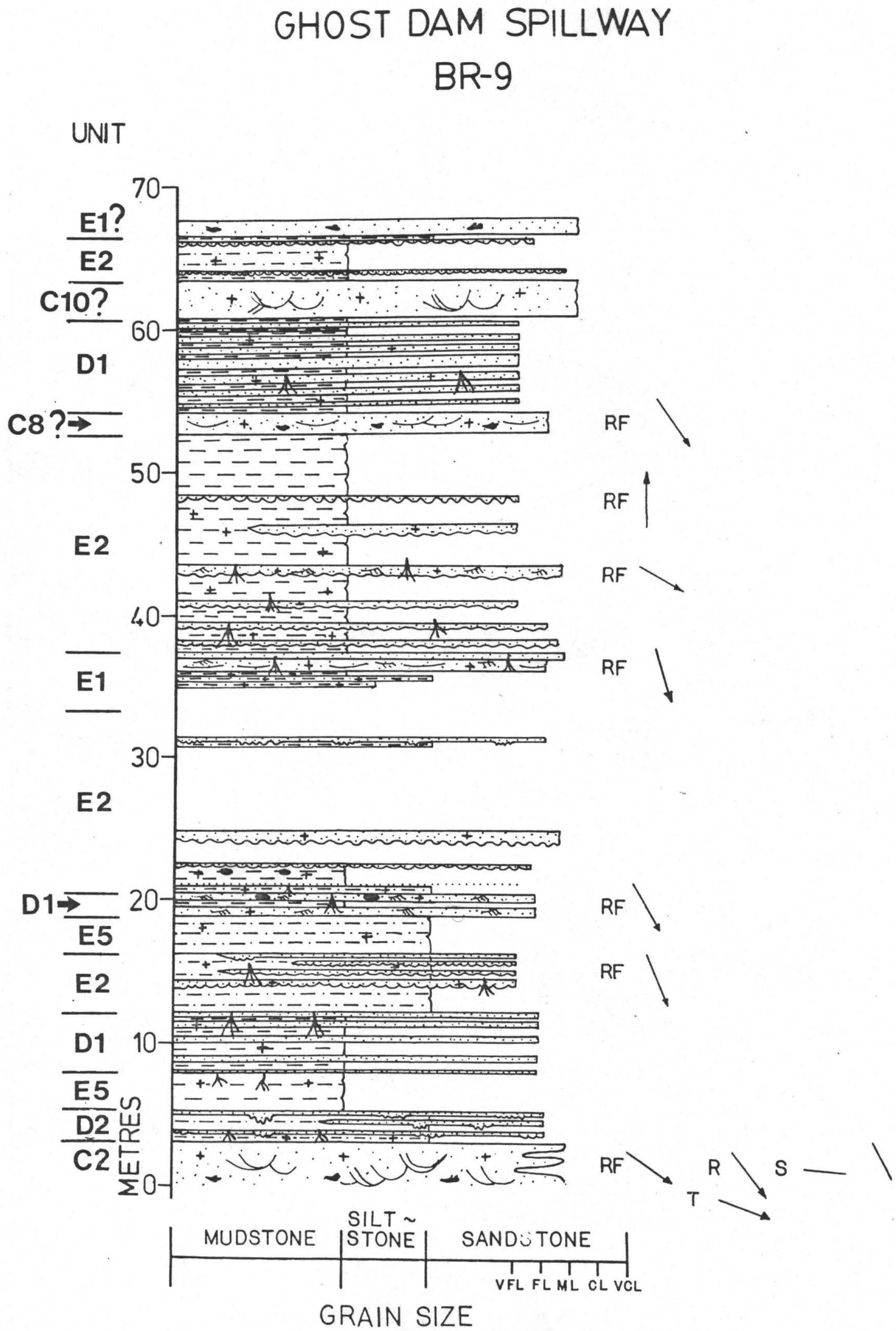

GHOST DAM SPILLWAY
BR-9
UNIT
E1?
E2
C10?
D1
C8?
E2
E1
E2
D1
E5
E2
D1
E5
D2
C2
70
60
50
40
30
20
10
0
METRES
RF
RF
RF
RF
RF
RF
RF
T
R
S
MUDSTONE
SILT ~ STONE
SANDSTONE
VFL
FL
ML
CL
VCL
GRAIN SIZE

Figure 2-7

(fold out), shows the positions of the sandstone units relative to one another.

Mudstone and interbedded mudstone-sandstone sequences have been classified into units based upon the type of organic content, the proportion of sandstone and/or sand sized content and the nature of the mudstone. The term "unit" used to describe these sequences refers to a particular package of lithologies which recur throughout the sections. Eleven different units are described and have been classified into three facies; Facies A consisting of Units A1 and A2, Facies D consisting of Units D1, D2 and D3 and Facies E consisting of Units E1 to E6.

FACIES A

Unit A1

Unit A1 consists of coarsening upward grey-black fissile mudstone or sandy mudstone. Bioturbation is extensive and horizontal traces are contained atop the unit. Within the unit, mussel remains and numerous foraminifera are present. Pyritized micro-burrows approximately 0.25 x 0.75 cm, and traces of glauconite are present towards the sandier upper portions.

The best exposure of Unit A1 occurs at the lowest portion of section BR-1 (Figure 2-1), is greater than 10 metres thick and contains numerous sideritic concretions up to 1 metre in size. The concretions, often in discrete layers, are a rusty colour and stand out from the more recessive mudstones. Towards the top of the sequence, the mudstone grades into a sandy siltstone.

Unit A2

The mudstone of Unit 2 is a dark grey colour, but also has a noticable orange tint due to numerous sideritic concretions. Concretions are up to 1.2 metres in diameter. The sandstone beds average 3.0 to 4.0 cm. in thickness, (maximum 5 cm.), have sharp bases and tops and contain parallel and ripple crossbedding. They are however, laterally discontinous, most are no more than 1 to 2 metres in lateral extent and occur at irregular intervals in the mudstone. Those best exposed are very fine grained, slightly calcareous and contain numerous horizontal trace fossils (including *Helminthoïda*) and vertical trace fossils (*Skolithos*).

INTERPRETATION

Coarsening and thickening upward sequences are generally regarded as prograding wedges of turbidites (Mutti and Ghibauda,1972). The coarsening upward trend exemplified by Unit A1 may be explained by this interpretation. The marine mudstone of Unit A2 is similar to that of Unit A1, however Unit A2 does not coarsen upwards. Thin sharp based sandstones interbedded with marine mudstone implies that the sediments were deposited episodically offshore. High velocity currents are required to produce parallel laminations in the sandstones; slower currents are required to produce ripple crossbedding. The presence of parallel laminations overlain by ripple crossbedding within a single ungraded bed therefore implies a waning current. Most probably, turbidity currents, which rapidly introduce sediment into the marine environment were responsible for the observed features of the sandstones.

The lateral discontinuity of the thin sandstones in Unit A2 probably arises from intense bioturbation, as supported by numerous horizontal and vertical trace fossils within the unit.

FACIES B

Unit B1 [BR-1: 99 to 100 metres]

Unit B1 consists of a 1.0 metre thick exposure of light grey sandstone which ranges in grain size from fine to very fine. The base is not exposed.

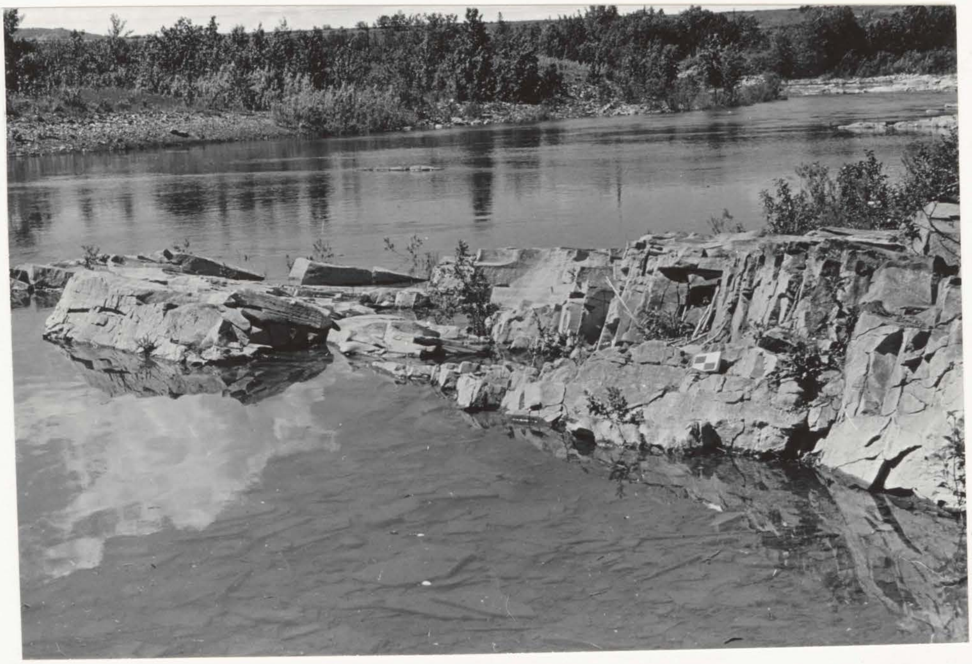
The dominant internal sedimentary structure in Unit B1 consists of hummocky cross-stratification (HCS); low angle trough shaped and upward doming laminae that intersect at low angles (Plate 2-1). Atop the HCS beds are asymmetric straight crested ripples trending towards 101°.

Horizontal trace fossils of high density cross the upper surface of the unit and are possibly of the genus *Macaronichnus segregatis* (Pemberton, personal

PLATE 2-1: Hummocky cross-stratification in Unit B1 of Facies B.

PLATE 2-2: Unit B2 characterized by low angle planar crossbedding. Field book is 19 cm. wide.


9cm



communication).

Unit B2 [BR-1: 100 to 102.5 metres]

Unit B2 consists of a clean light greyish-white, fine to very fine grained sandstone at least 2.35 metres thick. Unit B2 is separated from Unit B1 by a 0.75 metre covered interval.

The unit contains low angle crossbedding near its base with some very minor upward doming. Near the top of the unit, bedding becomes more planar with low dips of 4° towards the east after regional dip is removed (Plate 2-2). Parting lineations on the upper surface trend towards 042° - 222° and 078° - 258°; rib and furrow cross-bedding trend towards 035°.

Unit B2 also contains one to two centimetre long vertical carbonaceous roots and comminuted carbonaceous flecks ranging in size from microscopic to 2 cm x 2 cm.

INTERPRETATION

The general interpretation of Unit B1 is that it was deposited as a storm generated flow, below fair weather wave base, but above storm wave base in a shallow marine environment. This interpretation is based upon the presence of hummocky cross-stratification within the sandstone. The concept of HCS will be discussed at length in a later chapter.

Asymmetric ripples atop the hummocky cross-stratified sandstone are straight crested and are probably migratory wave ripples formed by a superimposed current flow after the deposition of the sandstone.

The basic interpretation of Unit B2 is that it was deposited in a beach environment. This interpretation is based upon the presence of carbonaceous rootlets and the shallow dipping planar bedding within the sandstone. Hoyt and Weimer (1963) report that the predominant sedimentary structure found in the foreshore areas of beach environments are parallel laminations dipping gently seawards at 2 to 3°. Based upon this observation, the paleo-sea during this time lay to the east.

<u>FACIES C</u>

<u>Unit C1</u> [BR-1: 134 to 137 metres]

Unit C1 consists of two separate sandstones, a lower 1.2 metre thick, medium grey sandstone, which fines upwards (from medium grained to very fine grained) and contains a 5 to 10 cm. thick mudstone parting; and an upper 1.8 metre thick greenish-grey, fine to very fine grained sandstone. Both portions are non-calcareous.

The lower sandstone contains poorly preserved, low angle crossbedding and is sharp based. Sole markings oriented 067° - 256° and 076° - 256° are found at the upper contact with the mudstone parting. The upper sandstone contains distinct inclined (0 to 15°) accretionary bedding structures measuring approximately 3.5 x 0.75 metres

(Plates 2-3, 2-4). Accretionary surfaces are differentiated from one another by sandy-siltstone drapes wich can be traced down to the base of the sandstone. Sedimentary structures within accretionary bodies consist primarily of low angle trough like crossbedding generally conformable to the lenticular shape of the bodies. Occasionally, siltstone drapes are observed truncating crossbeds.

Comminuted carbonaceous flecks, grass imprints, fossilized wood imprints up to 30 cm. x 3 cm. and vertical carbonaceous roots up to 4 cm. long are contained within both sandstones. The upper sandstone also contains a variety of deciduous type leaf imprints and becomes slightly concretionary towards the top.

Unit C2 [BR-9: 0 to 3 metres]

Unit C2 consists of a 3.0 metre thick, fine to medium grained, sharp based, medium grey sandstone. It is laterally discontinuous and within 15 metres towards the north, interfingers out into a series of interbedded sandstones and mudstones (Facies E) (Plate 2-5). Immediately beneath the main sandstone body is a 6 metre long, 0.6 metre thick lenticular sandstone similar to the main sandstone, but separated from it by a slightly silty mudstone. It trends at approximately 150°.

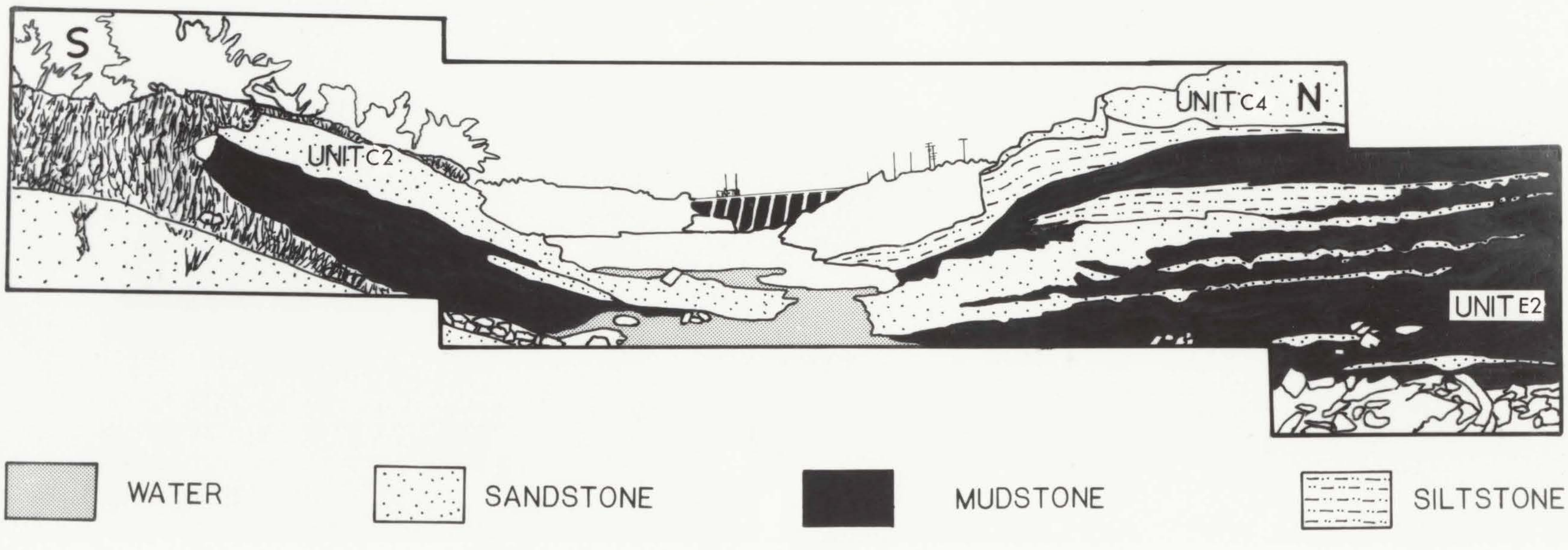
Sedimentary structures consist of trough crossbedding, (one trough had an orientation of 111°), containing 20 cm. long rib and furrow crossbedding sets oriented

PLATE 2-3: Unit Cl. Curving lateral accretion surfaces occur in the upper portion of the unit and are shown in the centre of the photograph.

PLATE 2-4: Detailed view of the lateral accretion surfaces of Unit Cl. Individual accretion surfaces are separated from one another by sandy-siltstone drapes.

PLATE 2-5: Panoramic photograph and sketch of Unit C2 and Unit C4. Unit C4 pinches out towards the south. Unit C2 interfingers out towards the north and merges into Unit E2 type interbedded mudstones and sandstones.


S
N


S
N
UNIT C2
UNIT C4
UNIT E2
WATER
SANDSTONE
MUDSTONE
SILTSTONE

towards 143°. Basal sole marks are oriented towards 095 and 160°.

Unit C2 is very calcareous and contains, comminuted carbonaceous flecks, a fossilized bone fragment (10 cm. x 4 cm.), petrified wood pieces (18 cm. x 5 cm.) and silt rip up clasts (3.0 cm. x 3.0 cm.).

Unit C3 [BR-5: 4.5 to 7.6 metres, BR-7: 14.6 to 18 metres]

Unit C3 consists of a medium grey coloured sandstone which has a sharp basal contact, a few load clasts up to 1.5 cm. wide, and is a maximum of approximately 3.1 metres thick. The sandstone body is lenticular measuring approximately 102 metres in length from a covered interval in the north, to a pinch out in the south (Plate 2-6). Grain size fines upwards slightly from fine to very fine.

Two well exposed drapes measuring 5 metres in depth by a maximum of 0.4 metres in width and composed of a recessive silty sandstone are contained in this unit (Plate 2-7). Strikes of the drapes are 095° - 275° and both dip towards the south. Trough crossbedding, measuring up to 1 metre x 0.35 metres in size, is present throughout the unit. Ripple crossbedding is also prominent, especially near the top. Paralleling the mudstone drapes atop the unit are two low angled, trough shaped, elongated depressions oriented at 090° - 270° and 100° - 280° (Plate 2-8). The depressions contain 25 cm. long sets of rib and furrow crossbedding oriented at 097° and measure 2 metres wide

PLATE 2-6: Panoramic photograph and sketch of Unit C3 showing mud drape at the extreme right and pinch out in the middle of the photograph and sketch. Unit C3 cuts into Unit E2, (interbedded mudstone and sandstone), truncating many of the sandstone beds. Unit C4 is also shown (left of centre) and overlies Unit E2 and Unit C3. Approximate degree of coverage 190°.


S
N

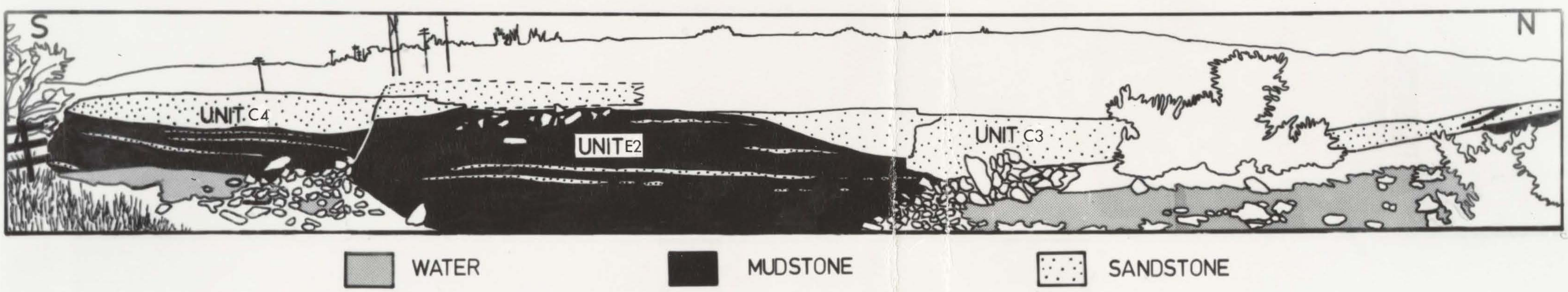
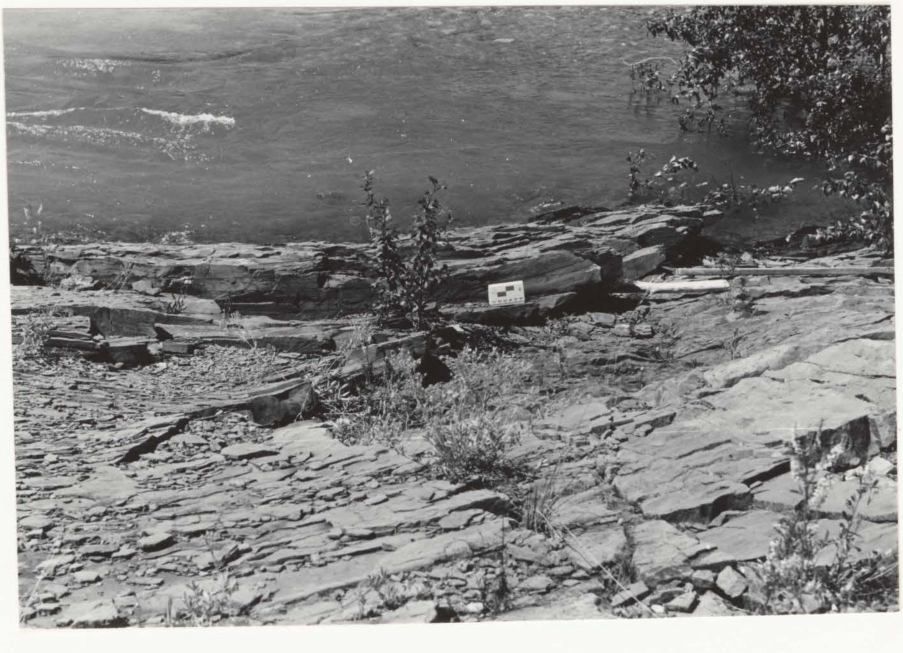

S
N
UNIT C4
UNIT E2
UNIT C3
WATER
MUDSTONE
SANDSTONE

PLATE 2-7: A well exposed southerly dipping drape consisting of a recessive silty sandstone in Unit C3. Field book immediately below drape at upper right of photograph is 19 cm. wide.

PLATE 2-8: A low angled trough shaped elongated depression atop of Unit C3. Orientation of the depression is 090-270° and 25 cm. long sets of rib and furrow crossbedding contained within the depression are oriented towards 097°.



by 0.3 metres deep. Elsewhere on the upper surface, rib and furrow crossbedding is oriented from between 094° and 127° (mean 110°). Near the base of Unit C3 are four will preserved sole marks oriented at 081° - 261°, 093° - 273°, 078° - 258° and 082° - 262°. A sample taken from the base of a trough in the mid-portion of the unit yielded a mean grain orientation of 122° - 302° (significance > 99.5%) (Figure 2-9). A sideritic concretionary horizon and many silt rip up clasts are located at the base of several troughs (Plate 2-9) which are emphasized by local grain size variations (Plate 2-10). Several marine trace fossils are present atop Unit C3 and include *Macaronichnus segregatis* (Plate 2-11), *Chondrites* and *Planolites* (Risk, personal communication) (Plate 2-12). The unit is non-calcareous until the top most portion where it is extremely calcareous. Comminuted carbonaceous flecks and fossilized wood fragments are common throughout Unit C3.

<u>Unit C4</u> [BR-8: 11 to 15 metres]

Unit C4 consists of a sharp based, medium grey sandstone which is a maximum of 3.90 metres thick. The lower contact slightly scours into the underlying mudstone unit. The sandstone is lenticular in shape, measuring 88 metres in width before it pinches out toward the south (Plate 2-13). Grain size varies slightly from fine grained at the base to very fine grained at the top.

Very little crossbedding is present in this unit,

FIGURE 2-9: Summary of paleocurrent data obtained from Unit C3. Rose plot represents grain orientation (mean = 122° - 302°, open arrows: significance >99.5%). Also shown are orientations of troughs, sole marks, rib and furrow crossbedding and chutes.

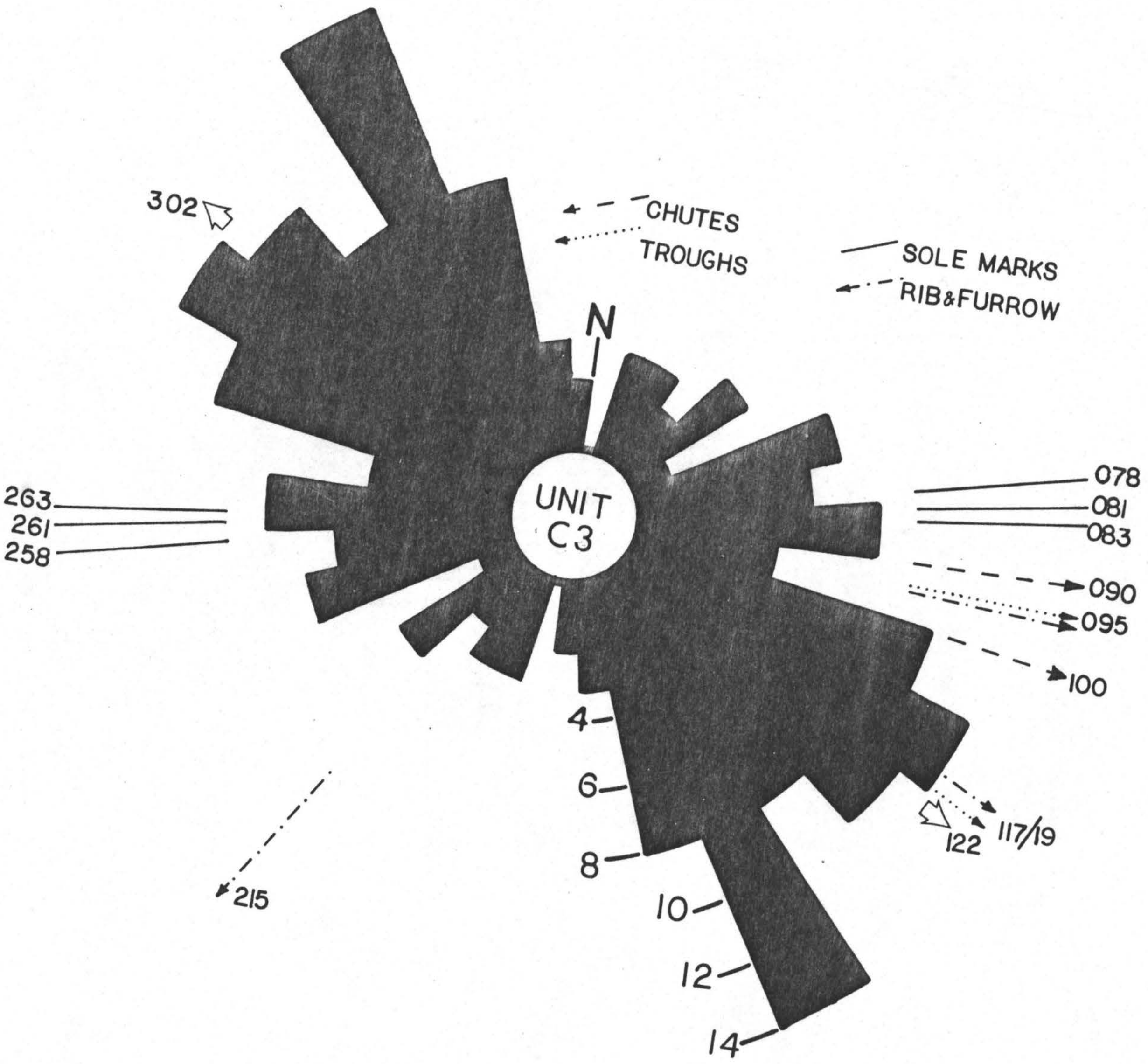
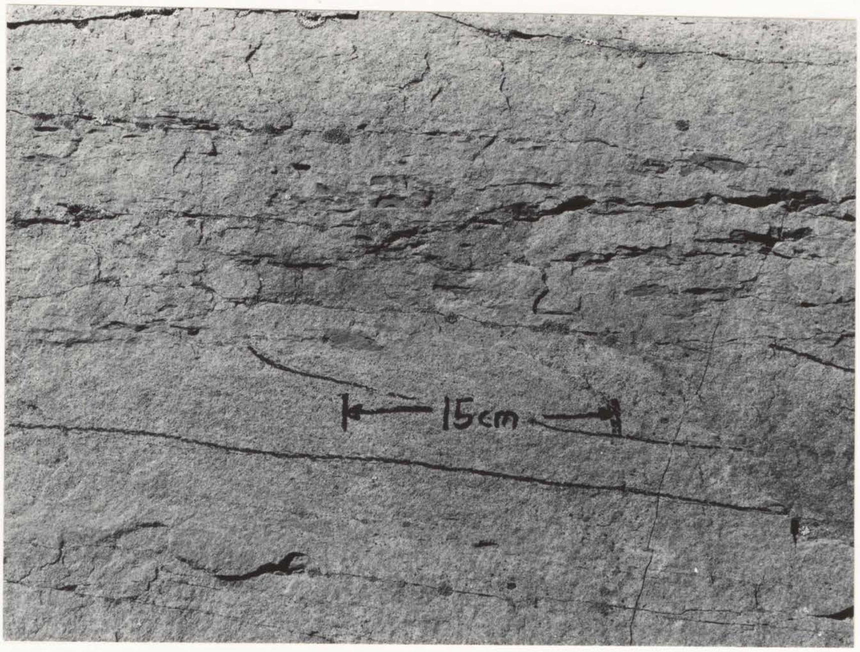

CHUTES
TROUGHS
SOLE MARKS
RIB&FURROW
N
UNIT
C3
302
263
261
258
078
081
083
090
095
100
117/19
122
215
4
6
8
10
12
14

PLATE 2-9: Silty rip up clasts and highlighted low angle trough crossbedding contained within Unit C3.

PLATE 2-10: Grain size variation in Unit C3. Five centimetre scale is drawn on fine sandstone. A sharp break at the middle of the photograph marks the contact with the underlying medium grained sandstone.


15cm

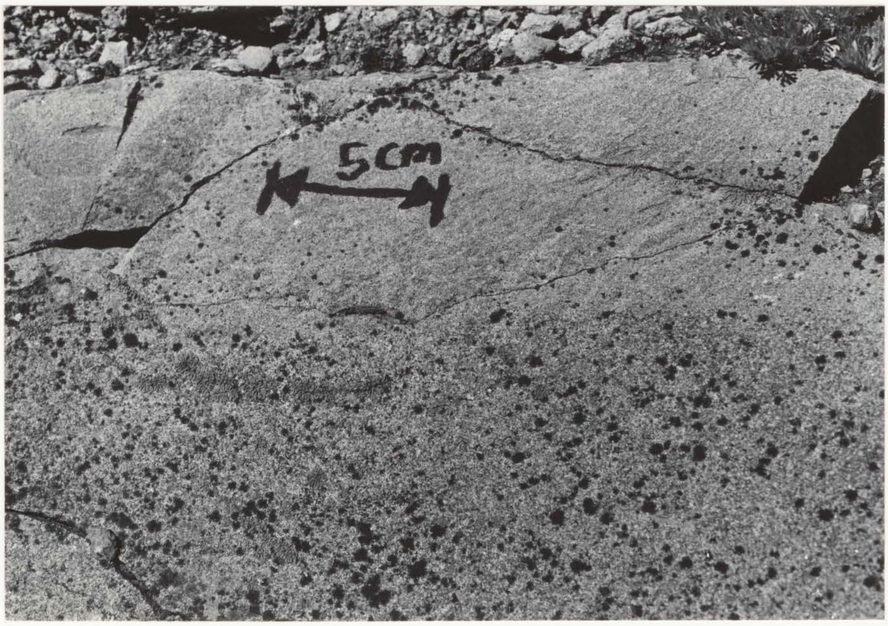
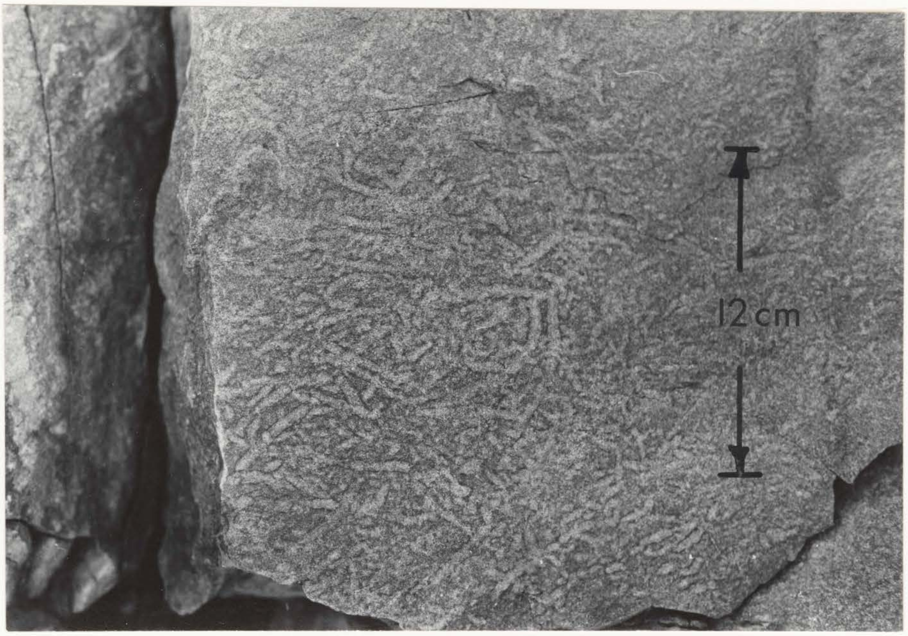

5cm

PLATE 2-11: Traces identified as *Macaronichnus segregatis* atop Unit C3.

PLATE 2-12: Traces identified as *Planolites* and *Chondrites* atop of Unit C3.


12 cm

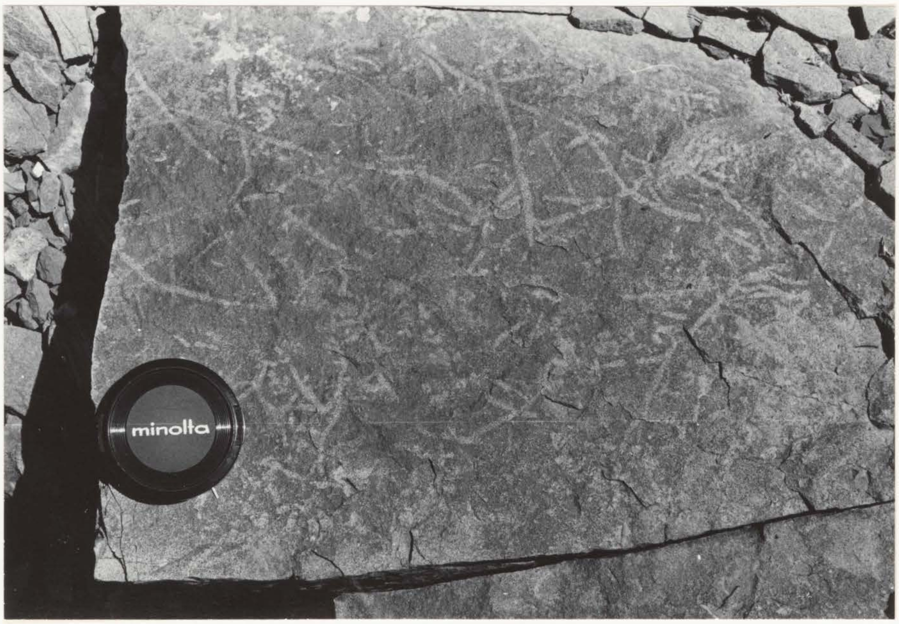
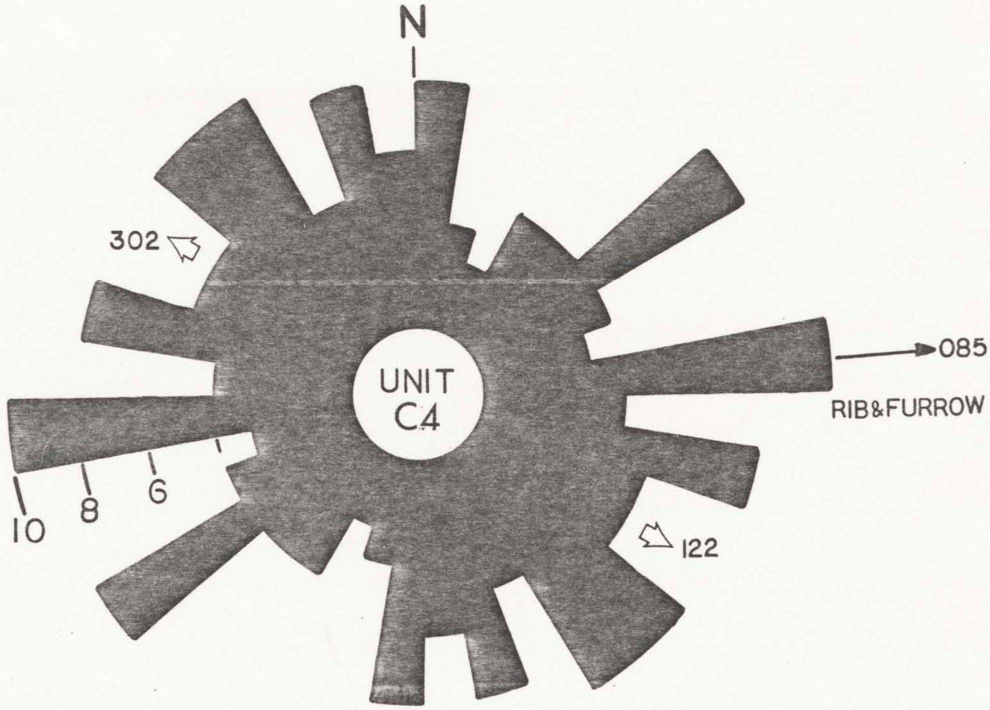

minolta

PLATE 2-13: Lateral variance of Unit C4. The sandstone is lenticular and pinches out towards the south (approximately between the arrows).

FIGURE 2-10: Summary of paleocurrent data for Unit C4. Rose plot represents grain orientations (mean = 122° - 302°, open arrows). A significance of 75% indicates a random distribution. Also shown are rib and furrow crossbedding orientations from atop the unit.


N
302
085
RIB&FURROW
UNIT
C4
10
8
6
122

the bulk of it being made up of ripple crossbedding with 15 cm. long rib and furrow sets trending at 085°. Mean grain orientation from an oriented sample taken from the mid-section of the unit is 122° - 302°, however a significance of less than 75% indicates a random distribution (Figure 2-10).

Carbonaceous roots, comminuted coal fragments and 1 cm. long grass imprints are common, especially at the very top of the unit. Individual roots are branching and range in size up to 30 cm. long with stock widths of up to 2 cm.

Poorly preserved horizontal trace fossils which maybe *Macaronichnus segregatis* are also contained atop the unit.

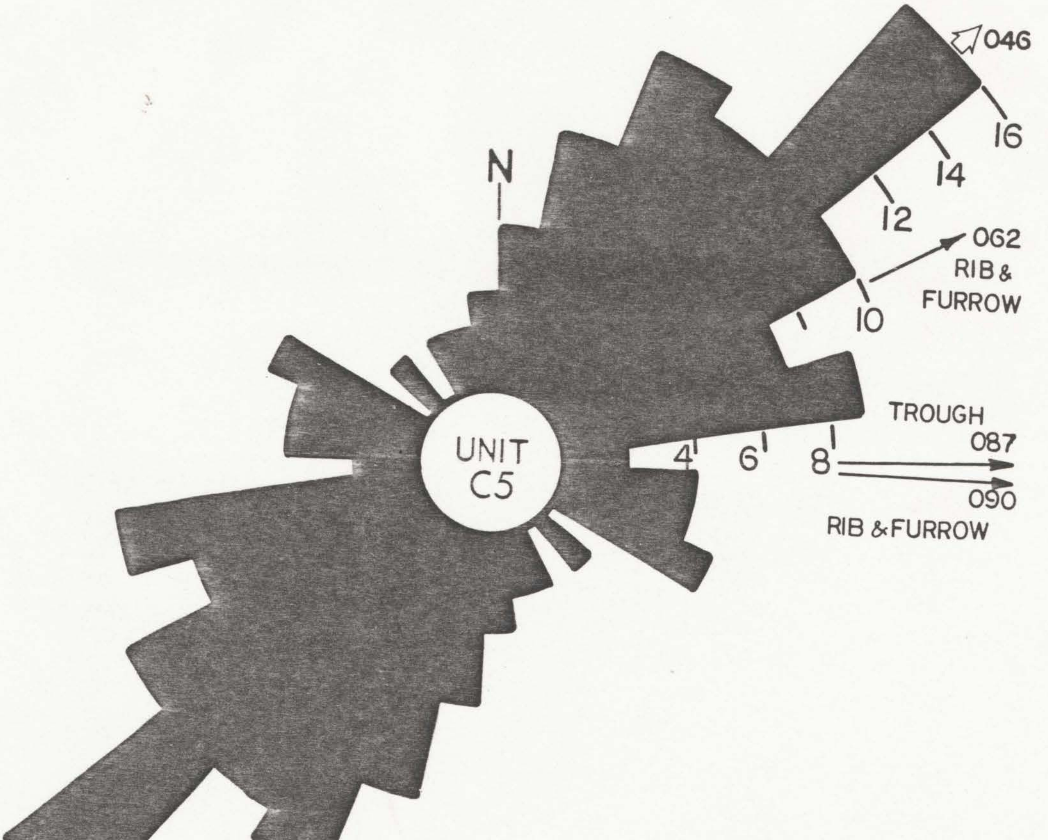
Unit C5 [BR-1: 162 - 165 metres]

Unit C5 consists of a 2.64 metre, fine to medium grained, non-calcareous buff sandstone with a sharp, flat base (Plate 2-14).

Low angle trough crossbedding is prominent and the mean dimensions of the troughs are 1.5 metres by 0.25 metres; few individual troughs are less than about 0.75 metres wide. One three dimensionally exposed trough is oriented towards 087° and contains 50 cm. rib and furrow crossbed sets oriented from 062° to 090°. A sample obtained from the base of a shallow trough yielded a mean grain orientation of 046° - 226° with a significance of greater than

PLATE 2-14: Unit C5 at high water stage. The sandstone is characterised by trough crossbedding overlain by ripple crossbedding.

FIGURE 2-11: Summary of paleocurrent data from Unit C5. Rose plot represents grain orientation (mean = 046° - 226°, open arrows: significance>99.5%). Also shown are rib and furrow crossbedding and trough crossbedding orientations.


046
16
14
12
N
062
RIB &
FURROW
10
TROUGH
087
UNIT
C5
4
6
8
090
RIB & FURROW
226

99.5 percent (Figure 2-11).

At the base of the troughs and within the unit are numerous greenish coloured silt rip up clasts up to 3 cm. in length and comminuted carbonaceous flecks. Atop the unit are extensive wood imprints measuring up to 25 cm. x 5 cm. in size and two fossilized bone fragments, the largest measuring 5 cm. x 3 cm.

Unit C6 [BR-7: 34 to 36 metres]

Unit C6 consists of a 1.9 metre thick very silty, sharp based sandstone. It is lenticular in shape and pinches out to a thin silty sandstone towards the south (Plate 2-15). Grain size is fine to medium at the base and fines to very fine near the top. The top of the sandstone is not exposed.

Unit C6 also has characteristics similar to Unit C2 as it interfingers northward with several mudstone beds (Plate 2-15). The entire lateral change, from pinch out to interfingering takes place within 30 metres.

Rare trough crossbeds, one oriented at 178°, and low angle (10° to 20°) crossbedding are found in the unit. Rib and furrow crossbedding (3 cm. sets) atop the sandstone trend at 180° and a sample obtained from near the base of the unit yielded a mean grain orientation of 166.5° - 346.5° (significance greater than 99.5%) (Figure 2-12).

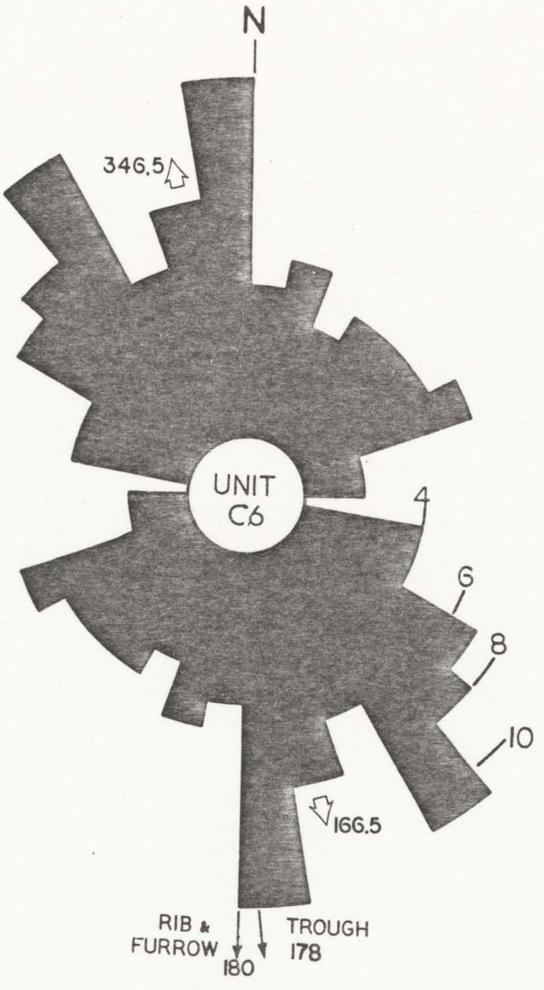
Comminuted carbonaceous flecks, 3 cm. long carbonaceous rootlets and occasional silt rip up clasts occur

PLATE 2-15: Panoramic photograph of Unit C6. The sandstone pinches out towards the south into a muddy siltstone. Towards the north it begins to interfinger with mudstones. Approximate degree of coverage 110°.


S
N

FIGURE 2-12: Summary of paleocurrent data for Unit C6. Rose plot represents grain orientation (mean = 166.5° - 346.5°, open arrows: significance>99.5%). Also shown are rib and furrow crossbedding and trough orientations.

PLATE 2-16: Large tree branch imprint at the base of the thickest portion of Unit C6. Tip of hammer at extreme bottom of photograph for scale.


N
346.5
UNIT
C6
4
6
8
10
166.5
RIB &
FURROW
180
TROUGH
178

throughout the unit. At the base of the thickest part of the sandstone is a large 1.5 metre long tree branch imprint (Plate 2-16).

Unit C7 [BR-1: 177 to 180 metres, BR-6/2/3: 3 to 6 metres]

Unit C7 consists of a sharp based 2.71 metre thick, light grey resistant sandstone; a middle 0.50 metre thick recessive silty sandstone; and an upper 0.52 metre thick resistant light grey sandstone. Grain size in the resistant sandstones is fine to medium.

Crossbedding is extensive and variable within Unit C7. Trough crossbedding is prominent in the lower resistant sandstone (Plate 2-17), 20 cm. thick planar tabular crossbedding is prominent in the upper sandstone (dips 16 to 21° towards 225°) (Plate 2-18), and 5 cm. rib and furrow crossbedding sets trending towards 150 and 330°, are prominent atop the unit. Mean grain orientation obtained from near the mid portion of the lower resistant sandstone is 156° - 330° (significance > 95%) (Figure 2-13).

The unit contains numerous greenish coloured silt rip up clasts measuring up to 1 cm. x 1 cm. in size, which are especially common atop the unit on bedding planes. Horizontal trace fossils possibly of the genus *Macaronichnus segregatis* cross the upper surface of the unit. Comminuted carbonaceous flecks and wood imprints up to 1.5 metres x 10 cm. are common throughout.

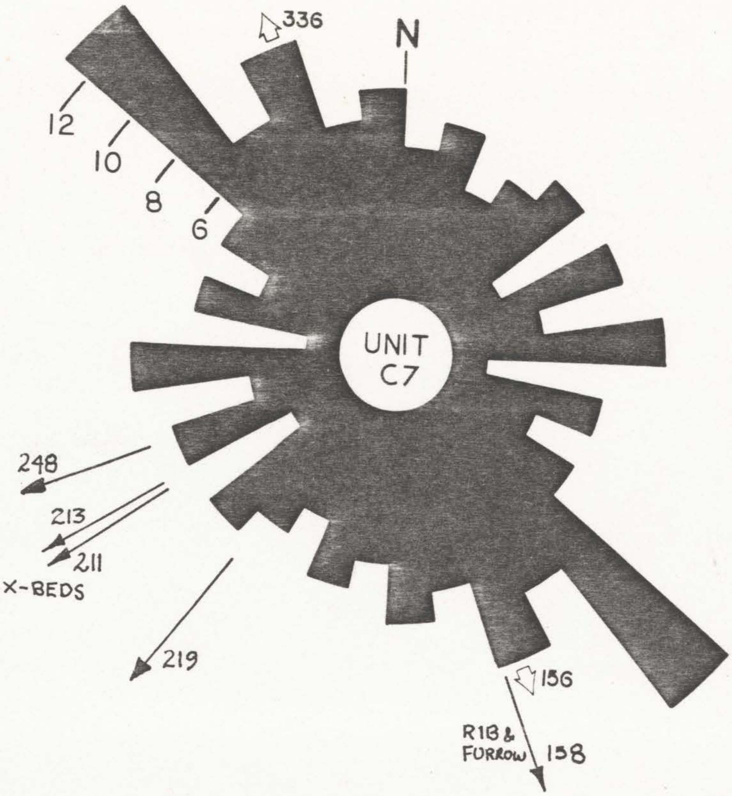
Unit C7 is also exposed in the middle of the Ghost

PLATE 2-17: Unit C7 exposure in BR-6/2/3. Trough crossbedding is prominent in this part of the exposure.

PLATE 2-18: Upper portion of Unit C7 in BR-6/2/3. Note the planar tabular bedding (trending 225°) which is overlain by a scoured surface. Ripple crossbedding is prominent above the planar tabular crossbedding (left of field notebook.

FIGURE 2-13: Summary of paleocurrent data for Unit C7 (BR6/2/3exposure). Rose plot represents grain orientation data (mean = 156° - 336°, open arrows: significance 95%). Also shown are orientations of planar tabular crossbeds and rib and furrow crossbedding.

PLATE 2-19: Exposure of Unit C7 in Ghost Dam spillway (BR-1). Note the recessive nature of the exposure, and the presence of trough cross-bedding. One reasonably exposed trough yielded a trend of 045° - 225°.


336
N
12
10
8
6
UNIT
C7
248
213
211
X-BEDS
219
156
RIB &
FURROW
158

Dam spillway in BR-1 (refer to Figure 2-8). Here however, the sandstone is very recessive and poorly exposed (Plate 2-19). One three dimensionally exposed trough did however yield of trend of 045° - 225°.

<u>Unit C8</u> [BR-4: 42 to 46 metres, BR-9 ?: 52 to 54 metres]

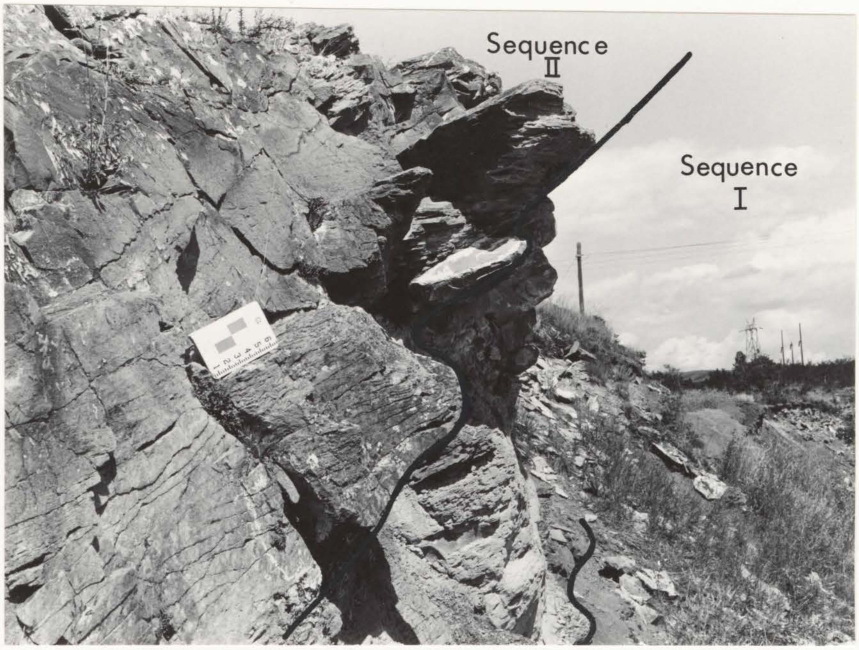
Unit C8 consists of the thickest single sandstone unit in the Ghost Dam spillway. It is 4.19 metres thick, light grey to white in colour and sharp based with very little loading. Two fining upward sequences are contained within Unit C8. The lower one is 1.33 metres thick, and fines upward from fine to very fine. The base of the upper 2.86 metre sequence scours into the lower sequence and grain size fines upwards from medium to fine (Plate 2-21).

Trough crossbedding is prominent in the lower portion of Unit C8 and gives orientations of 170° and 145°. An oriented sandstone sample obtained from this portion yielded a mean flow direction of 011.5° - 191.5° (significance >95%) (Figure 2-14). Rib and furrow cross-bedding and asymmetric ripples atop the upper sequence are oriented from between 085° and 105° (mean 090°) (Plate 2-21). An oriented sandstone sample from this portion yielded a mean grain orientation of 037° - 217° (significance >97.5) (Figure 2-14).

Unit C8 contains numerous silt rip up clasts measuring up to 4.0 cm. in length, and comminuted

PLATE 2-20: Unit C8, (BR-4 exposure). The two fining upward sequences are differentiated and identified in the photograph. The upper sequence scours into the lower sequence.

PLATE 2-21: Asymmetric ripples atop Unit C8, trending toward 085° (centre of photograph) and rib and furrow crossbedding (upper right of photograph) trending toward 097°.


Sequence
II
Sequence
I

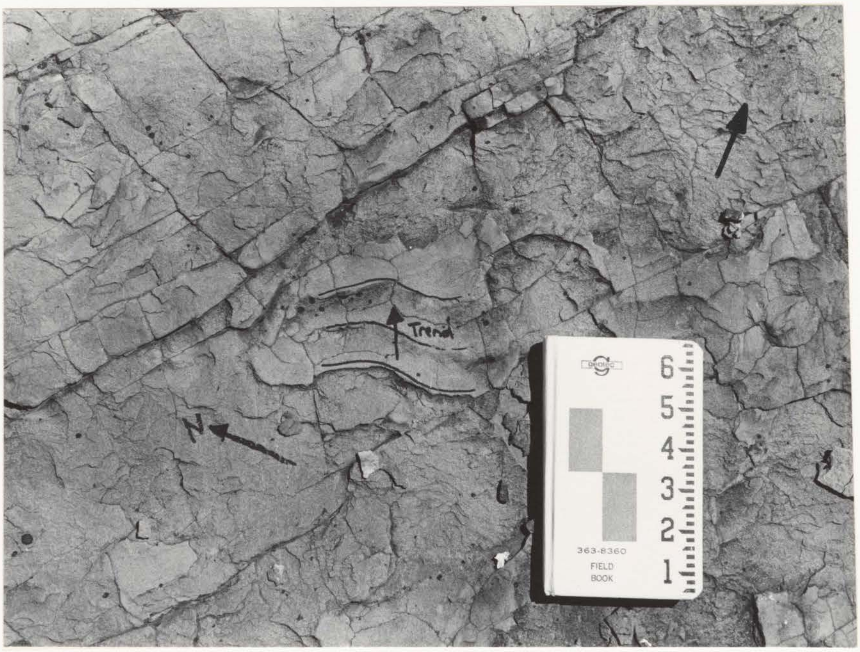
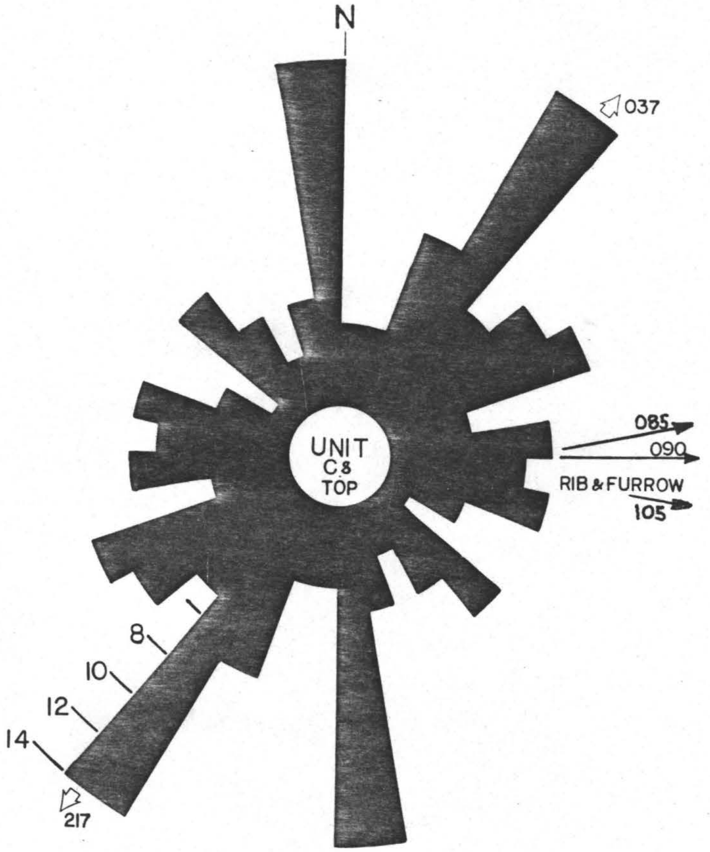
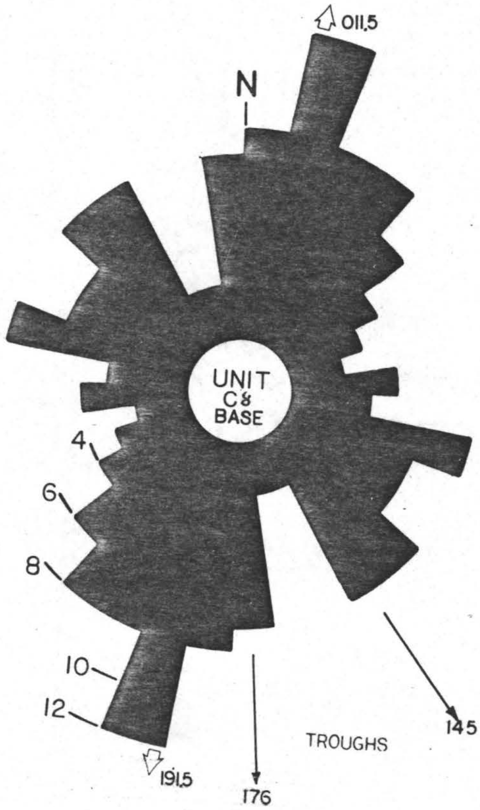

Trend
N
6
5
4
3
2
1
363-8360
FIELD
BOOK

FIGURE 2-14: Summary of paleocurrent data from the top and base of Unit C8. Open arrows indicate mean grain oriention. Mean grain orientation of the upper sandstone (037° - 217°) is significant at greater than 97.5%. The mean grain orientation of the lower sandstone (011.5° - 191.5°) is significant at greater than 95%. Also shown are orientations of rib and furrow crossbedding and troughs.


N
037
UNIT
C8
TOP
085
090
RIB & FURROW
105
8
10
12
14
217


011.5
N
UNIT
C8
BASE
4
6
8
10
12
191.5
176
TROUGHS
145

carbonaceous flecks.

Unit C9 [BR-5: 59 to 61 metres, BR-6: 34 to 36 metres]

Unit C9 consists of a 2.20 metre thick, poorly exposed clean white medium grained sandstone which contains several white or reddish-coloured calcareous concretions. Neither the base nor the top is exposed, and the sandstone is poorly consolidated leaving the exposure very recessive. As a result, concretions are very prominent and stand out from the sandstone (Plate 2-22). The concretions range in size from 1.3 x 0.65 metres to 2.3 x 0.5 metres and commonly occupy troughs. Trough crossbedding is extensive but poorly preserved and only one trend (045° - 225°) was obtained.

An isolated quartz pebble (3 cm. x 3 cm. x 0.5 cm.), silt rip up clasts, wood imprints and comminuted carbonaceous flecks are present in Unit C9.

Unit C10 [BR-4: 57 to 60 metres, BR-9 ?: 61 to 69 metres]

Unit C10 is the highest stratigraphic sandstone in the outcrop. It is 2.81 metres thick, medium grey in colour, sharp based, very fine to medium grained and ranges from non-calcareous at the base to very calcareous at the top (Plate 2-23).

Sedimentary structures range from trough crossbedding near the base (oriented towards 102° and 136°), to low angle trough crossbedding near the middle, and ripple crossbedding at the top.

PLATE 2-22: Exposure of Unit C9 in BR-6/2/3. Note the presence of large calcareous concretions and trough crossbedding.

PLATE 2-23: Exposure of Unit C10 at the top of the outcrop.

Across the spillway, (section BR-9) , may be an equivalent 2.26 metre thick sharp based, very fine grained sandstone. It is inaccessible for detailed analysis, but does contain low angle trough crossbedding and is non-calcareous.

<u>INTERPRETATION</u>

The basic interpretations of the units within Facies C is that they were deposited in a point bar environment associated with a meandering river. This interpretation is based upon characteristics observed in many of the units.

Accretionary bedding contained in the upper portion of Unit C1 strongly suggests that the sandstone was deposited as a laterally accreting surface (point bar). The prominent mudstone draped accretionary surfaces would indicate that the point bar growth was highly discontinuous and that wet and dry periods occurred during its development (Puigdefabregas and van Vliet, 1978).

Unit C2 is rather unique compared to other sandstones in Facies C as it interfingers into a series of mudstones. The interfingering is likely to have been caused by a series of flood events which deposited material along the margin(s) of the stream. The sandstones and mudstones are therefore regarded as a levee, built up along the channel during flooding. The concept of levees will be discussed in a later chapter.

The low angled, trough shaped elongated depressions, oriented in the same direction as paleocurrent indicators in Unit C3, are interpreted as being chutes which ran approximately parallel to the main channel. Fine grained drapes mark the top of a genetically related sequence (Reineck and Singh 1980, p. 268), a part of an overall fining upward sequence in point bars. Silt rip up clasts probably represent some form of channel lag deposit.

Other features indicative of a point bar origin to the sandstones include fining upward sequences (Units C6 and C8), lenticular pinch outs (Units C3, C4 and C6) and trough crossbedding, formed by large scale bed forms near the base of the active channel (Units C2 to C10).

Although few in number, the presence of marine trace fossils is puzzling, especially since they occur synchronously with roots. The possible interpretations of trace fossils and roots occurring together is discussed in Chapter 5.

FACIES D

Unit D1

Unit D1 is composed of interbedded sharply bounded sandstone and mudstone with a mudstone to sandstone ratio of less than one (Plate 2-24). The mudstones range in thickness from 1 to 25 cm. and commonly pinch and swell.

Sandstone grain size is very fine and beds range in thickness from 15 to 50 cm. Sedimentary structures

PLATE 2-24: Example of Unit D1. Sandstone beds are sharp based and more abundant than mudstone beds.

include parallel laminations and/or ripple crossbedding (Plates 2-25, 2-26). Some beds possess low angle trough crossbedding which have paleocurrent orientations similar to those of the point bar sandstones, (Facies C).

Silt rip up clasts and basal sole marks are contained in the sandstones; leaf imprints are less common. Comminuted carbonaceous flecks and rootlets are found in both the mudstone and sandstone interbeds.

Unit D2

Unit D2 consists of interbedded sandstone and mudstone in a ratio similar to that of Unit D1, however the sandstones are heavily loaded. Contacts between sandstone and mudstone beds are commonly diffuse (Plate 2-27).

The mudstones are commonly green in colour, are almost always silty or sandy and are variable in thickness, ranging from 15 cm. to a few millimetres.

The sandstones are very fine grained to fine grained, argillaceous and range in thickness from approximately 10 to 65 cm. (average 45 cm.). Owing to loading however, thickness is variable even within a single sandstone bed (Plate 2-28). Sedimentary structures are often distorted or destroyed due to intense loading. When preserved, the structures generally consist of ripple crossbedding. Orientations are comparable to those of the point bar sandstones.

Comminuted carbonaceous fragments and rootlets are

PLATE 2-25: Ripples crossbedding within a Unit D1 sandstone. Crossbedding is highlighted.

PLATE 2-26: Close up of ripple crossbedding within a Unit D1 sandstone.


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PLATE 2-27: Example of Unit D2. The mudstone to sandstone ratio is less than 1 to 1 and sandstone beds are very loaded.

PLATE 2-28: Variable thickness in Unit D2 sandstone beds due to loading.

found in both the mudstone and sandstone interbeds. Occasional seed imprints and insect castings are also contained within the mudstones.

Trace fossils are occasionally contained within Unit D2 type mudstones and/or sandstones. Vertical trace fossils (*skolithos*) (Plate 2-29) are found towards the tops of some units, and often appear truncated by overlying point bar sandstones (Facies C) (Plate 2-30). *Ophiomorpha nodasa* and *Teichichnus* (Plate 2-31) have also been identified.

Unit D3

Unit D3 consists of dark grey sandy siltstone and/or silty sandstone which may be slightly to extremely loaded. Thicknesses are variable, ranging from 5 cm. to 50 cm. or more depending upon the degree of loading of the siltstone. Thicker siltstones tend to be sharp topped and based while thinner siltstones tend to have more diffuse boundaries. Internal laminations are often parallel but undulatory, especially in siltstones that are extremely loaded. Ripple crossbedding is rare, but when present give paleoflow directions comparable to those determined from point bar sandstones (Facies C).

The unit may be slightly calcareous, contains carbonaceous roots up to 5 cm. in length, comminuted carbonaceous flecks, coal clasts and very fine sand grains. Occasionally there is a yellowish tint to the siltstone which may be due to the proximity of overlying sideritic

PLATE 2-29: Vertical trace fossil identified as *Skolithos* within Unit D2 (Facies D) sediments.

PLATE 2-30: Vertical trace fossil (*Skolithos*) in Unit D2 sediments truncated by a point bar sandstone (Unit C3).


4 cm

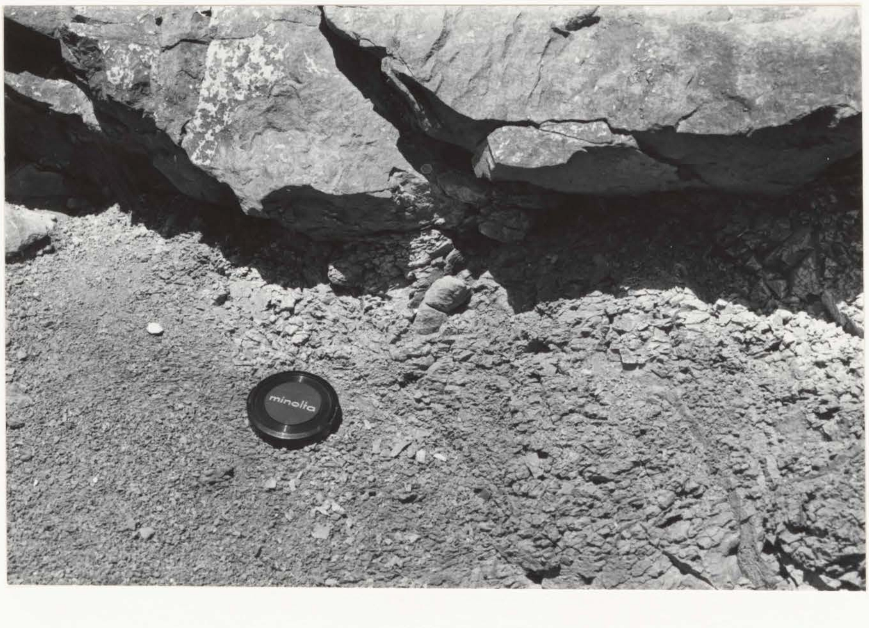

minolta

PLATE 2-31: Marine trace fossil identified as *Teichichnus* contained within Unit D2 sediments.


5cm

concretions.

INTERPRETATION

The units of Facies D are interpreted to have been deposited as overbank (flood) material in a meandering river system. Two general classes of overbank are recognized; proximal overbank (levees and crevasse splays), and distal overbank. Proximal overbank, or bank deposits (Reineck and Singh, 1980, p. 266) consist primarily of sandstones and are deposited close to channel margins during flooding. Units D1, D2 and D3 of Facies D, which contain high proportions of sandstone are therefore interpreted to have formed as overbank deposits in close proximity to channel margins. Loaded sandstones as opposed to sharp based sandstones probably develop if the heavier overlying sandstone, through soft sediment deformation, sinks into the underlying mudstone. Sharp based sandstones would indicate a less deformable underlying mudstone. The distinction between levee and crevasse splay deposits will be made in a later discussion.

FACIES E

Unit E1

Unit E1 consists of sandy green coloured mudstone alternating with sharp based to slightly loaded, grey sandstone (Plate 2-32). The mudstone contains comminuted carbonaceous flecks and clasts, small calcareous concretions and is commonly rooted. Small seed casts less than 1 cm.

in size, and insect castings are present, but are not abundant.

Sandstones range in thickness from 10 to 50 cm. (average 20 cm.), are very fine to fine grained and are very argillaceous. Ripple crossbedding is very common as are comminuted carbonaceous flecks, rootlets and leaf imprints. The sandstones commonly pinch and swell, often appearing lenticular.

Unit E2

Unit E2 consists of interbedded, loaded sandstone and mudstone in which the mudstone to sandstone ratio is greater than 1 to 1 (Plates 2-32, 2-33).

The mudstone interbeds are normally rooted, grey to green in colour and contain numerous carbonaceous fragments. Calcareous concretions are not uncommon.

The sandstones are very fine grained, argillaceous and contain roots up to 6 cm. long and 0.5 cm. wide. Comminuted carbonaceous flecks and leaf imprints are also present. Sedimintary structures range from parallel laminations to low angle trough shaped bedding. Loading at the base of the sandstones is often so intense that beds are discontinuous or lenticular (Plate 2-34). Many sandstones are also rippled, having orientations comparable to that of crossbedding in point bar sandstones (Facies C).

Unit E3 and Unit E4

Units E3 and E4 are mudstones distinguished from

PLATE 2-32: Example of Unit E1 and Unit E2 interbedded mudstone and sandstones. Unit E1 is characterized by sharp based sandstone and mudstone where the mudstone to sandstone ratio is greater than 1 to 1. Unit E2 is characterized by the same mudstone to sandstone ratio, but the sandstone beds are loaded.

PLATE 2-33: Example of Unit E2. Sandstone bed is extremely loaded and appears only as a resistant cap atop the mudstone.


E2
E1

PLATE 2-34: Load within Unit E2 sediments. Note the discontinuous appearance of the sandstone.


9cm

one another on the basis of colour and carbonaceous content.

Unit E3 consists of greenish coloured mudstone which may contain ellipsoidal calcareous concretions and trace amounts of grit or fine sand. It is commonly overlain by concretionary horizons which may or may not be calcareous. Rootlets are common, but are not always obvious due to the recessive nature of the mudstone. Seed imprints and insect castings are sporadically present; comminuted coal fragments and small coal clasts are always present.

Unit E4 is a brownish-grey to black mudstone which contains no grit or sand whatsoever. Carbonaceous roots are present and range in length up to 8 cm. but are obscured to a great extent by the recessive nature of the mudstone. Concretions are absent. Unit E4 contains much more carbonaceous material than does Unit E3 and probably owes its colour to this. Coal clasts range up to 1.5 metres x 3.0 cm. in size and as they often occur in descrete horizons, they give the appearance of a very thin, somewhat discontinuous coal layer.

Unit E5 and Unit E6

Units E5 and E6 consist of mudstones with varing amounts of sand sized grains.

Unit E5 is a slightly sandy mudstone, normally greyish-green in colour containing, comminuted carbonaceous fragments, rootlets and occasional coal clasts. Wood imprints are also present, normally on the centimetre scale.

Unit E6 consists of a grey to greenish-grey sandy mudstone. Comminuted carbonaceous fragments and clasts up to 3 cm. long, grass and wood imprints, and carbonaceous roots (10 cm. long by 2 cm. wide), are present within the unit. Occasional sandstone clasts or loads from overlying sandstone beds are present.

INTERPRETATION

The units of Facies E, like those of Facies D are interpreted to have been deposited as overbank material during flood events . However, Facies E is characterized by a higher mudstone to sandstone ratio and is interpreted as being more distal overbank than was Facies D. The finer grained nature of this facies would be due to the lower flow regime associated with being further away from the channel margins during flooding.

The relationships between the five facies and twenty three units described are summarized in Table 2-2. This table also gives the proposed general interpretation of each facies.

TABLE 2-2: Summary of units and facies distinguished at the damsite. Also indicated are proposed interpretations.

Facies	Unit	Basic Interpretation
A	A1, A2	Marine mudstone & prograding turbidites
B	B1, B2	Beach & storm deposits
C	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10	Point bar deposits
D	D1, D2, D3	Proximal overbank deposits
E	E1, E2, E3, E4, E5, E6	Distal overbank deposits

CHAPTER THREE

PALEOHYDROLICS AND PALEOMORPHOLOGY

Empirical relationships derived by geomorphologists and hydrologists (Leopold and Wolman, 1960) concerned with modern rivers can be used by geologists in estimating paleochannel morphology and flow parameters of ancient examples.

These formulae are based upon four main parameters; W, bankfull stream width; D, bankfull stream depth; Sc, percentage of silt/clay in channel bed relative to sandstone; and Sb, percentage of silt/clay in channel bank, relative to sandstone. D can be measured in the field, however, W is rather difficult to find preserved and Sc and Sb must be obtained through laboratory work.

Ethridge and Schumm (1978) summarize two methods for determining paleochannel hydrology and morphology. The first method requires the use of all four of the previously defined variables. The second method is simpler, requiring only D and W. Both methods have been applied to a well exposed point bar sandstone (Unit C3) at the damsite.

Leeder (1973) derived an empirical relationship between W and D for highly sinuous rivers, meaning that

W could be obtained mathematically. The sinuosity (P) of a river is defined as the ratio of channel length to down valley distance. Rivers having a sinuosity of less than 1.5 are straight and/or braided; those above 1.5 are sinuous and meandering and those above 1.7 are highly sinuous and meandering (Reineck and Singh, 1980, p. 258). Units C1 through C8 and C10, all less well exposed than Unit C3, have been analysed using Leeder's relationship and method two. This procedure has also been applied to Unit C3 in order to compare the results obtained by Leeder's relationship and method two, with the results obtained by method one.

There is considerable scatter around many of the regression lines represented by the equations used to determine paleohydrolics (Leeder, 1973, p. 270). For this reason, correlation coefficients (r) and ranges of values are included where possible. There is also the problem of using estimated values in subsequent equations compounding any errors inherent in the original estimate. Therefore, although the methods described give estimates which seem reasonable (probably within an order of magnitude), results must be viewed with some reserve.

METHOD ONE

The procedure behind this method is described in detail in Cotter (1971) and Ethridge and Schumm (1978). Channel depth (D) is determined from the thickness of epsilon cross-stratified point bar sequences and channel width (W) is estimated by measuring the width of the point bar. It is generally assumed that point bars make up three to four fifths of the width of a channel, (Leopold and Wolman, 1960) and several authors, (Allen, 1966, Cotter, 1971, Ethridge and Schumm, 1978), use the value of two thirds. Therefore, channel width can be determined by multiplying point bar width by a factor of 1.5.

The sediment load parameter (M) is a quantity relating the type of sediment in the channel and overbank deposit with the channel width and depth (Ethridge and Schumm, 1978),

$$1] \quad M = \frac{[Sc \times W] + 2[Sb \times D]}{W + 2D}$$

Sc is the percentage clay in the channel relative to sandstone, determined by point counting thin sections from the point bar. In the case of Unit C3, clay content amounts to 25 percent and Sc is 25. Sb is the amount of silt and clay in the overbank deposit and owing to the slightly sandy nature of the mudstone, (approximately 2 percent), is given a value of 98.

The width/depth ratio (F) can be obtained by either directly comparing W and D, or by the relationship,

$$2] \quad F = 255\ M^{-1.09} \quad (r = 0.91)$$

(Ethridge and Schumm, 1978).

If the two procedures give comparable results, then values of Sc and Sb were probably correct (Cotter, 1971).

Sinuosity (P) is determined by,

3] $P = 0.94M^{0.25}$ (r = 0.91) (Schumm, 1963)

and mean flood discharge (Qma), defined as the discharge associated with flooding recurring every 2.33 years, (Leopold, Wolman and Miller, 1964), is defined as;

4] $\log Qma = 0.268 + 0.469 \log M + 1.378 \log W$

Mean annual discharge (Qm) is given by either

5] $Qm^{0.38} = WM^{0.39}/37$ (r = 0.93)

or

6] $Qm^{0.20} = D/0.6M^{0.34}$ (r = 0.89)

(Ethridge and Schumm, 1978)

Finally, meander wavelength (L) and channel slope (S) are given by,

7] $L = 234\ Qma^{0.48}/M^{0.74}$ (r = 0.96) or 8] $L = 1890\ Qm^{0.34}/M^{0.74}$ (r = 0.96)

and

9] $S = 60M^{-0.38}Qm^{-0.32}$ (r = 0.84)
(Ethridge and Schumm, 1978)

METHOD TWO

Bankfull channel depth (D) is determined from the measured thickness (D*) of the unit in the field,

10] $D = 0.589/0.9 \times D^*$
(Ethridge and Schumm, 1978).

Bankfull channel width is obtained in the same manner as outlined in method one, or by the use of Leeder's (1973) relationship;

11] $W = 6.8D^{1.54}$ (r = 0.91)

The width/depth ratio (F) is given by,

$$12] \quad F = W/D$$

and is used to determine the sinuosity (P) of the channel (Schumm, 1963),

$$13] \quad P = 3.5\ F^{-0.27} \qquad (r = 0.89)$$

Mean annual discharge (Qm) is found by relating W and F according to,

$$14] \quad Qm = W^{2.43}/[18 \times F^{1.13}] \qquad (r = 0.90)$$

(Ethridge and Schumm, 1978)

and channel slope (S) is estimated by,

$$15] \quad S = 30[F^{0.95}/W^{0.98}] \qquad (r = 0.84)$$

(Ethridge and Schumm, 1978)

RESULTS AND INTERPRETATIONS

The relationships summarized by Ethridge and Schumm (1978), were derived from modern rivers in semi-arid environments and have not yet been shown to apply to more humid regions (Cotter, 1971). The relatively numerous occurrences of rooted sandstones at the damsite tend to favor the latter condition. However, Schumm (1969) states that channel hydrology and morphology should be controlled by the quantity of water and the quantity and type of sediment carried by them, rather than the climate. Cotter (1971) agrees and believes that these relationships will be shown to be directly applicable to rivers in wetter areas. For these reasons, the equations used are probably applicable to the paleochannel system at the Ghost Dam spillway exposure.

Values obtained for F, P and S in Unit C3 by method one fall within the suspended and dissolved load classification of stable alluvial channels, (Schumm, 1968, Table 1). The same parameters via method two indicate a mixed load type of channel. Values obtained from both methods are given in Table 3-1. Lithological evidence favors a mixed load channel as opposed to a solely suspended/dissolved load channel because of relatively large silty rip up clasts and large wood fragments found concentrated towards the base of main point bar sandstones, (Facies C). The difference in the values of the parameters obtained by the two methods are probably due to the use of different relationships, such as Leeder's relationship in method two, with different correlation coefficients. This is not to say that one method is more correct than the other, but that used together, a more representative range of values for the parameters is obtained.

The predicted sinuosity of the paleochannels is moderate (method two) to high (method one). Allen (1968) discussed the role of sinuosity in the development of the meandering river facies model. If sinuosity is low the stream is not confined to a meander belt, and is in turn free to sweep across the flood plain. Sandstones will normally make up a greater portion of the section than will mudstones, (Figure 3-1a). If on the other hand, sinuosity

TABLE 3-1: Summary of paleohydrolic data. (After Schumm (1963), Cotter (1971), Leeder (1973) and Ethridge and Schumm (1978)).

METHOD ONE

Unit	Thickness [m]	Width [m]	Sc	Sb	M	F	P	Qm [m^3/s]	Qma [m^3/s]	S [m/km]	L [m]
C3	3.10	22.1	25	98	41	4.6	2.6	6.2	111	0.5	242
						7.1	2.4	5.8			230

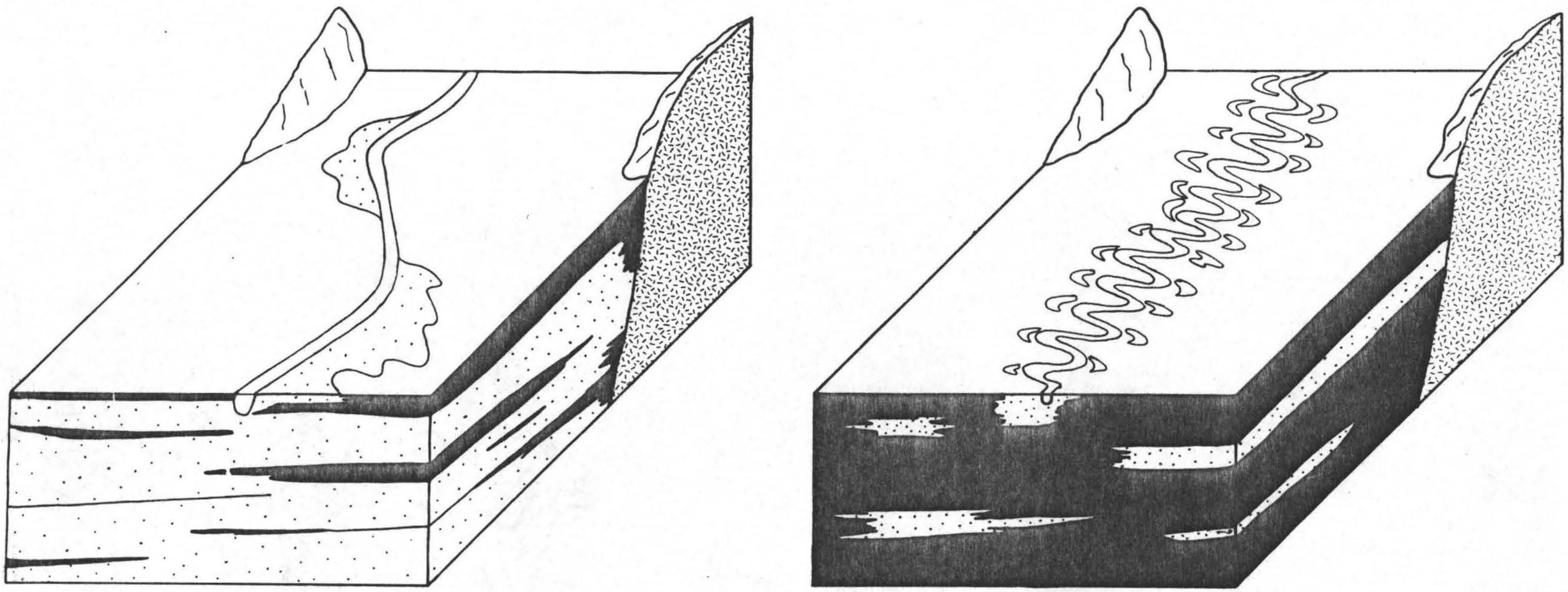
METHOD TWO

Unit	Thickness [m]	Width [m]	F	P	Qm [m^3/s]	S [m/km]	L [m]
C1	1.80	16.5	14.1	1.7	1.3	1.4	350
C2	3.10	38.1	18.9	1.6	7.0	0.8	727
C3	3.90	54.3	21.4	1.5	14.5	0.7	994
C4	3.00	36.3	18.5	1.6	6.4	0.8	696
C5	2.64	29.7	17.3	1.6	4.3	1.0	585
C6	1.90	17.9	14.5	1.7	1.5	1.3	375
C7	2.70	30.8	17.5	1.6	4.6	0.9	606
C8	4.19	60.4	22.2	1.5	18.2	0.6	1090
C10	2.81	32.6	17.9	1.6	5.2	0.9	636
Average			18.0	1.6	7.0	0.9	671

FIGURE 3-1: Models of meandering rivers.

a) Low sinuosity river. Deposits are characterized by a high sandstone to mudstone ratio.

b) High sinuosity river. Deposits are characterized by a low sandstone to mudstone ratio and less laterally extensive sandstones. (from Allen, 1968).



A LOW SINUOSITY

B HIGH SINUOSITY

is high, the stream is confined to a meander belt by channel fill and is not free to sweep across the flood-plain. Sandstones may also be thinner and will be less abundant than mudstones in the section due to numerous neck and chute cutoffs, (Allen, 1968) (Figure 3-1b).

On the basis of observed mudstone-sandstone proportions and the determined sinuosity values, the paleo-channel system that existed in this location during the Campanion, was probably a moderately to highly sinuous meandering river system similar in appearance to that depicted in Figure 3-1b.

Discharge levels are relatively low, (Table 3-1), indicating a small stream system. The value of between 5.8 and 7.0m^3/sec. for Unit C3 (the best exposed point bar sandstone, and therefore the best for evaluation) is similar to the mean annual discharges of the Credit River measured in Erindale, Ontario (7.93m^3/sec.), and the Humber River measured in Weston, Ontario (5.59m^3/sec.). These rivers are recommended for discharge comparison purposes. Mean annual discharge values of several other rivers in Ontario and Alberta are summarized in Table 3-2.

TABLE 3-2: Mean stream discharge data of rivers in Ontario and Alberta. (After Inlandwaters Directorate, Ontario (1979) and Inlandwaters Directorate, Alberta (1979)).

River name	Station number	Location	Mean discharge $[m^3/s]$
Bow River	05BH004	Calgary, Alta.	92.1
Athabasca River	07AA002	Jasper, Alta.	89.1
Grand River	02GA003	Galt, Ont.	34.7
Belly River	05AO005	Mountain View, Alta	8.84
Credit River	02HB002	Erindale, Ont.	7.93
THIS STUDY			5.8 to 7.0
Humber River	02HC003	Weston, Ont.	5.59

CHAPTER FOUR

PETROGRAPHY

Thin sections were cut from fifteen samples taken from specific sandstone units in the Ghost Dam spillway outcrop. The thin sections were cut in two orientations; normal to bedding for petrographic composition and cross-sectional grain size analysis of the constituents; and parallel to bedding for grain orientation. For several of the Facies C sandstones, a sample was taken from the base, middle and top to analyse petrographic and grain size trends within individual units. Mean and maximum grain sizes were also determined for each of the Facies C thin sections (Table 4-1).

The petrographic composition of each slide was determined by microscopic identification of 300 points using a mechanical stage. In addition, 100 quartz grains in each of eight thin sections were counted to obtain the percentages of the four basic quartz types used by Basu *et al.*(1975), to determine the provenance of the source rocks.

PETROGRAPHIC RESULTS

Unit B2 (Facies B), interpreted as being a

TABLE 4-1: Maximum and mean grain sizes of specific sandstone units. The grain size trend within individual units is also shown. Refer to Figure 2-8 for sample locations.

Facies	Unit/ Location		Maximum grain size [μm]	Mean grain size [μm]	Trend fine—coarse
B	B2		261	128	
C	C3		218	162	
	C4		229	143	
	C5	Top	206	182	
		Middle	251	212	
		Base	273	162	
	C6	Top	115	87	
		Middle	243	172	
		Base	306	276	
	C7	Top	326	253	
		Base	293	268	
	C8	Top	268	187	
		Middle	414	379	
		Base	291	163	
D	D1		187	92	

beach deposit on the basis of sedimentary structures and stratigraphic position, consists of subangular to rounded grains of quartz, chert, feldspars, clay fragments and calcite cement in the relative proportions given in Table 4-2 (Plate 4-1). Subangular, poorly sorted grains and constituents such as clay fragments are not characteristic of beach deposits which normally contain well rounded grains and are devoid of fine material (Blatt, Middleton and Murray, 1980, p. 73). Poor sorting and a lack of rounding may indicate that sediments were transported only a short distance, and that the beach was of low energy, incapable of winnowing out the finer mudstone clasts.

Units C1 through C10 (Facies C), interpreted as point bar sandstones, and an example of an overbank sandstone (Facies D1), are all composed of the same constituents as is Unit B2, and in similar proportions (Table 4-2). Calcite cement is the one constituent which varies in amount between and within, sandstone units.

All but one of the sandstones examined lay between the litharenite and the feldspathic-litharenite fields in a Q - F - R diagram adopted from Folk (1968). The lone exception is the overbank sandstone, which owing to the higher feldspar content, lies in the lithic arkose field (Figure 4-1).

TABLE 4-2: Rock composition in percent based upon 300 counts. Sample locations are indicated on Figure 2-8.

Facies	Unit/ Location		Quartz	Chert	Alkali F-spar	Plag. F-spar	Clays & Micas	Iron Oxides	Volcanic Rock Frags.	Calcite Cement
B	B2		28	30	07	06	09	--	02	19
C	C3		38	22	05	06	25	02	01	--
	C4		31	18	05	04	31	02	02	07
	C5	Top	19	24	06	02	04	--	02	42
		Middle	36	37	09	06	07	01	02	06
		Base	36	35	11	05	09	02	01	05
	C6	Top	18	10	04	04	09	02	01	52
		Middle	39	24	08	06	15	02	02	04
		Base	40	26	08	04	18	02	01	01
	C7	Top	37	38	02	05	11	--	02	04
		Base	34	34	04	06	14	01	02	06
	C8	Top	35	27	04	04	09	02	--	05
		Middle	31	46	04	04	05	--	01	09
		Base	36	36	02	06	14	--	02	04
D	D1		28	14	14	05	36	04	02	--

PLATE 4-1: Unit B2 stained to show carbonate cement (Ct). Note the detrital clay fragments (C) and subangular to subrounded quartz grains (Q). (Power 63 x , crossed polars).

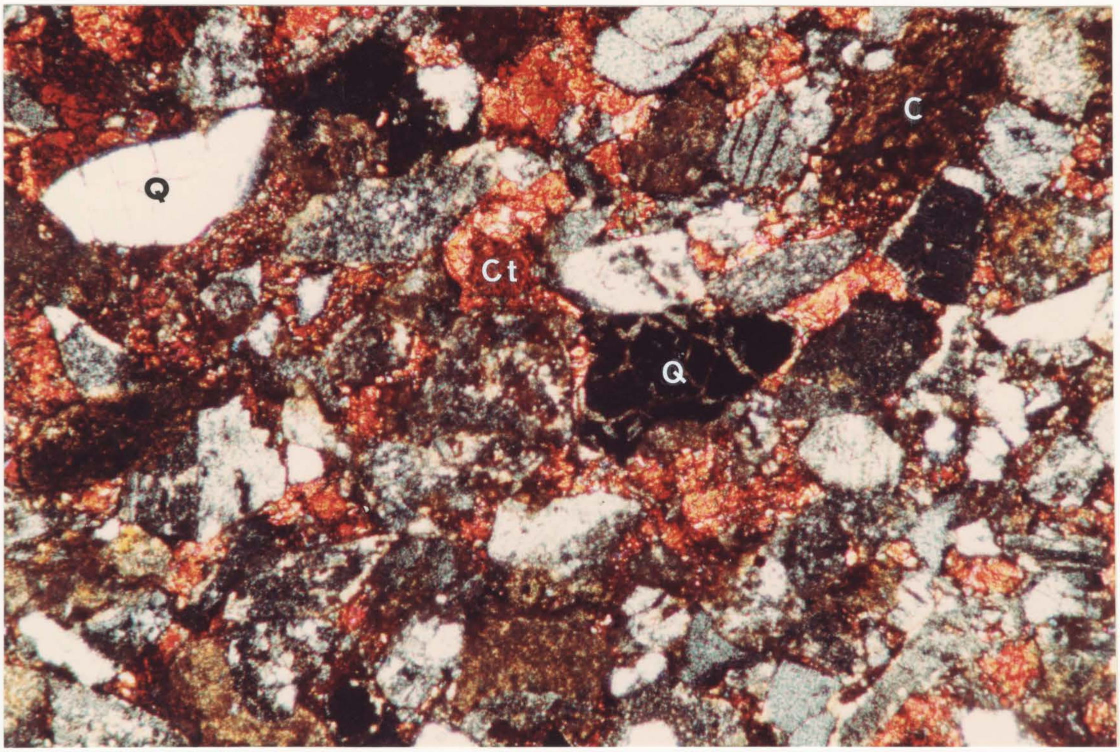
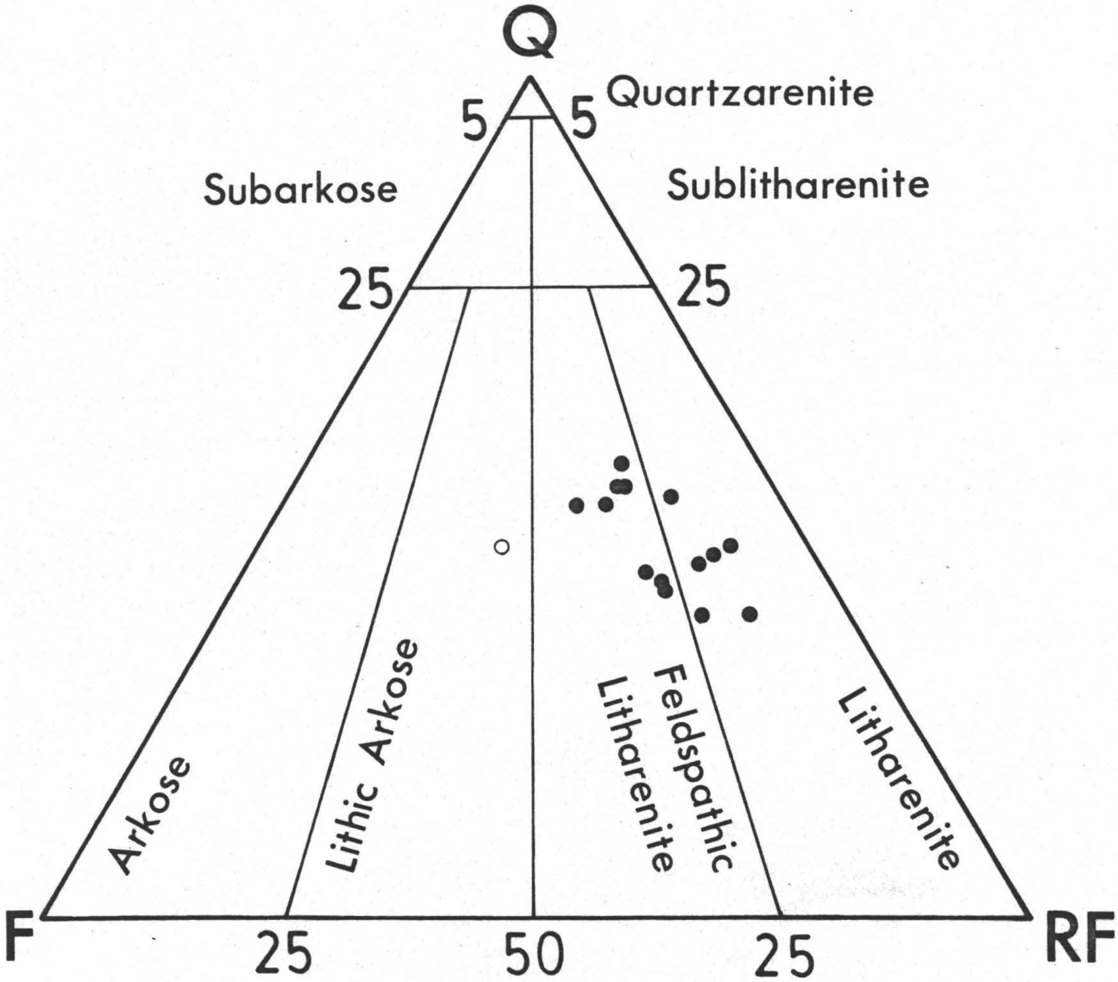

Q
C
Ct
Q

FIGURE 4-1: Quartz - Feldspar - Rock Fragment plot of the Belly River Formation sandstones in the Ghost Dam spillway. Filled circles represent point bar sandstone (Facies C) and beach samples (Facies B). The open circle refers to an overbank sandstone (Facies D). (After Folk, 1968).


Q
Quartzarenite
5
5
Subarkose
Sublitharenite
25
25
Arkose
Lithic Arkose
Feldspathic Litharenite
Litharenite
F
25
50
25
RF

CONSTITUENTS

Quartz grains normally make up the majority of the thin sections and can be classified into one of four types;

1] non-undulatory,

2] undulatory; requiring greater than 5° to become fully extinct,

3] polycrystalline; 2 to 3 crystals per grain,

4] polycrystalline; > 3 crystals per grain (Basu *et al.* 1975).

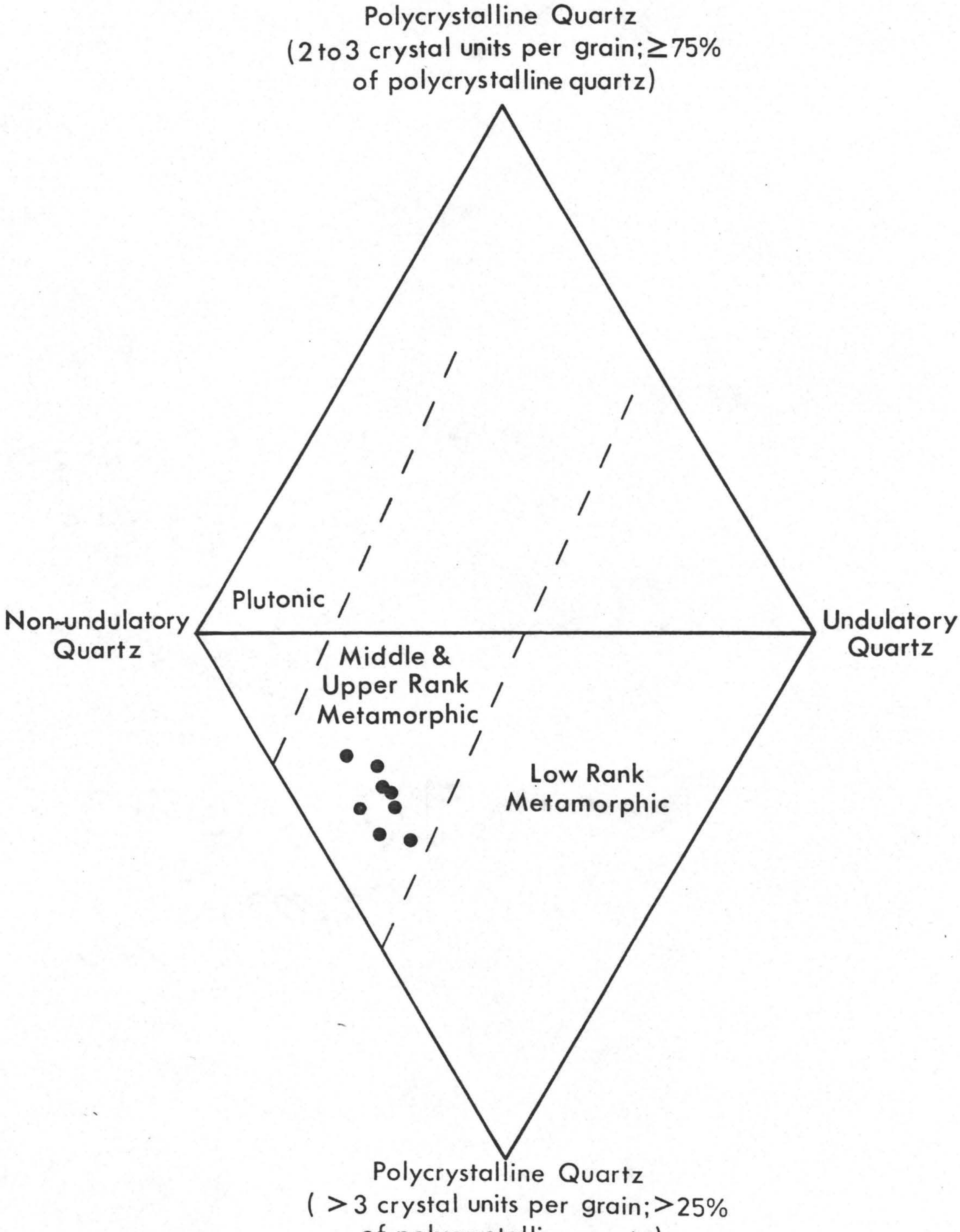
Basu *et al.* (1975), reports that the number of crystal units within the polycrystalline grain is related to the source rock of the grain. Those made up of fewer than three crystals per grain have been shown to have been derived from a plutonic source; those grains containing more than three crystals have been derived from a metamorphic source. The majority of the quartz grains in this study are either non-undulatory or polycrystalline with greater than three crystals per grain (Table 4-3). All seven samples indicate a middle to high rank metamorphic source when plotted on a double triangle diagram relating the four types of quartz (Figure 4-2).

Much of the quartz in the sandstones contains inclusions of heavy minerals. The most common are either zircon or tourmaline. Rutile needles are rare.

TABLE 4-3: Summary of quartz point counting data, in percent based upon 100 counts. Refer to Figure 2-8 for sample locations.

Facies	Unit	Non-undulatory	Undulatory	Polycrystalline	
				2-3/grain	>3/grain
B	B2	58	17	01	24
C	C3	55	16	05	24
	C4	51	11	04	34
	C5	46	15	04	35
	C6	51	12	03	34
	C7	53	14	02	31
	C8	54	16	03	27
D	D1	64	13	05	18

FIGURE 4-2: Double triangle plot relating the 4 types of quartz used in determining the provinance of source rocks. Sample plots are indicated by closed circles. (After Basu *et al.*, 1975).


Polycrystalline Quartz
(2 to 3 crystal units per grain; ≥75% of polycrystalline quartz)
Plutonic
Non-undulatory Quartz
Undulatory Quartz
Middle & Upper Rank Metamorphic
Low Rank Metamorphic
Polycrystalline Quartz
(>3 crystal units per grain; >25% of polycrystalline quartz)

The shape of the grains ranges from subangular to rounded. Polycrystalline grains containing more than 3 crystals are normally more rounded than the other three types. Syntaxial quartz over growths are uncommon, only a few being observed in thin section.

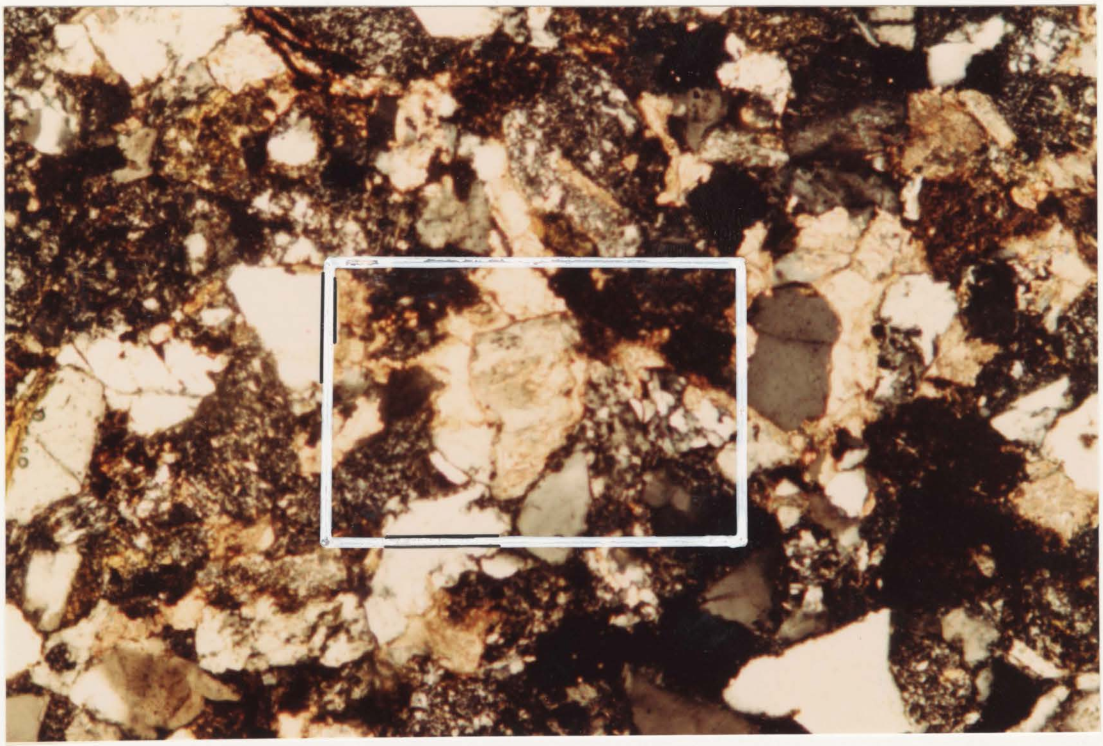
Chert is very abundant in all of the sandstone samples examined. Most of it is cryptocrystalline to coarsely crystalline, but microcrystalline chalcedony, some with radiating structure is not uncommon. No fossiliferous spicules were observed in any of the cherts. Grain shape ranges from subangular to rounded and grains are often surrounded by a rim of iron oxides. A brown, possibly phosphatic variety, is found in some of the thin sections.

Feldspar is present in all samples and ranges in shape from subangular to subrounded. Plagioclase grains are found in various stages of alteration, commonly altering to calcite (Plates 4-2, 4-3, 4-4). Alkali feldspar is normally less altered.

Lithic and volcanic rock fragments are present in varing amounts in the samples. Volcanic rock fragments are a minor constituent throughout the sandstones (zero to three percent). They are generally made up of fine subhedral crystals, possibly plagioclase, embedded in a grey-brown, fine grained matrix. Lithic rock fragments, primarily mudstone with some siltstone, are much more

PLATE 4-2: Alteration of plagioclase feldspar grain in Unit C8. Boxed area is that of Plate 4-3. (Power 63 x, crossed polars).

PLATE 4-3: Enlargement of Plate 4-2. Note intricate replacement of plagioclase (Plg) by calcite cement around the grains (Ct). Polycrystalline quartz (Q) is also being replaced by calcite. A single zircon crystal (Z) occurs in the quartz grain in the lower left of the photograph. (Power 160 x, crossed polars).



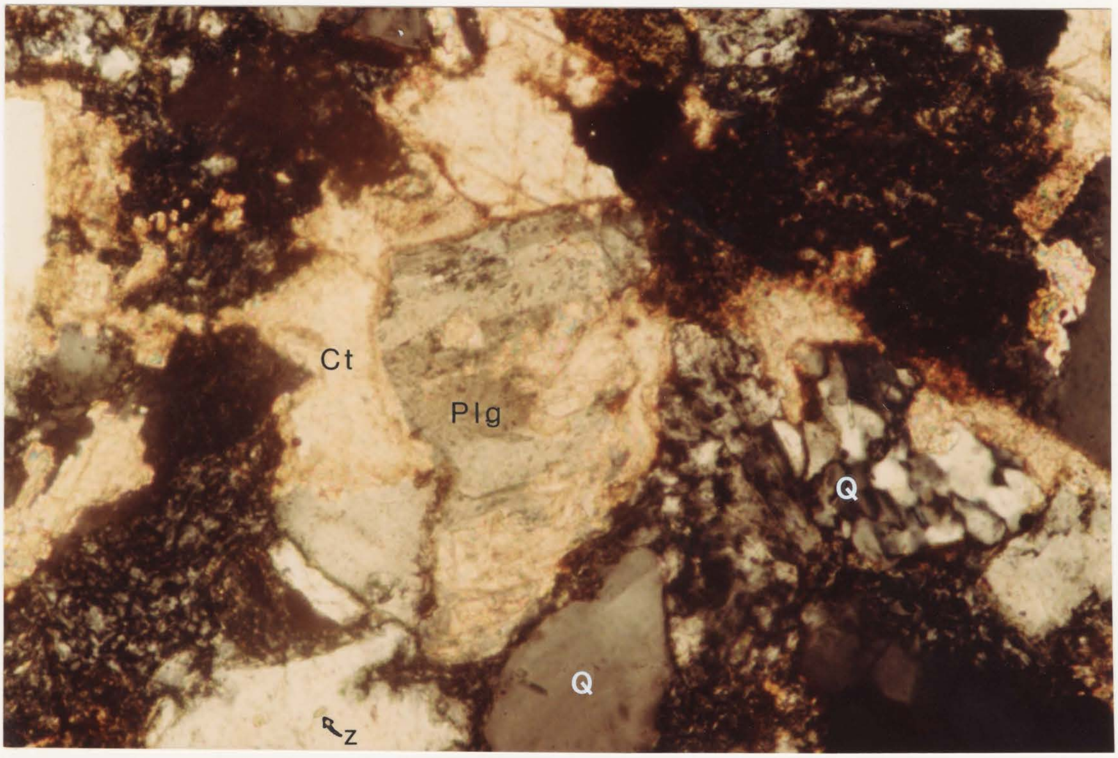
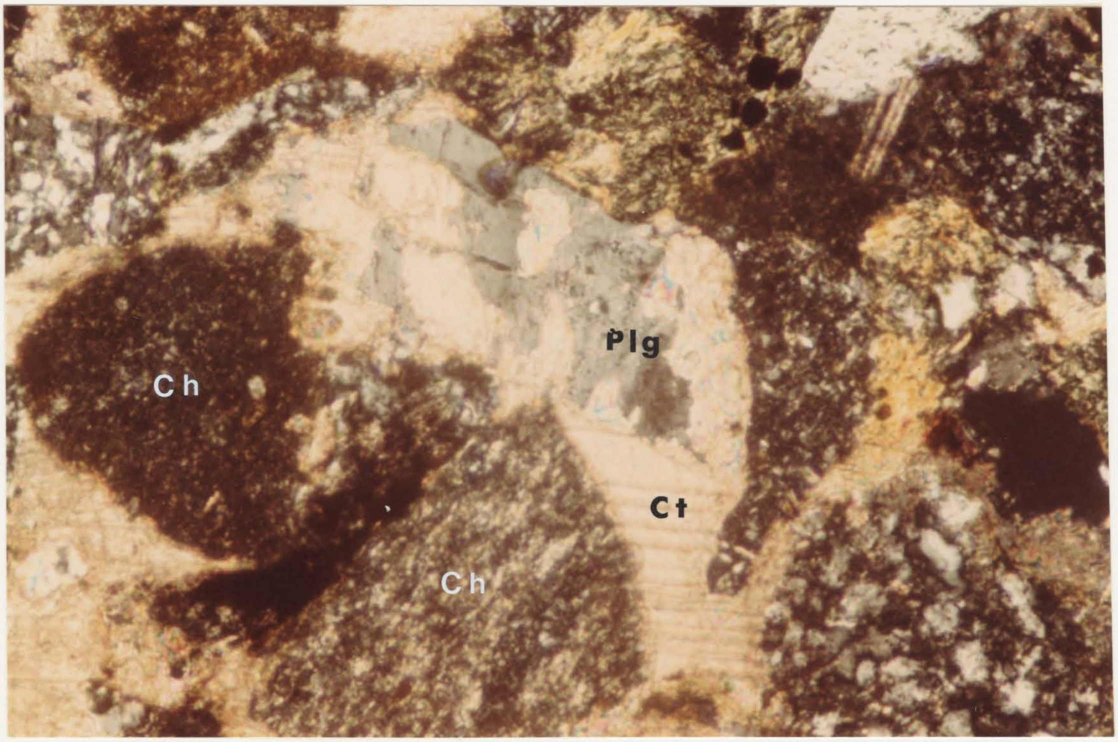

Ct
Plg
Q
Q
z

PLATE 4-4: Calcite (Ct) replacement of plagioclase (Plg) in Unit C5. Note how calcite obtained from the alteration is acting as a cement for not only the plagioclase, but also other grains, most noticably chert (Ch). (Power 160 x, crossed polars)


Plg
Ch
Ct
Ch

abundant accounting for from 4 to 35 percent of the thin sections. They are occasionally found sandwiched between other larger grains and show distinct compressional features.

A few accessory minerals are found within the thin sections, the most abundant including muscovite, biotite and iron oxides, primarily hematite.

CEMENTS

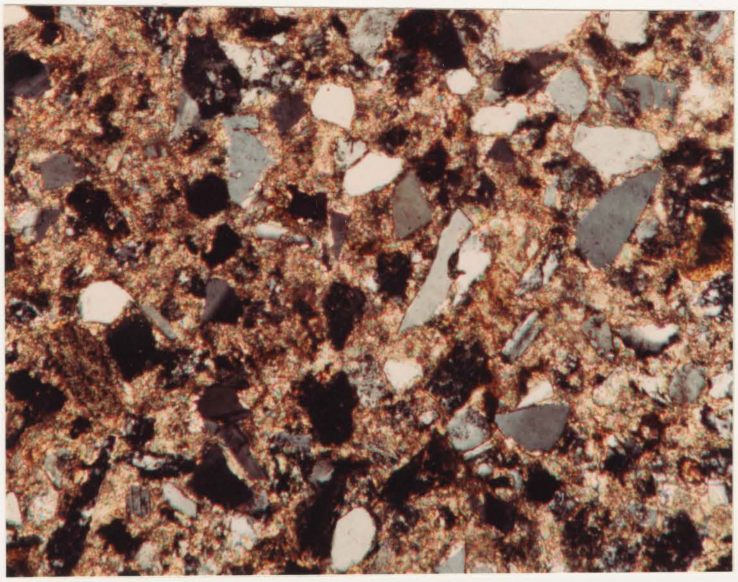
Calcite is present in many samples as an interstitial diagenetic cement. The amount of cement present however, varies considerably, even within a single sandstone unit. Unit C6 for example, contains over 50 percent calcite near the top, but at the base only 1.0 percent. Towards the middle of Unit C6, calcite is present in low proportions, (4.0 percent) (Plates 4-5, 4-6, 4-7).

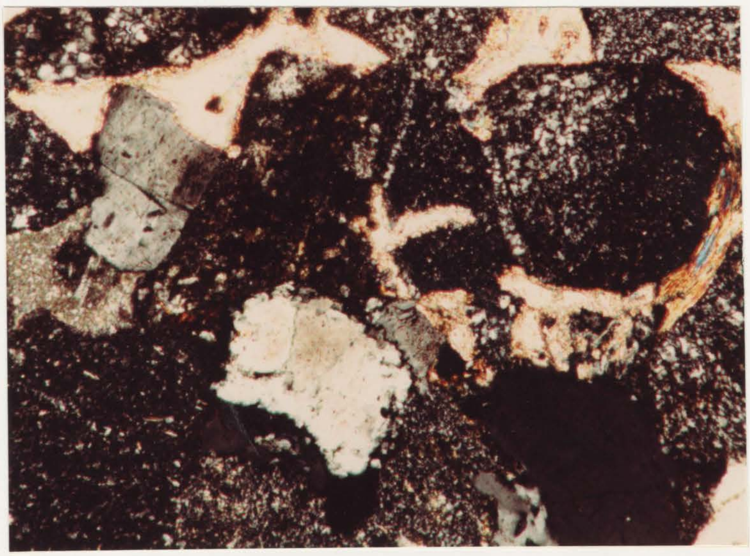
Carbonate cement is normally an early diagenetic mineral, forming before significant compression has occurred (Schmidt and MacDonald, 1979). It can even being precipitated out in some modern river and desert sand and soils (Tucker, 1981). Carbonate cement is not normally present in volumes higher than 30 percent, the original porosity of the sediment. Where present in larger quantities, it is invariably etching, corroding and replacing detrital grains, causing them to be irregularly shaped (Blatt, Middleton and Murray, 1980, p. 345) (Plate 4-5). As a result of calcite precipitation, there is often a displacement of grains so that the grains have

PLATE 4-5: Sample of Unit C6 near top. Note abundance of carbonate cement and lack of grain contacts. Mean grain size 87μm. (Power 63 x, crossed polars).

PLATE 4-6: Sample of Unit C6 near middle. Carbonate cement is present in low proportions (4.0%). Grains are in contact with one another and are larger than those in Plate 4-5. Mean grain size 172μm. (Power 63 x, crossed polars).

PLATE 4-7: Sample of Unit C6 near its base. Grains are larger than those in Plate 4-6 and only 1.0% of cement is contained in the sample. Mean grain size 276μm. (Power 63 x, crossed polars).





the appearance of floating in the cement (Tucker, 1981). Plate 4-5 shows that grains are not in contact with one another and do appear to be "floating".

Calcite precipitation occurs when the solubility product of calcite is exceeded. This may occur for a number of reasons; through evaporation of vadose or near surface phreatic groundwater (prominent near surface); or an increase in pH and/or temperature (prominent at depth). The low percentage of calcite in the base of Unit C6 may be attributed to insufficient initial porosity which is necessary to develop an early diagenic cement. Here calcite development was restricted to localized plagioclase alteration and detrital grain replacement.

The presence of a fining upward trend in Unit C6 (Plates 4-5, 4-6, 4-7), probably had little to do with calcite development because relatively constant grain sized sandstones, such as Unit C5, can also possess an upward increase in carbonate cement.

Silica cement was not observed in thin section analysis, possibly because it was obscured by the presence of fine grained interstitial mudstone fragments or iron oxide particles. The source of the iron oxides was probably the alteration and weathering of ferro-magnesium minerals such as biotite or chlorite.

AUTHIGENIC MINERALS

The abundance of mudstone fragments between detrital grains makes the observation of fine grained authigenic clay minerals very difficult with a transmitting microscope, as they tend to mask authigenic clays which also infill voids between grains. The added early development of carbonate cement in some of the rocks effectively reduces the porosity available and necessary for the development of clays, to zero.

A PSEM 501B scanning electron microscope was used to observe the relationship between authigenic clays, (if present), cement and detrital grains. Three point bar sandstone samples (Facies C) containing varying amounts of carbonate cement, and one overbank sandstone sample (Facies D) , were studied. Plate 4-8a shows the extent of calcite cementation in the upper portion of Unit C8. Cleavage is prominant as are numerous platy and angular minerals which may be clay fragments or broken calcite fragments. This is typical of all the samples examined, much of the rock appears fragmental, cementation has reduced porosity substantially and well developed clay minerals are not common. Plate 4-8b may display poorly formed booklets of authigenic kaolinite growing on calcite in Unit C8 and Plate 4-8c and d shows a clay mineral, possibly illite, growing on an etched feldspar grain.

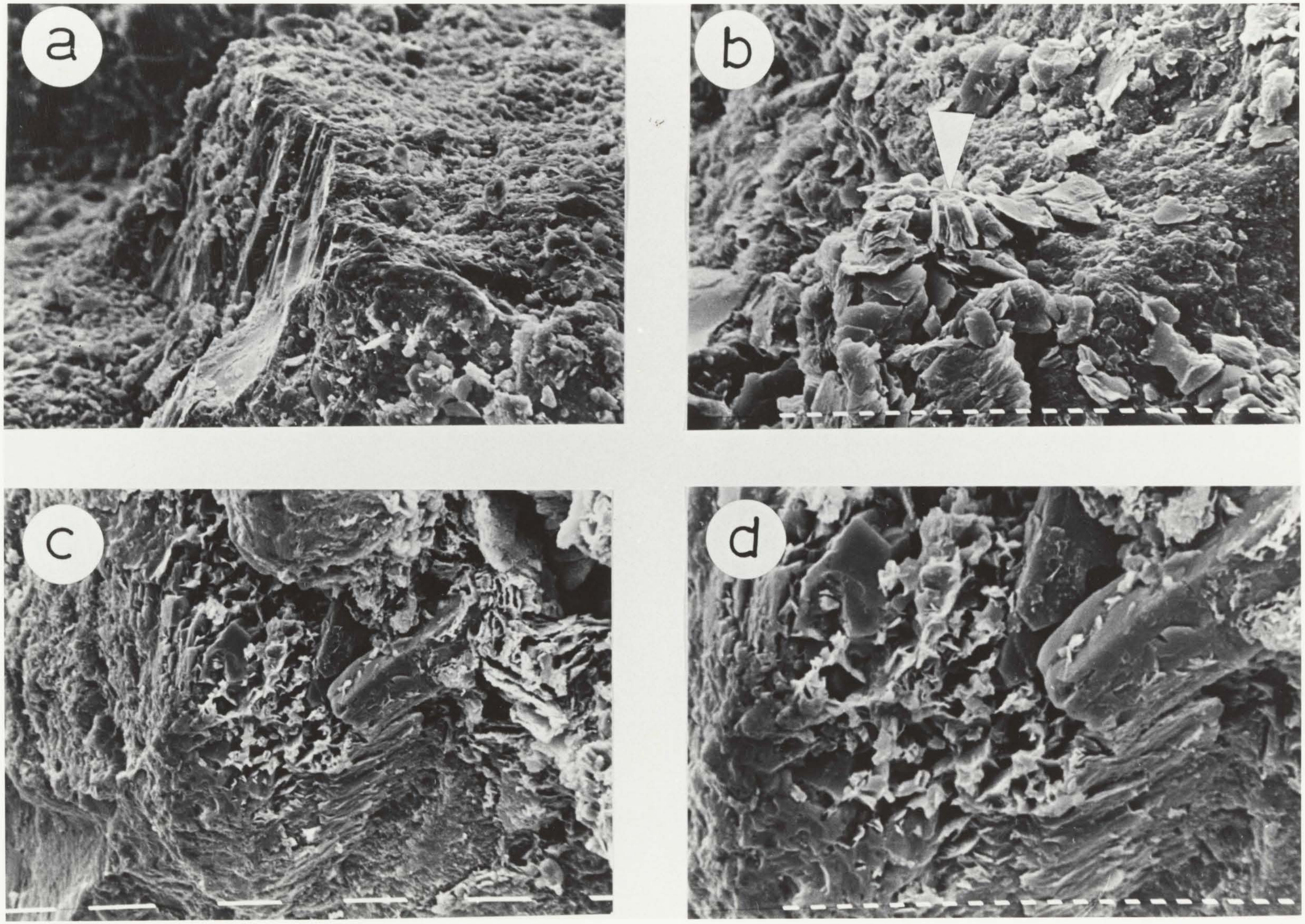
Much of the authigenic mineral growth in the sandstone is of columnar of tabular minerals probably of the zeolite family. Several of the minerals are shown in

PLATE 4-8: a] Calcite cement showing cleavage in close proximity to platy and angular fragments in Unit C8 (Power 2500x).

b] Possible example of authigenic kaolinite atop calcite cement in Unit C8 (at arrow). Scale at bottom indicates 10^0 microns (Power 2500x).

c] Clay mineral, possibly illite growing in partially corroded feldspar. Scale bar at bottom indicates 10^1 microns (Power 1250x).

d] Enlargement of c] Scale bar at bottom indicates 10^0 microns (Power 2500x).


a
b
c
d

Plates 4-9a, b, and c. Plate 4-9c may also contain chlorite growing in close proximity with calcite.

Scanning electron microcsope photographs of detrital mica flakes from Unit C4 are shown in Plate 4-10 a and b. Both flakes appear compressed between other larger grains, or embedded in carbonate cement. Syntaxial quartz overgrowths, although uncommon because of the presence of carbonate cement, were occasionally observed. Plate 4-10c and d are photographs of an overgrowth embedded in carbonate cement in Unit C8.

PLATE 4-9: a] Authigenic growth of unidentified tabular minerals,possibly zeolites in Unit C6. Scale at bottom 10^1 microns (Power 1250x).

b] Enlargement of a] centred on columnar shaped mineral and cauliflower shaped aggregates. Scale at bottom 10^o microns (Power 2500x).

c] Possible zeolite growth in Unit C8 platy minerals towards the lower left of the photograph may be chlorite flakes (arrow). Smooth area at lower left is calcite cement. Scale at bottom 10^o microns (Power 2500x).

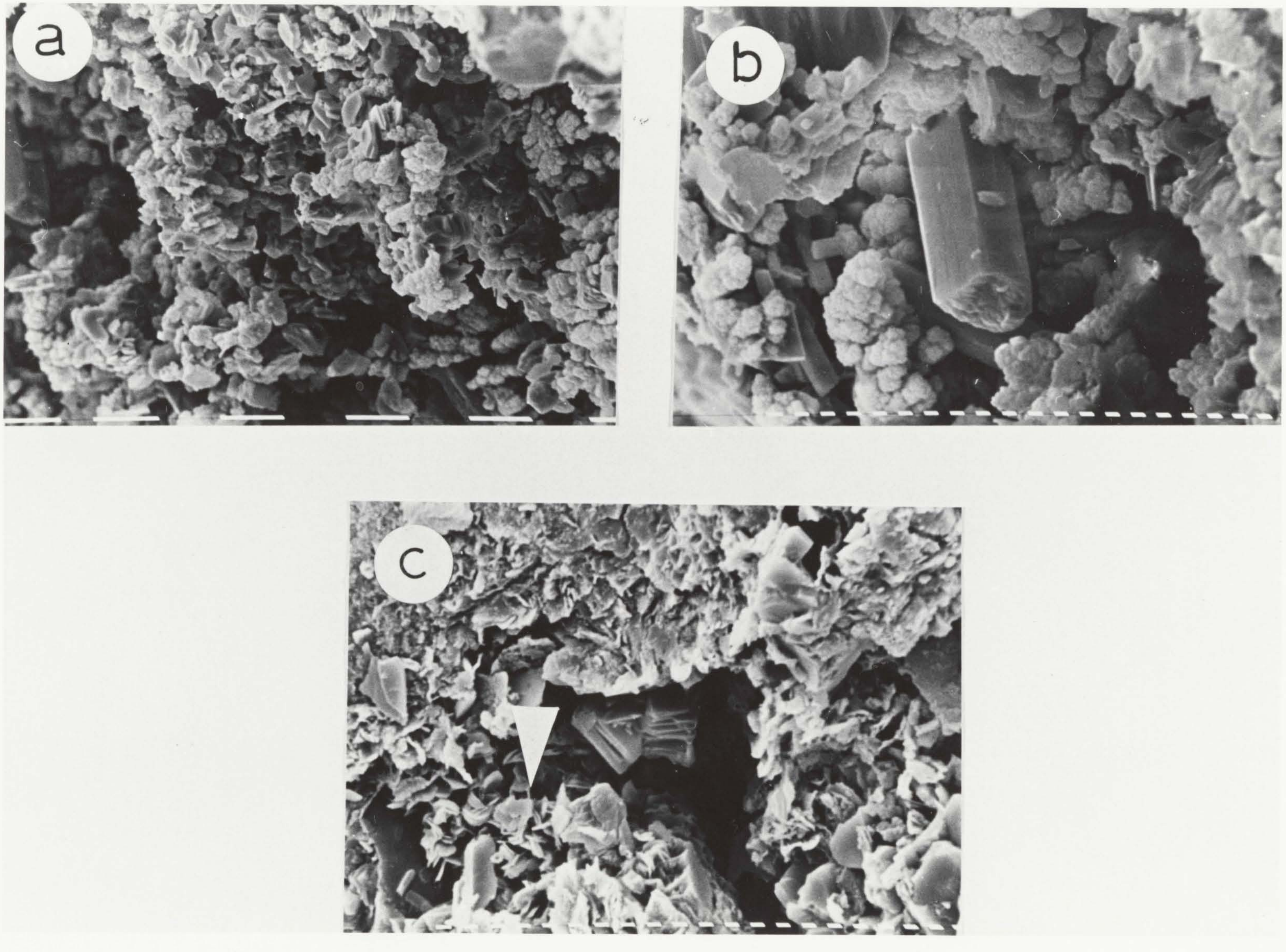
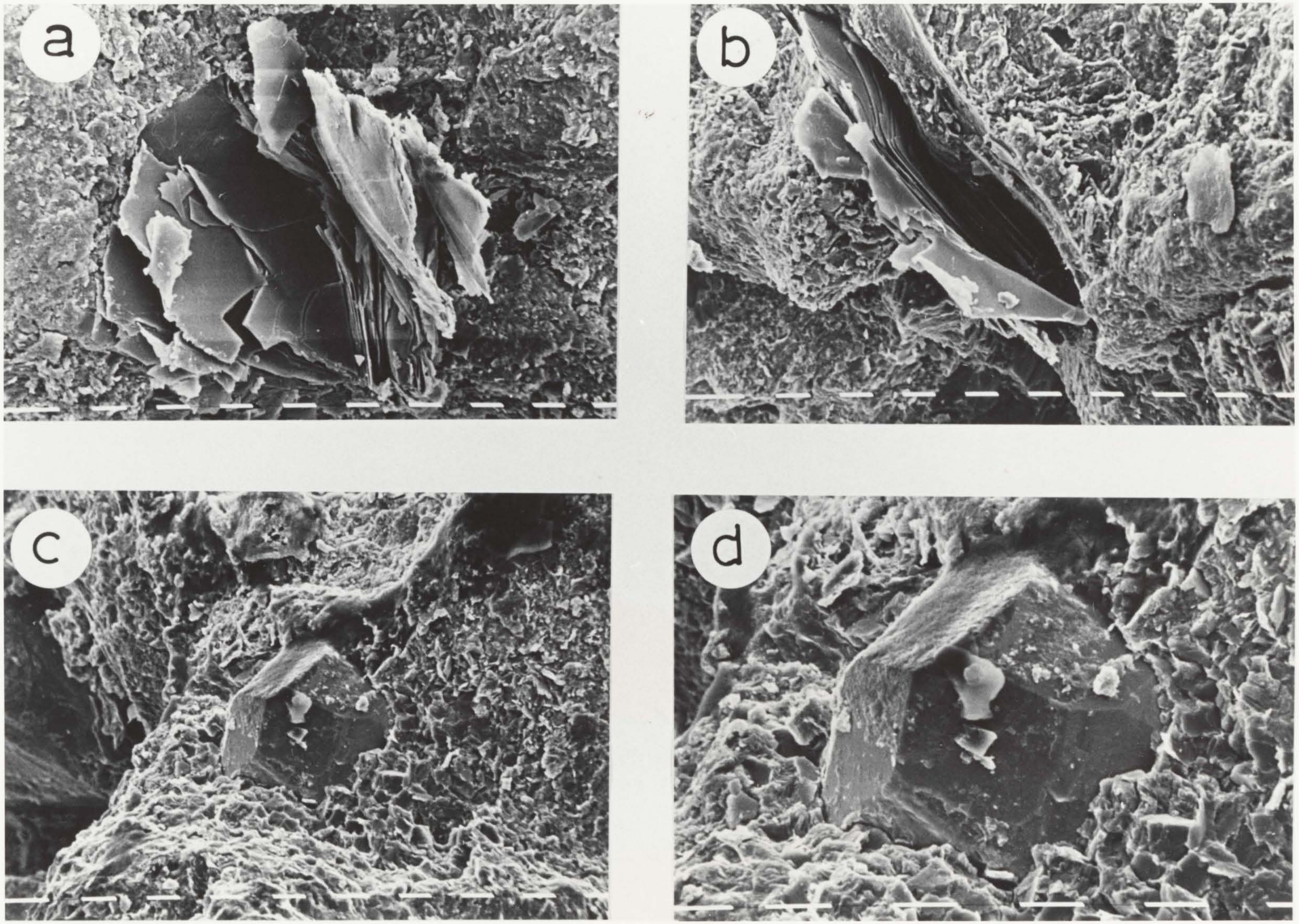

a
b
c

PLATE 4-10: a & b] Detrital mica flakes in Unit C4. Scale bar at bottom 10^2 microns (Power 640x).

c] Quartz overgrowth embedded in carbonate cement. Scale bar at bottom 10^2 microns (Power 640x).

d] Enlargement of c] showing close up of quartz overgrowth. Scale at bottom 10^1 microns (Power 1250x).


a
b
c
d

CHAPTER FIVE

INTERPRETATIONS AND DISCUSSION

The purpose of this chapter is to integrate the previously discussed, although generalized, unit descriptions and interpretations into a coherant facies model explaining the observed vertical succession of units as a whole.

Facies models serve two major purposes; to develop a norm or standard which results from synthesis of many examples, and to act as a predictor or for comparative purposes (Walker, 1979). In this study, facies models are proposed for the Wapiabi - Belly River transition and the Belly River Formation, however, they are applicable only to this study area and any wider application can only come after comparisons with other similar sequences.

Wapiabi - Belly River Transition

The sediments of the Wapiabi - Belly River transition were deposited during a regression in the Late Santanian and Early Campanian (Williams and Burk, 1966).

Units A1 and A2 (Facies A) found in the lowest portion of BR-1 were probably deposited in a relatively deep marine environment. Unit A1 is characterized by an upward increase in the sandstone to mudstone ratio. This coarsening upward trend may be produced by prograding turbidite lobes. Studies on the Wapiabi - Belly River transition at the Highwood River (Hunter, 1980) and at Lundbreck Falls (Bullock, 1981), revealed sharp based turbidites increasing in number upwards in the section. Laterally extensive turbidites are absent in the Ghost Dam spillway. The Wapiabi Formation at this location also differs from the exposures at the Highwood River and Lundbreck in the amount of sandstone within the Formation. Rosenthal, (presently studying the Wapiabi - Belly River transition at several outcrops in the Alberta foothills), has suggested that the lack of sandstone in the Ghost Dam spillway is due to northward pinch outs of the main sandstone members of the Wapiabi Formation (Chungo and Highwood members) (Figures 5-1 and 5-2). The relatively small amounts of sandstone that did sweep far enough north (as prograding turbidites), were soon bioturbated resulting in the coarsening upward mudstones, characteristic of Unit A1.

The presence of HCS within sandstones atop Units A1 and A2 indicates that density currents were affected by large storm waves and must therefore have been located above storm wave base. This supports a environment shallower than for the units below.

Density currents are normally associated with failure and acceleration on a slope with deposition at the base of the slope. However, previous studies in the Fernie- Kootenay

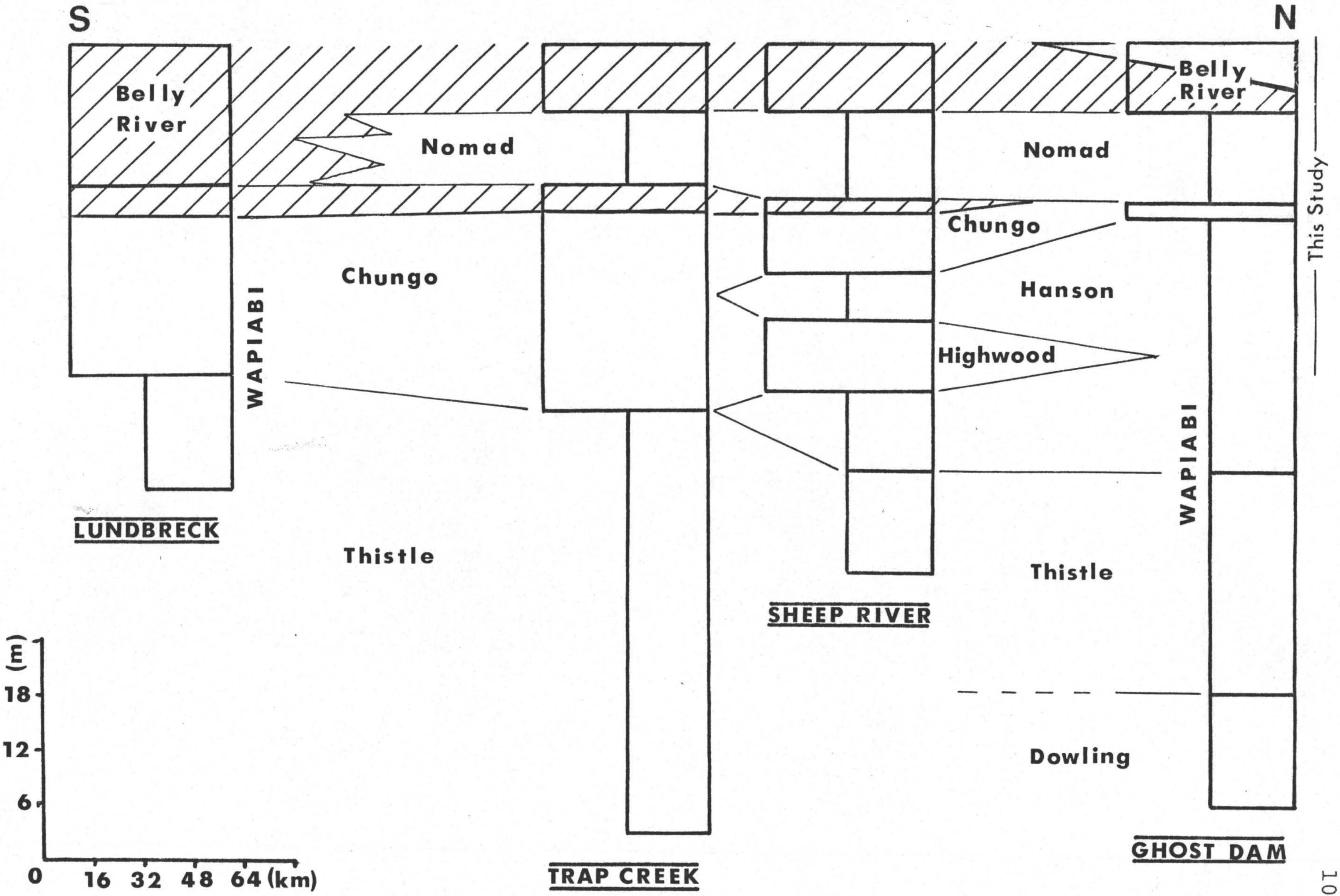
FIGURE 5-1: Location map of Wapiabi Formation cross-section AA'.

1] Lundbreck
2] Trap Creek
3] Sheep River
4] Ghost Dam


EDMONTON
ALBERTA
A´
4
CALGARY
3
2
MEDICINE HAT
0 20 60 100
(km.)
A
1

FIGURE 5-2: Schematic cross-section of the Wapiabi Formation in four outcrops in the southern Alberta foothills. The lack of sandstone in the Wapiabi Formation at the Ghost Dam exposure can be attributed to northward pinch outs of the main sandstone members of the Wapiabi Formation (Chungo and Highwood members).

The stippled areas refer to nonmarine deposits. The presence of marine trace fossils in the Belly River Formation at the Ghost Dam has also been indicated and is shown as a marine unit within the Formation.
(L. Rosenthal, personal communication)


S
N
Belly River
Nomad
Chungo
Hanson
Highwood
Thistle
Dowling
WAPIABI
This Study
LUNDBRECK
TRAP CREEK
SHEEP RIVER
GHOST DAM
(m)
18
12
6
0
16
32
48
64
(km)

transition (Hamblin and Walker, 1979) and the Wapiabi - Belly River transition (Hunter, 1980 and Bullock, 1981), have found no evidence supporting this. An alternative process accounting for the generation of density currents in the Fernie - Kootenay transition has been proposed by Hamblin and Walker. They believe that water driven shoreward in storm surges carries with it upon returning to the sea, large quantities of suspended sediment. The increased density of the sediment laden water causes it to flow along the sea bottom and results in a density current deposit. Should the deposit lie below storm wave base, a Bouma turbidite is obtained. If however, the deposit lies between storm wave base and fairweather wave base, hummocky cross-stratified sandstones are obtained (Figure 5-3). The presence of HCS and the lack of any evidence of a slope in the Ghost Dam spillway would tend to favor storm generated deposits as opposed to slope initiated deposits.

The direction in which a density current flows is however controlled by regional paleo-slope. A lack of paleocurrent directions in this portion of the outcrop does not permit an accurate determination of the paleo-slope, but asymmetric current ripples atop the HCS sandstone, oriented towards 101°, would indicate it trended towards the east. This is consistent with the rising cordillera in the west and the proposed shoreline of Williams and Burk (1966), (Figure 5-4). Recent studies by Hunter (1980) and Bullock

FIGURE 5-3: Mechanism proposed for creation of hummocky cross-stratified sandstones and turbidites and relative positions where they would form.

A major storm 1 causes a storm surge tide 2 which can be greater than 6 metres high. As the wind abates, a seaward flowing density current is generated 3 . Above storm wave base but below fairweather wave base, waves still affect the sediments resulting in HCS. Below storm wave base, waves have no affect on the sediment and Bouma turbidites are obtained. Above fairweather wave base, normal processes rework HCS effectively erasing it. (Modified after Walker, 1979).

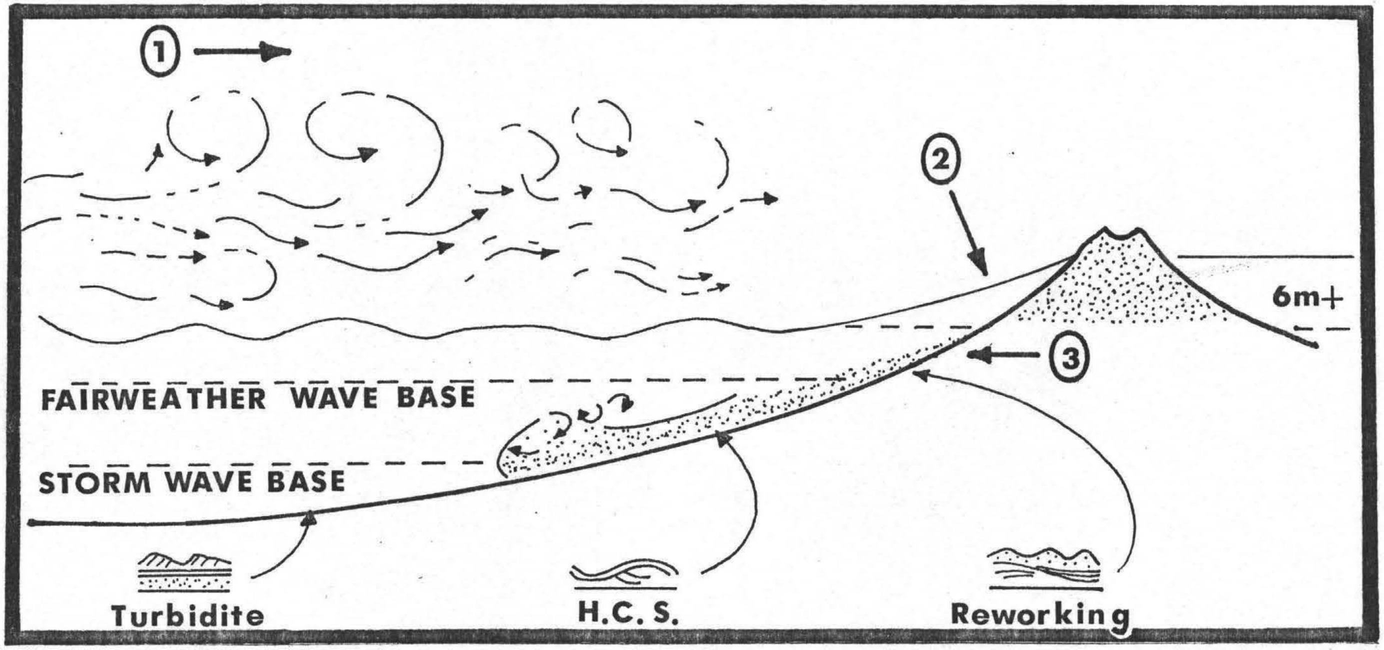
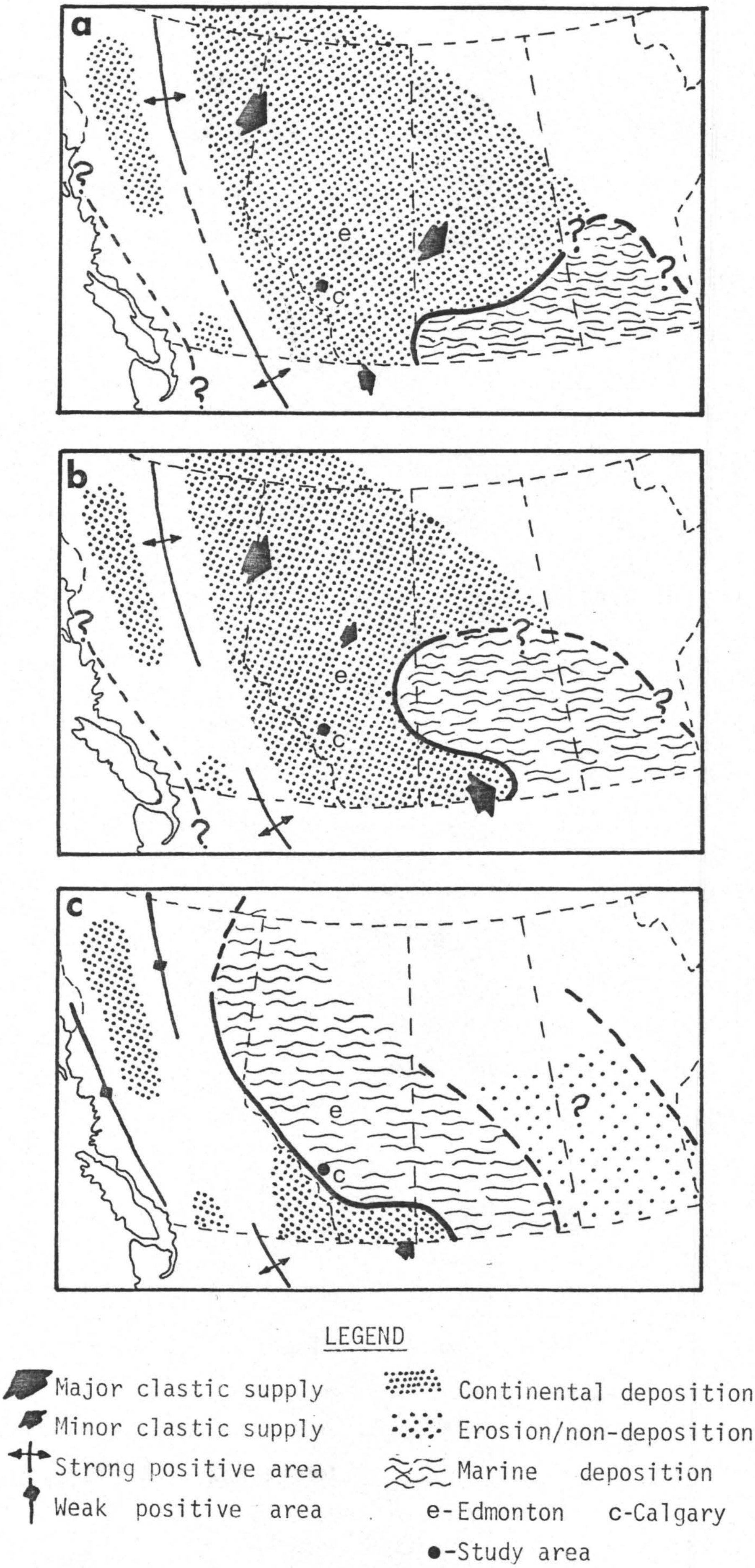

1
2
6m+
3
FAIRWEATHER WAVE BASE
STORM WAVE BASE
Turbidite
H.C.S.
Reworking

FIGURE 5-4: Paleogeographic maps of Western Canada during Upper Cretaceous. (Modified after Williams and Burk, 1964 and Ogunyomi and Hills, 1978).

a] Upper Belly River Sea (Middle Campanian)
b] Lower Belly River Sea (Middle Campanian)
c] Milk River Sea (Lower Campanian)


a
b
c
e
c
?
LEGEND
Major clastic supply
Minor clastic supply
Strong positive area
Weak positive area
Continental deposition
Erosion/non-deposition
Marine deposition
e-Edmonton c-Calgary
●-Study area

(1981), determined through very consistent paleocurrent data, that turbidites flowed to the north. Hunter proposed that the northerly flow directions resulted from density currents which were swept into a northerly trending trough between the emerging cordillera and Aptian ridge. The density currents flowed into the trough from the southwest and then were funnelled to the north-northwest. Bullock suggests that a similar mechanism is responsible for the northerly trending flow directions determined at Lundbreck Falls.

The lone easterly oriented paleocurrent direction in this exposure, although far from being definitive, may indicate that density currents here were not influenced by the trough, possibly because it was too far offshore.

Hummocky cross-stratification in sandstones according to theory forms above storm wave base which has a maximum depth of approximately 150 metres (Duke, personal communication). It is normally only preserved when deposited below fairweather wave base. HCS in sandstones deposited above fairweather wave base is not usually preserved because of reworking by normal wave action (refer to Figure 5-3) (Duke, personal communication).

The close proximity of the beach to the HCS sandstone in Facies B, and the presence of *Macaronichnus*, nowadays confined to subtidal-intertidal-estuarine environments (Clifton and Hunter, 1978), supports a relatively shallow origin of the HCS. If this interpretation is correct, it would indicate that the shoreline area was of low energy incapable of erasing HCS formed by periodic storms.

Low energy environments also favor the development of thin beaches (Duke, personal communication), for which the upper portion of Facies B (Unit B2) certainly qualifies. An alternate explanation for the close proximity of the beach and the hummocky cross-stratified sandstone is that there was a slight drop in sea level followed by a rapid progradation of beach deposits.

The petrographic nature of Unit B2 is very uncharacteristic of a beach and contains clay constituents which should have been winnowed out by wave action. The clay clasts were probably transported to the shoreline by fluvial systems, and the fact that they were not winnowed out, provides further evidence for a low energy environment.

Belly River Formation

In previous chapters, the concept of a meandering river system responsible for the development of the channel system has been discussed. However the presence of several marine trace fossils throughout the Belly River Formation suggests some sort of marine influence over the channel system, (refer to Figure 5-2). This therefore requires a more detailed discussion of not just a meandering river facies model, but several models in which meandering channels can develop.

Comparison with a Meandering River Facies Model

The classic meandering river facies model consists of point bar sandstones situated in interbedded sandstones and mudstones. Helicoidal (cyclic) flow around meander bends causes erosion on the outside of meander loops (cutbank) and deposition on the point bar. The diminishing velocities and depths associated with the up-slope component of flow over the point bar surface causes bed shear stress to fall and therefore gives an upward reduction in grain size (Reading 1978, p. 33). The result is a fining upward sequence, typical in meandering river system. Fining upward trends were observed in Units C3, C4, C6, C7 and C8.

Multiple fining upward sequences, such as that exhibited by Unit C8, can potentially form in two circumstances. The first possibility involves the deposition of the lower sequence as a separate point bar. An upper fining upwards sequence would develop over the older one, if a new channel migrated across the flood plain directly above the older sequence. A scoured contact would also seem likely. A second possibility which would give a similar multiple fining upwards sequence, involves increased discharge through the channel system due to a flood event. The resulting increase in water could effectly scour down into the already existing point bar and deposit a new fining upward sequence atop it.

Certain characteristics may be used to differentiate between the two possibilities. If the second fining upward sequence was due to a new channel and if scouring did not extend too deeply into the lower sequence, one might expect to find truncated rootlets at the contact between the two sequences, and horizontal mud drapes or partings at the contact which scouring failed to remove. If however the second sequence was formed due to flooding, one would not expect to observe truncated rootlets, or mudstone partings. It may also be argued that paleocurrent data could be used to distinguish between the two possibilities, as a second channel system overlying the first might be expected to contain radically different paleocurrent directions. While this is generally true, it must be remembered that flows during flooding stages need not be confined within the banks of a channel and could therefore effectively "straighten up" meander loops and also produce dramatically differing paleocurrent directions.

In Unit C8, paleocurrent data is fairly inconclusive as grain orientations tend to be similar in both fining upward sequences, and crossbedding orientations tend not to be. However since no truncated roots, or mudstone partings were observed, it seems more likely that the second fining upwards sequence was formed by increased discharge levels during flooding.

The upper stream portion of the point bar may contain chutes which act to funnel water along adjacent to, and generally parallel to the main channel during high flood stages. The floors of chutes rise downstream until the flow is no longer confined and can therefore expand laterally to develop chute bars at the downstream end of point bars. Chutes are described atop Unit C3 and are oriented in the same direction as paleocurrent indicators in the point bar deposit. No chute bar deposits were found in the study area but this may be due to limited exposure.

During low flood stages, or during channel abandonment, fine material can be deposited in the channel. This sediment may be eroded during the next high water phase or during reoccupation of the channel. Some of the fine grained sediment may remain however, and the result is preserved mudstone drapes. Mudstone drapes are contained within Unit C1 and C3.

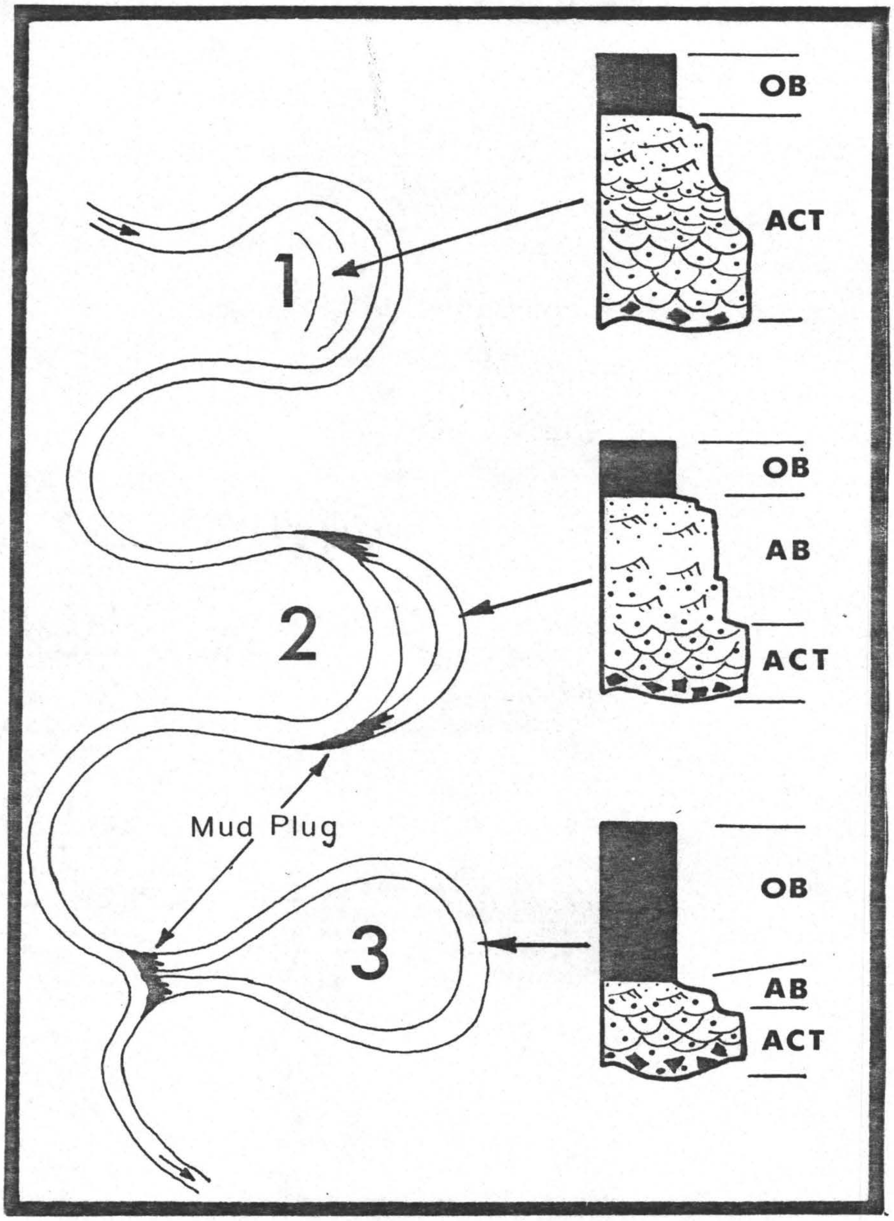
Meandering channel systems are inherently unstable as differing rates of erosion in adjacent meander loops lead to cut offs in one of two forms; gradual chute cut off or sudden neck cut off, (Fisk 1947, Allen 1965) (Figure 5-5). At flood stage, the main flow may travel in sheets, thereby straightening the course of meander bends. Chutes become deepened and as they take an increasing proportion of the discharge, fine material may be deposited at the cut off point (mud plugs) effectively daming off the main channel. Activity in the main channel is reduced and the channel is

FIGURE 5-5: Possible fates and associated sedimentology of meander loops.

1] Uninterrupted meander migration (lateral accretion). The stratigraphic sequence consists of a basal channel lag and trough crossbedding of the active river (ACT), which merges upward into smaller scaled trough crossbedded, the result of reduced velocities and depth of water flowing of the point bar. Atop the sequence are overbank deposits (OB).

2] Chute cut off, the result of the reoccupation of an old swale and gradual abandonment of the main channel. (Walker, 1979). The resulting sequence is similar to that depicted in 1], although a relatively thick sequence of ripple cross-laminated fine sand representing low flow conditions during gradual abandonment (AB) might be expected to overly trough crossbedded sands.

3] Neck cut off, fine grained ripple cross-laminated sands atop the active deposits are thin, the result of sudden channel abandonment. (Modified after Walker, 1979).



OB
ACT
1
OB
AB
ACT
2
Mud Plug
OB
AB
ACT
3

gradually filled in by finer and finer sediments. The result is a gradual fining upward sequence accompanied by a similar upward reduction in the scale of bed forms, (Walker, 1979). Clearly differentiating between this type of cut off and normal fining upward processes operation in point bars is difficult and Units C3, C4, C6, C7 and C8 could equally be of either type.

If the concave banks of adjacent meander loops erode toward one another, and if the neck is breached, the river will rapidly abandon the channel because it has shortened its course(Allen, 1965). The abandoned channel is rapidly plugged and will only receive sediment from suspension during flood stages. The result is a relatively thin point bar deposit with a poorly defined fining upward trend and a similarly poorly defined reduction in bed form size. Unit C5 may represent a channel which was subjected to this type of cut off.

Overbank or flood deposits, as discussed earlier can be divided into proximal (Facies D) and distal (Facies E) deposits. Proximal deposits incorporate levees and crevasse splays. Flood waters rapidly loose their sediment carrying capacity and as a result, the coarsest grained component of the load is deposited as levees along the channel banks. Owing to fluctuating water stages however, levees are made up of variable sized fractions. Sedimentary structures are not well known (Reading 1978, p. 38) although climbing ripple cross-laminations and parallel laminations are common. Levees act to contain river channels and are only submerged during the highest flood stages. They have a low preservation potential because they occur mainly on concave (cut) banks which unless the channel is cut off, will be eroded away. If however the channel has not migrated substantially, levees could be preserved on the convex (point bar) side and this may be the case with Unit D2.

Crevasse splays originate due to a break in levees during flooding and consist of sandstones deposited in the form of fans or tongues of sand elongated away from the river. Crevasse splays are similar to density currents and therefore contain similar internal structures. The presence of rootlets can however partially (or entirely) homogenize the sandstone thereby erasing sedimentary structures. Many of the sandstones contained within Facies D are probably of this origin and it is quite likely that sandstones deposited in the more distal deposits of Facies E also originated from crevasse splays. The actual differentiation between levees and crevasse splays is often difficult because of the homogenization by rootlets and because there is rarely a clear relationship between specific overbank and point bars deposits. Except for possibly Unit C2, the distinction can not be made in this study.

Distal overbank deposition occurs from suspension and therefore only fine grained sediments are deposited, inundated with an occasional sandstone bed derived from splays. Only major floods deposit more than a centimetre or two of sediment at any one time (Reading, 1978. p.38). This is thought to be the mode of deposition of Facies E deposits.

If we ignore the marine trace fossils, a meandering river facies model appears to explain the features observed in the field. In an attempt to schematically illustrate the possible conditions operating during this time, several block diagrams explaining the features observed in Units C2, C3, C4 and C7 are shown in Figure 5-6. The block diagrams are just models and certain aspects of them, primarily the overall geometry and orientation of meander loops, are strictly hypothetical.

Climate dictates to a large extent the nature of the post depositional effects on the meandering river system, especially on the flood plain (overbank) deposits. In arid regions, dessication cracks may occur when the flood plain dries out between floods and vegetation may be sparse. No dessication cracks were found in this study and numerous roots and organic rich (carbonaceous) layers were present. For these reasons, a humid rather than arid climate is preferred for the deposition of the overbank and point bar deposits.

<u>Comparison with a Meandering Estuarine Facies Model</u>

There are few well documented descriptions of

FIGURE 5-6: Possible modes of origin of certain point bar sandstones. Arrows give paleocurrent directions obtained in exposures of the sandstones. Thicknesses of sandstones are approximations.

a] Development of Unit C2. The interfingering and siltstone associated with the northern edge of the unit (refer to Plate 2-5) may be associated with levee deposits.

b] Development of Unit C3. Note in particular the development of chutes trending generally parallel to the direction of the main channel. Mudstone drapes are also present.

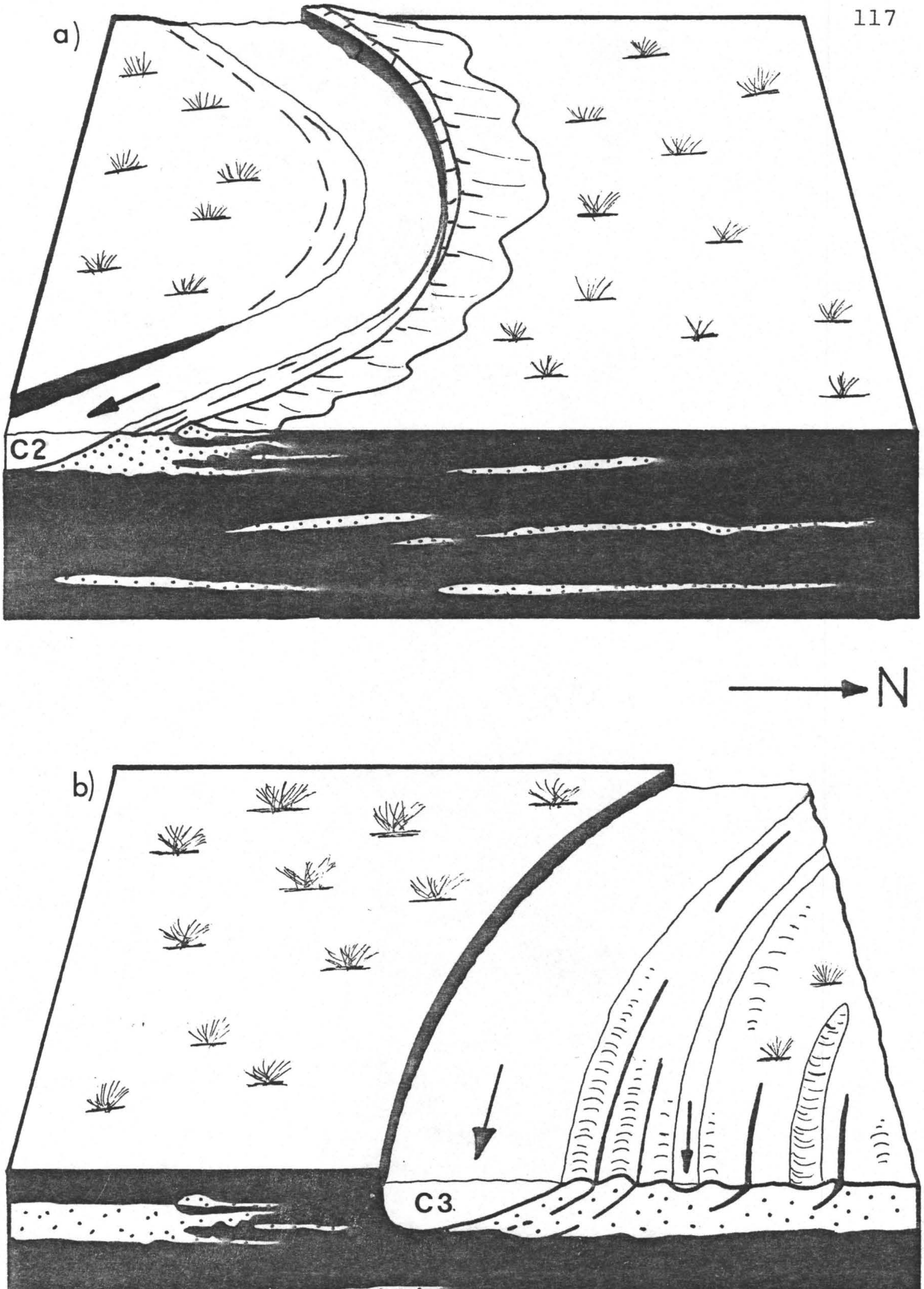
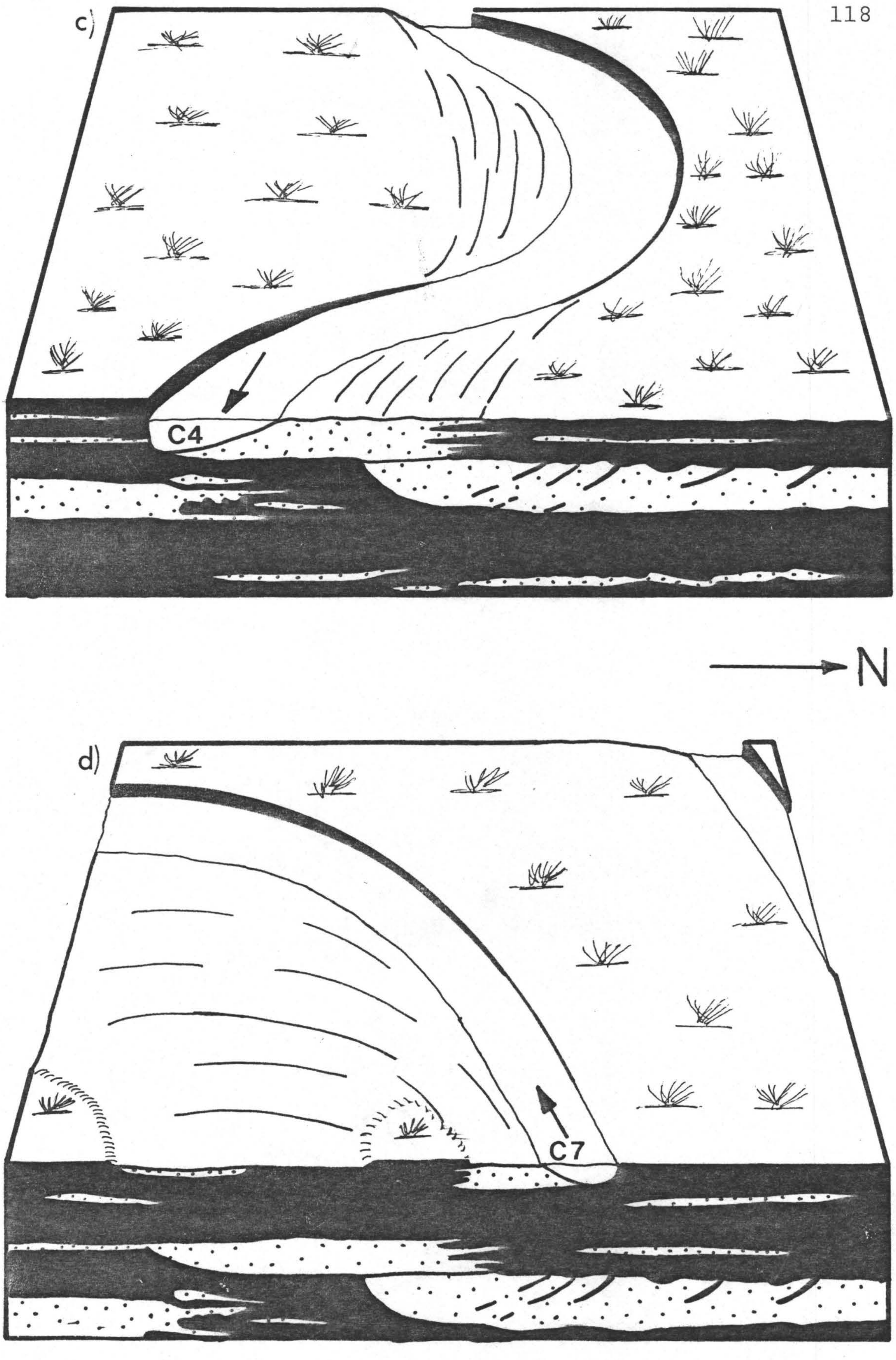

a)
C2
N
b)
C3

FIGURE 5-6 cont'd: c] Development of Unit C4. The northern exposure of Unit D was not observed and therefore, the interfingering is hypothetical. Flow directions are generally to the east.

d] Development of Unit C7.


c)
C4
N
d)
C7

modern meandering estuaries, but those that have been done have found many similarities between meandering and estuary systems (Land and Hoyt, 1966). Among the similarities are an upward decrease in grain size, point bar deposition, the presence of roots due to back water marshes and overbank deposits. Land and Hoyt (1966) stress that there are really only two factors which can be used to differentiate between fluvial and estuarine point bar deposits; a reversing tidal flow causing paleocurrent orientation of roughly opposite orientation within a single bed and the marine water influence resulting in an abundant marine fauna, especially in mudstones adjacent to channels.

One of the trace fossils, *Macaronichnus*, is of shallow water origin which would fit an estuarine environment; others such as *Chondrites* or *Planolites* can be found preserved in rocks over varying water depths (abyssal basin to tidal flats). Several mudstone samples examined for marine foraminifera content were devoid of any and therefore the marine trace fossils can hardly be regarded as "abundant" marine fauna.

Other features characteristic of estuarine environments but absent in these rocks are lenticular and flaser bedding, wavy bedding, thinly interlayered sand/mud bedding and a shell lag deposit at the base of point bar sandstones. Because none of these features were observed in any portion of the outcrop, the point bar deposits were probably not developed in an estuarine environment.

Comparison with Deltaic Facies Models

Deltas are comprised of two basic components; a delta front which extends offshore and a low-lying delta plain, developed behind the delta front. Many models of deltas have been described (Fisher *et al.* 1969 , Galloway, 1975 , Coleman and Wright, 1975) but most deltas are either dominantly fluvial or are tidally influenced. Deltas dominated by tides (Cf. Ganges-Brahmaputra Delta, Galloway, 1975) are characterized by reversed flow direction ripple laminations and since this was not observed in any of the point bar sandstones, this model is thought not to be applicable to this study.

Fluvial dominated deltas (Cf. Ebro and Mississippi deltas, Galloway, 1975)(plain areas), are characterized by unidirectional flow with periodic stage fluctuations. High sinuosity patterns are common. However, even in low energy basins, the lower reaches of the distributary channels are influenced by basinal processes and in modern examples such as the Ebro delta, abandoned channel mouths are sealed by wave deposited beach sands (Kruit, 1955).

Sequences of distributary point bars resemble alluvial point bars and often contain erosive basal contacts with a lag deposit, followed by trough crossbedding, ripple laminated finer sands and finally silts and muds penetrated by roots (Reading, 1978, p. 103). Mudstone drapes can also be contained within point bars on certain occasions. Between channels is a varied assemblage of bays, flood plains, lakes,marshes, swamps, tidal flats and salinas depending upon climate.

As was argued in the discussion concerning meandering rivers, an arid climate is thought unlikely because features characteristic of dry conditions, (evaporites, pseudomorphed halite crystals, a lack of vegetation and calcrete), are not present. More humid regions give rise to abundant vegetation in saline mangrove swamps, freshwater swamps or marshes. Overbank flooding is prominent, depositing fine grained laminated sediments over the entire area. Crevasse splays are also common.

A fluvial dominated delta, characterized by meandering distributary channels and situated in a region with a humid climate would deposit a sequence of rocks similar to that observed in this study. However, most of the studies done on ancient delta systems document prodeltaic marine shales below channel (point bar) sandstones and the occurrence of paralic sandstones nearby. For the same arguments posed in the estuarine discussion, the lack of marine foramifera in any of the mudstones samples analysed tends to eliminate deltas as a possible depositional environment for this study. In addition, the occurrence of beach sediments below the Belly River Formation indicates that progradation must have already have taken place prior to the development of the channels. No evidence of a transgression was found above the beach deposits, and therefore the Belly River Formation at this location must be regarded as a meandering fluvial network, possibly associated in initial stages with a prograding delta. The problem of interpreting the presence of marine trace fossils may not be resolved until a detailed of the palyonology and forminifera of the mudstones contained within the formation is undertaken. If none or few foraminifera are contained within the rocks, a fluvial meandering river facies model would be further supported. If however foraminifera are very abundant in the rocks, perhaps a re-evaluation of presently existing facies models (especially meandering estuaries), is called for.

Facies Relationships

In chapter two, five facies were developed which incorporated the twenty three previously described units. Of considerable interest are the actual relationships between the facies, specifically the order in which transitions occur. In order to preserve clarity and because the boundary between individual units, (especially interbedded mudstones and sandstones), are often ambiguous, only transitions between facies will be discussed. For example, a transition from Unit D1 to D2, both of Facies D, is not regarded as a facies transition whereas a transition from Unit D1 to E3 (Unit E3 is part of Facies E), is considered a facies transition.

Table 5-1 summarizes in matrix form, the actual facies transitions observed in the study and Figure 5-7 is a facies

TABLE 5-1: Tally matrices representing observed facies transitions. Matrix ① is the observed facies transitions, matrix ② is the predicted (random) facies transitions and matrix ③ is the difference between the two.

Numbers underlined in matrix ③ are positive quantities; those not underlined are negative quantities.

①

to / From	A	B	C	D	E	Total
A	—	1				1
B		—			1	1
C			—	5	6	11
D			11	—	11	22
E			4	14	—	18
Total	0	1	15	19	18	53

②

to / From	A	B	C	D	E	
A	—	.02	0.3	0.4	0.3	
B	0.0	—	0.3	0.4	0.3	
C	0.0	0.2	—	3.9	3.7	
D	0.0	0.4	6.2	—	7.5	
E	0.0	0.3	5.1	6.5	—	

③

to / From	A	B	C	D	E	
A	—	.98	0.3	0.4	0.3	
B	0.0	—	0.3	0.4	0.7	
C	0.0	0.2	—	1.1	2.3	
D	0.0	0.4	4.8	—	3.5	
E	0.0	0.3	1.1	7.5	—	

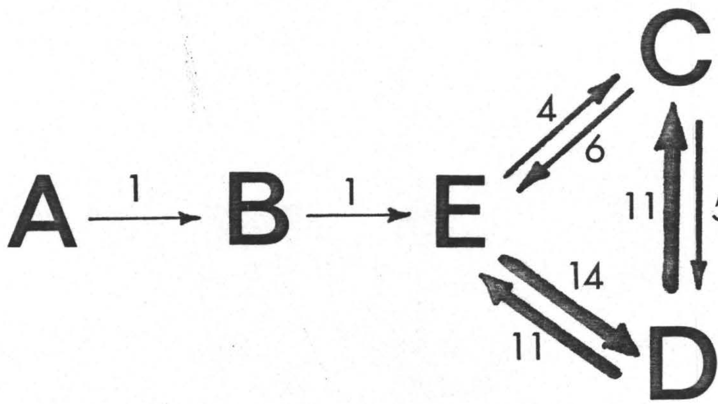
FIGURE 5-7: Facies relationship diagrams displaying the observed transitions in this study.

A - Facies A: Marine mudstones and sandstones
B - Facies B: HCS sandstone and beach
C - Facies C: Point bars
D - Facies D: Proximal overbank
E - Facies E: Distal overbank

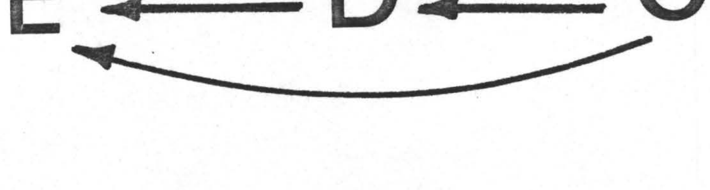
a] obtained from matrix (1). Numbers refer to total number of observed transitions

b] obtained from matrix (3).

a)



b)



relationship diagram (FRD) displaying the obtained relationships. (Refer to Walker,(1979) for a discussion on FRDs).

A second tally matrix which gives the predicted or random facies transition can be obtained by cross multiplying the row and column totals of the observed transition matrix and dividing by the total number of transitions. A third matrix, obtained by taking the difference between the observed number of transitions and the number of transitions predicted in a random case can then be obtained. Both of these matrices are also given in Table 5-1. The transitions in the third matrix which are positive quantities occur more frequently than random and those that are negative quantities occur less frequently than random.

In this study a clear trend is established with Facies C, D and E. Distal overbank deposits, (Facies E), are commonly overlain by more proximal overbank deposits (Facies D). This is not surprising since one would expect more proximal overbank deposits to be encountered prior to the channel itself.

Proximal overbank deposits tend to be overlain by either point bars or more distal overbank deposits in roughly equal proportions. When Facies D is overlain by Facies C the expected channel migration sequence is completed;

distal overbank → proximal overbank → point bar
Facies E → Facies D → Facies C

Those occurrences when Facies D is overlain by Facies E may indicate that the channel was abandoned due to a cut off before migrating far enough. The relative values obtained would indicate that cut offs were rather common, which is supported by the predicted moderate to high sinuosities given in chapter three.

Overlying point bars are roughly equivalent occurrences of proximal and distal overbank deposits. Distal overbank may represent sudden sediment reduction (as would occur in a neck cut off) and proximal overbank may represent a more gradual cut off such as would occur in a chute cut off (refer to Figure 5-5).

CONCLUSIONS

1] The vertical sucession of units which make up the Wapiabi - Belly River transition in the Ghost Dam spillway can be interpreted in terms of a shallowing trend produced by progradation of the Belly River shoreline.

2] The shallowing trend is reflected in the vertical sucession of deposits. Bouma BC turbidites deposited in relatively deep water and destroyed by bioturbation are overlain by hummocky cross-stratified sandstones deposited between fairweather wave base and storm wave base, and low angle, planar crossbedded beach deposits.

3] Turbidites and hummocky cross-stratified sandstones have probably been generated by storms.

4] The close proximity of hummocky cross-stratified sandstones to beach deposits and the petrographic nature of the beach suggests a low energy environment.

5] The Belly River Formation consists of a series of sandstones and interbedded sandstones and mudstones deposited in a meandering river environment.

6] Thick sandstones (greater than 2.0 metres), were deposited in point bar environments and often fine upwards. Interbedded mudstones and sandstones were deposited as overbank (flood) deposits either proximal or distal to the active channels.

7] Paleohydralic and paleomorphological data indicates that the river system was moderately to highly sinuous and had an estimated discharge of between 5.8 and 7.0 m^3/s. This discharge is roughly comparable to the Humber and Credit Rivers (Ontario).

8] Occasional marine trace fossils are contained within the Belly River Formation indicating a marine influence. This influence is not fully understood.

9] A facies relationship diagram for the five facies identified indicates that distal overbank deposits are usually overlain by proximal overbank which is in turn overlain by either point bar or distal overbank deposits. Point bars may be overlain by distal or proximal overbank.

10] The sandstones are made up mostly of quartz, plagioclase and alkali feldspars, chert, rock fragments, iron oxides, clay and mica minerals and carbonate cement

11] Besides carbonate cement, other authigenic minerals may include kaolinite, illite and zeolites.

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APPENDICES

TABLE OF APPENDICES

APPENDIX ONE

FORAMINIFERA STUDIES

A] Preparation of Foraminifera Samples

Foraminifera and insect castings can be obtained quickly and efficiently from mudstone samples by mechanically breaking down the mudstone matrix. The following procedure is recommended:

1] Place mudstone samples in a beaker containing a solution of Quaternary O (10 ml/l H_2O) and transfer to an ultrasonic cleaner. Avoid over filling the beaker with mudstone. Results are best for approximately a 4 : 1 solution to mudstone ratio. Several samples can be run simultaneously and may be left overnight unmanaged, making the method very attractive.

2] Most samples, although usually efficiently broken down, require additional working. Suspend the beakers over a bunsun burner flame and allow the solution to come to a boil. Continue boiling for three to five hours adding water to the beakers to maintain a constant level.

3] Repeat steps 1 and 2 as necessary.

B] Retrieving Foraminifera

1] After cooling, pass the samples through a series of 3 sieves, (60 mesh on top, 80 mesh in the middle and 115 mesh on the base), making sure to collect each fraction separately. By separating the three size fractions, one avoids the unpleasant situation of having constantly to re-focus the microscope when scanning for foraminifera.

2] Transfer the fractions to petre dishes and allow to dry.

3] Examine samples under a binocular microscope, collect foraminifera or insect castings and mount on a slide for examination and identification.

APPENDIX TWO

CALCITE STAINING

Selected thin sections were stained for calcite using an Alizarin red - S solution to enhance calcite cement when present. The procedure used in staining is that of Lindholm and Finkelman (1972).

1] Etch thin sections, prepared without cover glasses, in 2% HCl, (98ml distilled water + 2ml concentrated HCl), for 20 seconds.

2] Immediately transfer the slide to a solution of Alizarin red - S solution in 0.2% HCl, (1 gram of Alizarin red - S to 998ml distilled water and 2ml concentrated HCl) and immerse for 4 minutes.

3] Rinse the thin sections in distilled water to remove excess Alizarin red - S and allow to dry.

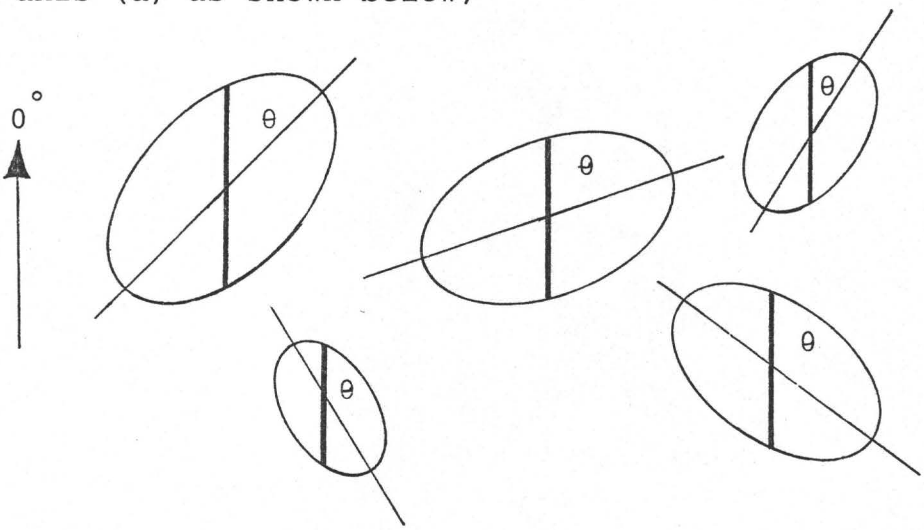
APPENDIX THREE

GRAIN ORIENTATION MEASUREMENTS

1] Prepare thin sections from oriented sandstone samples cut parallel to bedding. If calcite cement is prominent, staining is advised to aid in distinguishing grain boundaries. (see appendix two for method).

2] Using a Shadow Master projector, orient the thin section relative to a reference grid on the screen of the projector.

3] For grains that contain axial ratios of greater than or equal to 2:1, measure the orientation of the long axis (a) as shown below;



4] Repeat for a minimum of 100 grains per sample. Data summarized in Table A-1.

TABLE A-1: Orientation of grains.

Section	Unit	Orientation [degrees]	Chi Square	Significance [%]
BR-5	C3	121.6 - 301.6	27.25	>99.5
BR-8	C4	121.7 - 301.7	02.13	<75
BR-1	C5	045.9 - 225.9	37.59	>99.5
BR-7	C6	166.6 - 346.6	13.96	>99.5
BR-6	C7	156.3 - 336.3	06.20	>95.0
BR-4	C8 Top	037.2 - 217.2	07.56	>97.5
	C8 Base	011.7 - 191.7	07.04	>95.0

APPENDIX FOUR

COMPUTER PROGRAM AND MODIFICATIONS

A computer program by Martini (1965) was used to analyze grain orientation data from samples obtained in the Ghost Dam spillway. While the program worked well, it was felt that a visual display of the data would be more effective in presenting the paleocurrent data. The program was therefore modified to include subroutines which would produce a computer generated "rose diagram" to display the data. Martini's program, complete with modifications, is included in this appendix.

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      PROGRAM VM   (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C ***** TUKEY CHI SQUARE AND VECTOR MEANS, MARTINI PROGRAM, TECH MEM.652
C ***** PROGRAM CLEANED UP BY RGW, NOV., 1974, AND PRT,NOV.,1976
******* FITTED WITH A ROSE DIAGRAM PLOT BY DWH, APR. 1982
C *****  MAXIMUM SPACE FOR SHARED-TIME OPERATION IS 124K.
C
C
C     ***********************************************************
C
C    INPUT INSTRUCTIONS
C
C
C     CARD 0
C
C       NTOT = NUMBER OF DIFFERENT GROUPS OF SAMPLES
C
C    CARD 1  (FORMAT (I5,I5) )
C
C     M=TOTAL NUMBER OF SAMPLES IN THIS GROUP
C     MH=(NO. SAMPLES-1) IF GROUPED DATA INPUT(HISTOGRAMS),OTHERWISE 0
C     APLACE = NAME OF THIS GROUP OF SAMPLES
C
C    CARD 2  (FORMAT (I3,2X,10A6) )
C
C     NA IS THE REFERENCE AZIMUTH
C     ANAME REPLACES MARTINIS EL AS SAMPLE DESIGNATION
C
C    CARD 3  (FORMAT(I5,3(1X,I1)) )
C
C     NT=NUMBER OF READINGS IN EACH SAMPLE FOR INDIVIDUAL DATA INPUT
C     NT=NUMBER OF READINGS IN FIRST SAMPLE FOR GROUPED DATA INPUT
C     ND=1 FOR VECTOR DATA
C     ND=2 FOR LINE OF MOVEMENT DATA
C     ND=4 FOR LINE OF MOVEMENT DATA, 4 THETA TRANSFORMATION
C     MR=1 FOR GROUPED DATA INPUT, OTHERWISE ZERO
C     MZ=1 IF TYPE OUT IS REQUIRED OF THE ORIGINAL DATA TRANSFORMED
C          IN DIRECTED ANGLES FALLING WITHIN 90 DEGREES EITHER SIDE
C          OF THE REFERENCE AZIMUTH
C
C     MM=NUMBER OF SAMPLE BEING CALCULATED.   IT IS CUMULATED BY THE
C          PROGRAM AND IS NOT PUNCHED IN AS DATA
C
C
C    INDIVIDUAL DATA INPUT
C
C     CARD 0 AT BEGINNING OF DATA DECK
C     CARD 1 AT BEGINNING OF EACH GROUP OF SAMPLES
C     CARD 2 AND CARD 3 AT BEGINNING OF EACH SAMPLE DATA SET
C     SAMPLE DATA SET FORMAT (16F5.0)
C
C
C    GROUPED DATA INPUT
C
C     CARD 0 AT BEGINNING OF DATA DECK
C     CARD 1, CARD2, AND CARD 3, FOLLOWED BY DATA
C     DATA FORMAT (9(1X,I4))
C
C     ***********************************************************
C
      DIMENSION N(9),X(9),V(9),L(9),ANAME(10),APLACE(10)
      DIMENSION A(1000),ASTOR(1000),Z(1000)
      READ (5,901) NTOT
  901 FORMAT (I5)
      NCNT=0
   30 CONTINUE
      IF(NCNT.EQ.NTOT) GO TO 31
      NCNT=NCNT+1
      READ (5,2002) M,MH,APLACE
 2002 FORMAT (2I5,10A6)
      WRITE (6,902) APLACE
  902 FORMAT (1H1,10A6//)
      WRITE (6,2003)M
 2003 FORMAT(26H0***   NUMBER OF SAMPLES =,I5///)
```

```
      MM=0
      NTCUM=0
C
C *** NTCUM IS THE CUMULATIVE VALUE OF NT SUMMED FROM EACH SAMPLE
C
 2005 MM=MM+1
      READ(5,100) NA,ANAME,STRIKE
  100 FORMAT (I3,2X,10A6,F4.0)
      WRITE(6,101) ANAME
  101 FORMAT(1H ,10H**********,5H     ,10A6///)
      READ(5,4) NT,ND,MR,MZ
    4 FORMAT(I5,2(1X,I1),1X,I1)
      IF(NT.EQ.0) STOP
      IF(ND.EQ.1) AR=180.0
      IF(ND.EQ.2) AR=90.0
      IF(ND.EQ.4) AR=45.0
      ANT=NT
      PANT=ANT/9.
      XX=SQRT(PANT)
      WRITE(6,3002)NT,ND,MR,MH,MZ,MM
 3002 FORMAT(11H ***    NT =,I4,7H   ND =,I2,7H   MR =,I2,7H   MH =,I4,
     17H   MZ =,I2,7H   MM =,I3///)
      IF (MH.NE.0) GO TO 700
      WRITE (6,105) NT,NA
  105 FORMAT(22H            NO. MEAS. =,I5,25H           DEC.  COR.      =,I
     15/)
  700 IF (MR.EQ.1) GO TO 600
      AA=NA
C
C ***** READ IN THE INDIVIDUAL DATA IN SAMPLE
C
      READ (5,1)(A(I),I=1,NT)
    1 FORMAT(16F5.0)
      IF(AA.EQ.0.) GO TO 950
C
C ***** CHANGE ORIGIN TO TRUE NORTH
C
      DO 900 KK=1,NT
      A(KK)=AA-A(KK)
C   SUBTRACT SAMPLE STRIKE FROM EACH GRAIN ORIENTATION
      A(KK)=A(KK)-STRIKE
  900 CONTINUE
  950 CONTINUE
C
C ***** STORE DATA IN INDIVIDUAL SAMPLES SEQUENTIALLY IN ASTOR
C ***** FOR FINAL COMPUTATION OF GRAND VECTOR MEAN
C
      DO 2004 JJ=1,NT
 2004 ASTOR(JJ+NTCUM)=A(JJ)
      NTCUM=NTCUM+NT
 2007 CONTINUE
      DO 11 I=1,9
   11 N(I)=0
      SB=0.0
      SC=0.0
      ANT=NT
      DO 10 I=1,NT
      IF(AA.EQ.0.) GO TO 200
      IF(MZ.EQ.0) GO TO 200
      Z(I)=A(I)
      IF(Z(I).LT.(-90.)) Z(I)=Z(I)+180.
      IF(Z(I).GT.90.) Z(I)=Z(I)-180.
  200 IF(ND.NE.1) GO TO 300
C
C ***** SORT INTO 40 DEGREE CLASSES (0-40,40-80, ETC)
C ***** SORT INTO 20 DEGREE CLASSES (0-20,20-40,ETC)
C
      AK=A(I)/40.0
      N(AK+1.0)=N(AK+1.0)+1
      GO TO 301
C
  300 IF(A(I).LT.0.)  A(I)=A(I)+360.0
C
      IF(A(I).GE.180.)  A(I)=A(I)-180.0
```

```
      AK=A(I)/20.0
      N(AK+1.0)=N(AK+1.0)+1
C
C ***** CONVERT TO THETA IN RADIANS
C
  301 A(I)=A(I)*(3.14159/AR)
C
C ***** CALCULATE SUMS OF SINS AND COSINES
C
      B=SIN(A(I))
      C=COS(A(I))
      SB=SB+B
   10 SC=SC+C
      IF(MZ.EQ.0) GO TO 201
      WRITE (6,1)  (Z(I),I=1,NT)
C
C ***** CALCULATE R, THETA
C
  201 R=SQRT((SB*SB)+(SC*SC))
      RL=(R/ANT)*100.0
      TH2=(ATAN2(SB,SC))*180.0/3.14159
      IF(ND.NE.1) GO TO 22
      IF(TH2.LT.0.) TH2=360.0+TH2
   22 IF(ND.NE.2) GO TO 21
      IF(TH2.GE.0.) TH2=TH2/2.
      IF(TH2.LT.0.) TH2=(360.0+TH2)/2.
      WRITE(6,6)
   21 IF(ND.EQ.1) WRITE(6,2) N
      IF(ND.EQ.2) WRITE(6,2) N
      IF(ND.EQ.4)  WRITE(6,7) N,RL,TH2
      IF(MR.EQ.0) GO TO 503
  600 READ(5,501)(N(I),I=1,9)
C
C ***** ADD SAMPLE HISTOGRAMS
C
      IF(MH.EQ.0) GO TO 503
      DO 33 KJ=1,MH
      READ(5,501)(L(I),I=1,9)
      DO 33 KI=1,9
      N(KI)=N(KI)+L(KI)
   33 NT=NT+L(KI)
      MHS=MH+1
      WRITE(6,106) NT,NA,MHS
      ANT=NT
      PANT=ANT/9.
      XX=SQRT(PANT)
  503 SB=0.0
      SC=0.0
      SSB=0.0
      SSC=0.0
      SD=0.0
      SG=0.0
      DO 12 I=1,9
      X(I)=(FLOAT(N(I))-PANT)/XX
      IF(ND.EQ.1) GO TO 800
      A(I)=(20.0*FLOAT(I-1))*3.14159/AR
      IF(ND.NE.1) GO TO 801
  800 A(I)=(40.0*FLOAT(I-1))*3.14159/AR
  801 B=SIN(A(I))
      C=COS(A(I))
      SB=SB+(X(I)*B)
      SC=SC+(X(I)*C)
      V(I)=FLOAT(N(I))
      SD=SD+(V(I)*B)
      SG=SG+(V(I)*C)
      SSB=SSB+(B*B)
   12 SSC=SSC+(C*C)
      B=SB/SQRT(SSB)
      C=SC/SQRT(SSC)
      IF(MR.EQ.0) GO TO 504
C
C ***** CALCULATE L, THETA FOR GROUPED DATA
C
```

```
      RX=SQRT((SD*SD)+(SG*SG))
      RXL=(RX/ANT)*100.0
      TH2=(ATAN2(SD,SG))*180.0/3.14159
      WRITE(6,505)
      IF(ND.NE.1) GO TO 23
      IF(TH2.GE.0.) TH2=TH2+20.
      IF(TH2.LT.0.) TH2=(360.0+TH2)+20.
   23 IF(ND.NE.2) GO TO 20
      IF(TH2.GE.0.) TH2=(TH2/2.)+10.
      IF(TH2.LT.0.) TH2=((360.0+TH2)/2.)+10.
      WRITE(6,6)
   20 IF(ND.EQ.1) WRITE(6,2) N
      IF(ND.EQ.2) WRITE(6,2) N
      IF(ND.EQ.4) WRITE(6,7) N,RXL,TH2
      RL=RXL
      MM=999
C
C ***** END OF GROUPED DATA CALCULATION
C
  504 R=B*B+C*C
      CALL PLSUB(N)
      WRITE(6,3) TH2, RL, R
      IF(R.LT.2.77) GO TO 4000
      IF(R.GT.2.77) CHISQ=75.0
      IF(R.GT.4.61) CHISQ=90.0
      IF(R.GT.5.99) CHISQ=95.0
      IF(R.GT.7.38) CHISQ=97.5
      IF(R.GT.9.21) CHISQ=99.0
      IF(R.GT.10.6) CHISQ=99.5
      WRITE(6,4001) CHISQ
 4001 FORMAT(64H ***   THIS VALUE OF CHI SQUARED IS SIGNIFICANT AT GREAT
     1ER THAN ,F5.1,21H PERCENT, WITH 2 D.F.///)
      GO TO 4002
 4000 CONTINUE
      WRITE(6,4004)
 4004 FORMAT(71H ***   THIS VALUE OF CHI SQUARED IS SIGNIFICANT AT LESS
     1THAN 75 PERCENT///)
 4002 CONTINUE
      WRITE(6,3001)
 3001 FORMAT(52H ***************************************************)
      IF(MM.LT.M)GO TO 2005
      IF(MM.EQ.999)GO TO 30
      IF(M.EQ.1) GO TO 30
C
C *****  IF IT GOES TO 2005,IT WILL READ ANOTHER BATCH OF DATA
C *******IF IT GOES TO 30, THE GVM SHOULD ALREADY HAVE BEEN PRINTED OUT.
C *******IF IT CARRIES ON BELOW, IT WILL COMPUTE THE GVM FROM THE DATA
C          PRESENTLY IN ASTOR.
C
      DO 2006 J=1,NTCUM
 2006 A(J)=ASTOR(J)
      NT=NTCUM
      WRITE(6,902) APLACE
      WRITE(6,2008)
 2008 FORMAT(1H0,49H           GRAND VECTOR MEAN NOW BEING CALCULATED.///
     1)
      MM=999
      GO TO 2007
  106 FORMAT(13H NT          =,I10,20H , MICROM. CORREC. =,I4/27H NO. SPL
     1 HISTOGRAMS ADDED =,I5)
  501 FORMAT(9(1X,I4))
  505 FORMAT(10X,19H GROUP DATA CALCUL      )
    2 FORMAT(1H0,21H            HISTOGRAM =,9I6)
    6 FORMAT(1H0,63H            ***CALC WITH TWO THETA TRANSF, OUTPUT TRAN
     1SF TO THETA)
    7 FORMAT(13H HISTOGRAM  =,18I6/13H L            =,F14.3/13H FOUR THETA
     1=,F14.3)
    3 FORMAT(1H0,21H            THETA      =,F15.3,33H                VECTOR
     1 LENGTH   =,F9.3,33H               CHI  SQUARE   =,F15.3///)
   31 CONTINUE
      CALL PLOT(0.0,0.002,999)
      STOP
      END
```

```
*
**************************************************************
*
******* SUBROUTINE TO PLOT ROSE DIAGRAM
*
**************************************************************
*
        SUBROUTINE PLSUB(N)
        DIMENSION N(9), X(9), Y(9), X1(9), Y1(9)
*
******* XC = X COORDINATE FOR CENTRE OF ROSE PLOT
******* YC = Y COORDINATE FOR CENTRE OF ROSE PLOT
******* PHI = STARTING VALUE TO DETERMINE INITIAL THETA
******* CONST = CONVERSION FACTOR TO RADIANS
******* RMAX = MAXIMUM RADIUS OF ARC SEGMENTS (5.0 INCHES)
*
        XC = 0.
        YC = 0.
        PHI = - 40.0
        CONST = 8. * ATAN(1.)/360.
        FORTY = 40.0 * CONST
        RMAX = 5.0
        CALL FMAX(N,NMAX)
        WRITE(6,11)
     11 FORMAT(7X,"N",4X,"TOTAL",3X,"THETA",7X,"R",7X,"X(I)",
        + 7X,"Y(I)",5X,"X1(I)",5X,"Y1(I)")
        DO 1011 I = 1,9
        PHI = PHI + 40.0
        THETA = PHI * CONST
        R = FLOAT(N(I))/FLOAT(NMAX) * RMAX
        X(I) = (R*COS(THETA))
        Y(I) = (R*SIN(THETA))
        X1(I) = (R*COS(THETA + FORTY))
        Y1(I) =(R*SIN(THETA + FORTY))
*
******* TABULATE DATA FOR REFERENCE PURPOSES
*
        WRITE(6,10)I,N(I),THETA,R,X(I),Y(I),X1(I),Y1(I)
10      FORMAT(1X,2I7,6F10.4)
 1011   CONTINUE
        CALL PLOT(-5.0, -5.0, 40)
*
******* PLOT THESE VALUES
*
        DO 1012 I = 1,9
        CALL PLOT(X(I), Y(I), 3)
        CALL ARC(X(I), Y(I), X1(I), Y1(I), XC, YC, 0.005)
        CALL PLOT(X1(I), Y1(I), 3)
        CALL PLOT(XC, YC, 2)
        CALL PLOT(X(I), Y(I), 2)
 1012   CONTINUE
*
******* PRODUCE GRID SYSTEM
*
        CALL PLOT(-5.0,0.0,3)
        CALL PLOT(5.0,0.0,2)
        CALL SPOT(-5.5,0.0,0.5,1HS,90.0)
        CALL SPOT(5.0,0.0,0.5,1HN,90.0)
        RETURN
        END
*
**************************************************************
*
******* SUBROUTINE TO DETERMINE THE MAXIMUM N TO CALCULATE FMAX
*
**************************************************************
*
        SUBROUTINE FMAX(N,NMAX)
        DIMENSION N(9)
        NMAX=-999
        DO 10 I=1,9
        IF(N(I).GT.NMAX)NMAX=N(I)
10        CONTINUE
        RETURN
        END
```

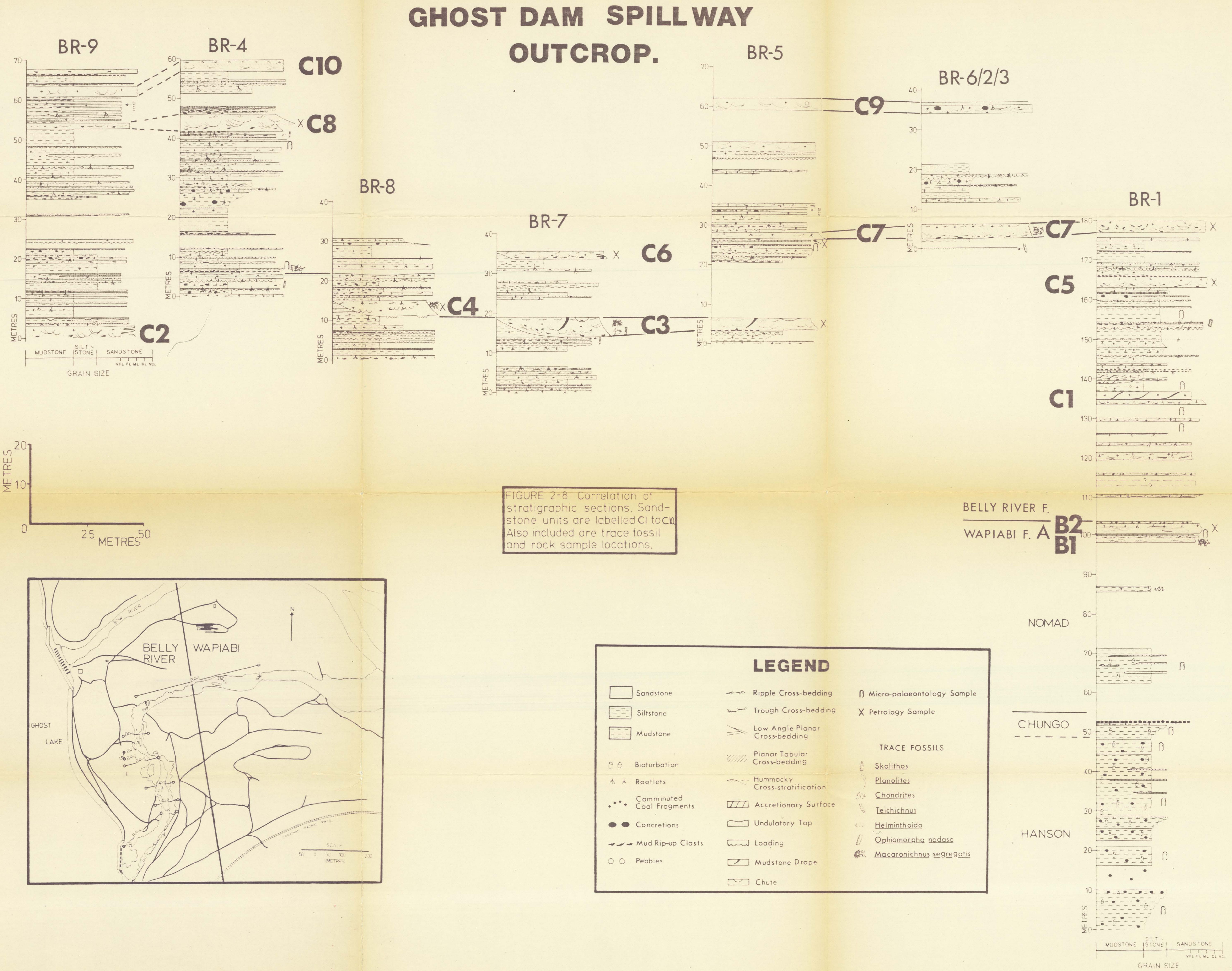

FIGURE 2-8 Correlation of stratigraphic sections. Sandstone units are labelled C1 to C10. Also included are trace fossil and rock sample locations.