SEDIMENTOLOGY OF THE CARDIUM FORMATION

LOCHEND FIELD, ALBERTA

SEDIMENTOLOGY OF THE CARDIUM FORMATION
(UPPER CRETACEOUS),
LOCHEND FIELD, ALBERTA

By

CERI J. CHAMBERLAIN

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AUTHOR: Ceri J. Chamberlain

SUPERVISOR: Professor R. G. Walker

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ABSTRACT

Examination of 22 cores and over 100 petrophysical logs of the Turonian (Upper Cretaceous) Cardium Formation in the Lochend region permitted the identification of 9 facies which could be arranged into 3 major coarsening-upward cycles.

At Lochend, the Burnstick Sequence comprises 5 distinct facies that progressively coarsen upward from a silt laminated mudstone through various bioturbated mud and sand facies into a gravelly conglomerate. There is a sharp return to a dark mud facies.

The overlying Raven River sequence in this region is characterized by a double coarsening upwards cycle which can be described in terms of 6 facies. The first cycle coarsens upward from a black laminated mudstone into various bioturbated mud and sand facies. The sands become progressively cleaner upwards before returning to a muddier bioturbated facies which marks the base of the second coarsening upward cycle. This cycle similarly decreases in mud content upwards but never 'cleans' to the extent of the lower cycle.

The upper-most "zone" sequence comprises muddy bioturbated facies which coarsen upwards into a 2 cm thick capping of conglomerate.

There are no preserved physical sedimentary structures associated with any of the facies.

The trace fossil assemblage indicates a sedimentary environment below fair weather wave but above storm wave base.

The regional sandstone distribution of all coarsening upward

sequences was investigated by cross section correlation of petrophysical logs between Lochend and Crossfield (to the west) and Caroline (to the north).

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CHAPTER 1: INTRODUCTION

1.1 Introduction and Aim

Shallow marine clastic environments appear to be the most complex of the marine depositional systems. As of yet, no powerful facies models have been described which satisfy both the ancient shallow marine sandstone bodies and their modern analogues. The synthesis of specific facies models are complicated by the interaction of different processes working on the shelf as well as the modification of recent shelf sediments by the Holocene sea level rise (Walker, 1984).

In all shallow marine sandstone interpretations of the Cretaceous Western Interior Seaway, there is a general recognition of storm influence as a major transporting process. Storm influence is favoured because the sands must have been transported considerable distances offshore to rest in the muddy environments. The mechanism of deposition is a highly controversial topic at this stage in the research. The two mechanisms receiving the most discussion are i) storm generated currents producing incremental transport of the sands and ii) turbidity current depostion of the sands as single catastrophic events.

The Cardium Formation of the Cretaceous Western Interior Seaway is an example of a shallow marine sandstone body which has been interpreted as having been deposited by storm influenced mechanisms.

The Cardium sands provide prolific subsurface data in the form of well logs and core due to its continued success as an oil and gas producer. The Cardium is therefore a basis of research for shallow marine studies in a continued effort to gain insight into the depositional mechanisms of shelf and shallow marine sandstones.

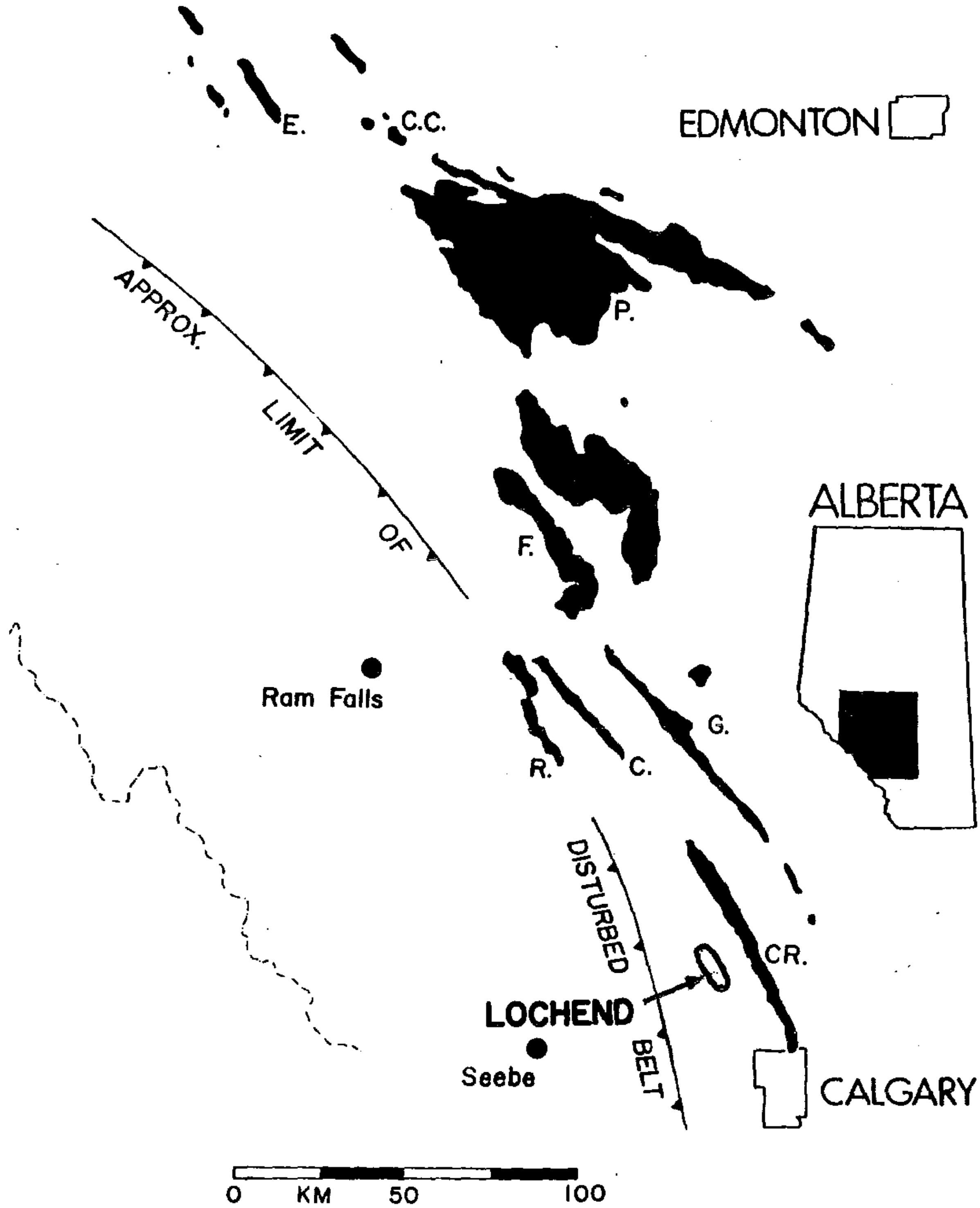
This subsurface study of the Lochend field is part of a much broader long term project at McMaster University undertaken to investigate the depositional environment of the Upper Cretaceous (Turonian) Cardium Formation in the Plains and Foothills of Alberta.

Lochend is a single offshore sandstone body deposited along the western margin of the Cretaceous Seaway. It is one of many elongate oil producing sandstones of the Cardium Formation in the Alberta Plains (Fig 1.1). The Lochend study provides a detailed description of the southern-most extent of the Cardium in the subsurface. Its relatively small size permitted a complete data collection on which to base a self contained study.

The Lochend field lies parallel to Crossfield (to the east) and directly on trend with Caroline to the north. This enabled detailed correlations and comparisons with surrounding Cardium fields. The correlations are essential if an overall depositional history of the Cardium sandstones is ever to be deciphered.

The objective of this thesis is to provide a well documented study of the facies, facies sequence and distribution of the Cardium Formation at the Lochend field. The study is based on all of the 15 available cores at Lochend as well as 5 cores from Crossfield and 2 cores north of Lochend extending into the Caroline field (Fig. 1.2). In addition to the core, well over

Fig 1.1 Location of the Lochend field. The inset to the right shows the location of the region in the figure. Positions of Calgary and Edmonton are included for reference and the approximate eastern limit of the disturbed belt in the Rocky Mountains is shown. The positions of two Foothills Cardium exposures, Ram Falls and Seebe are shown. In black are approximate locations of producing Cardium fields. (E=Edson, CC=Carrot Creek, P=Pembina, F=Ferrier, WG=Willesden Green, R=Ricinus, C=Caroline, G=Garrington and CR=Crossfield; information from G.S.C. Map 1559A).



E.
C.C.
EDMONTON
P.
APPROX. LIMIT OF
F.
ALBERTA
Ram Falls
R.
C.
G.
DISTURBED BELT
CR.
LOCHEND
Seebe
CALGARY
0 KM 50 100

100 petrophysical logs were used. Contrary to previous studies of Ricinus, Caroline and Garrington (Walker, 1983b), it was clear that the resistivity logs (not the gamma ray logs) showed the most strongly correlative marker horizons. Correlations are therefore based predominantly on the resistivity logs although gamma ray logs are always included where available.

1.2 Geologic History

The Cardium Formation of late Turonian age within the Upper Cretaceous Alberta Group. The Alberta Group comprises three formations. The lowest stratigraphic formation, consisting of 400 m of marine shales, is the Blackstone Formation. This is overlain by 100 m of the interbedded sandstones and mudstones of the Cardium Formation, which is subsequently overlain by 600 m of Wapiabi Formation marine shales (Fig 1.3).

During Cretaceous time, what presently exists as the Western Interior Plains was the broad depositional trough of the interior basin . The basin was bound to the west by the rising Cordillera and to the east by the Canadian Shield. The greatest inundation of this shallow continental basin occurred during late Cretaceous time. At this time the marine muds of the Alberta Group accumulated extensively over the plains. The Alberta Group sediments represent a period of little tectonic activity in the west. The deposition of the muds was interrupted temporarily as the Cardium sands were deposited along the western margin on the seaway. Deposition of marine muds resumed as the seaway returned to a quiet and stable sedimentary environment.

The influence of sea level changes during the Cardium time

Fig. 1.2 Map of the Lochend study area showing the location of wells from which cores and petrophysical logs from the Cardium Formation were examined. Solid circles indicate the location of well cores that were logged. Open circles indicate the location of wells of which logs were used for correlation.

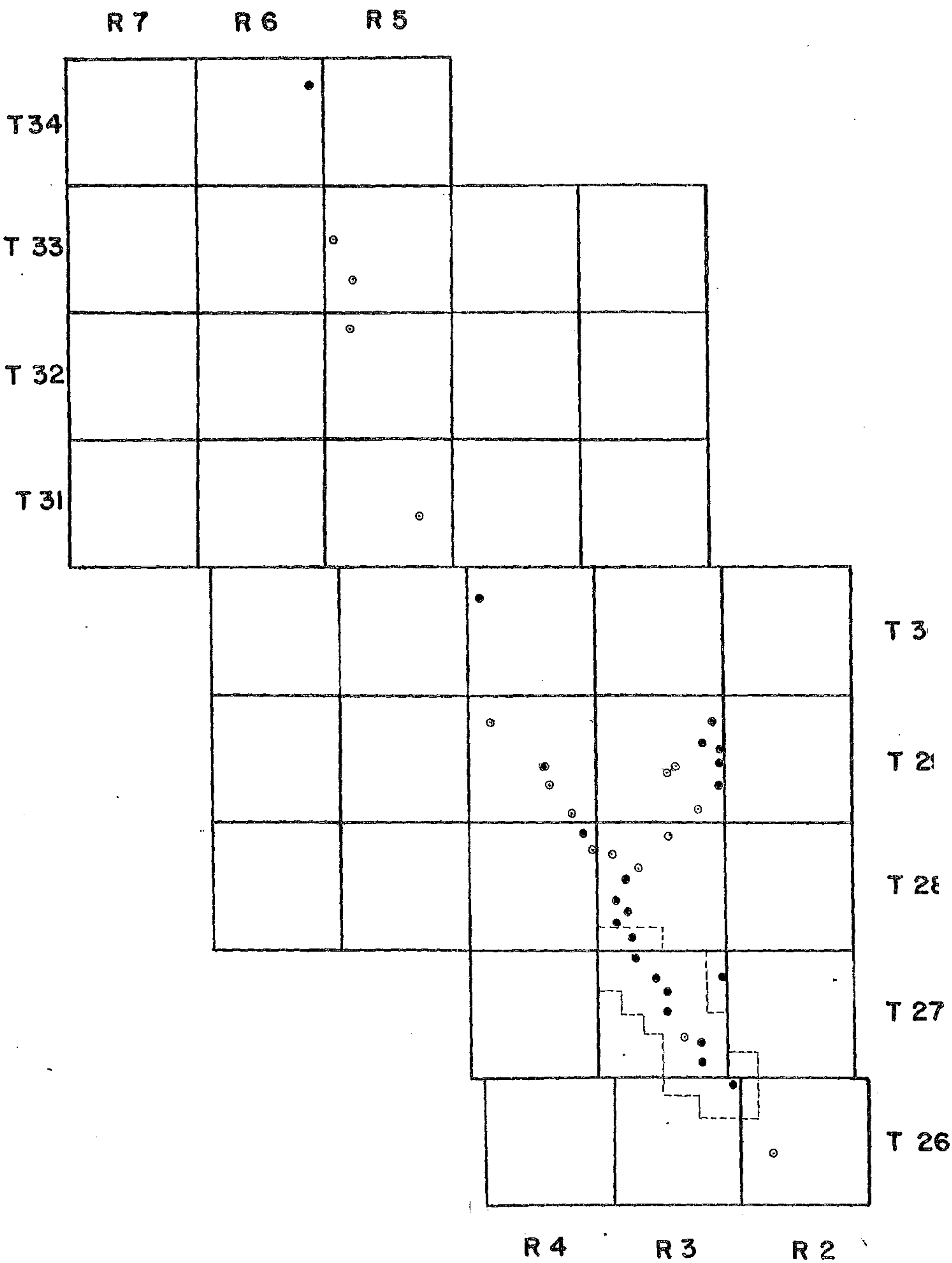
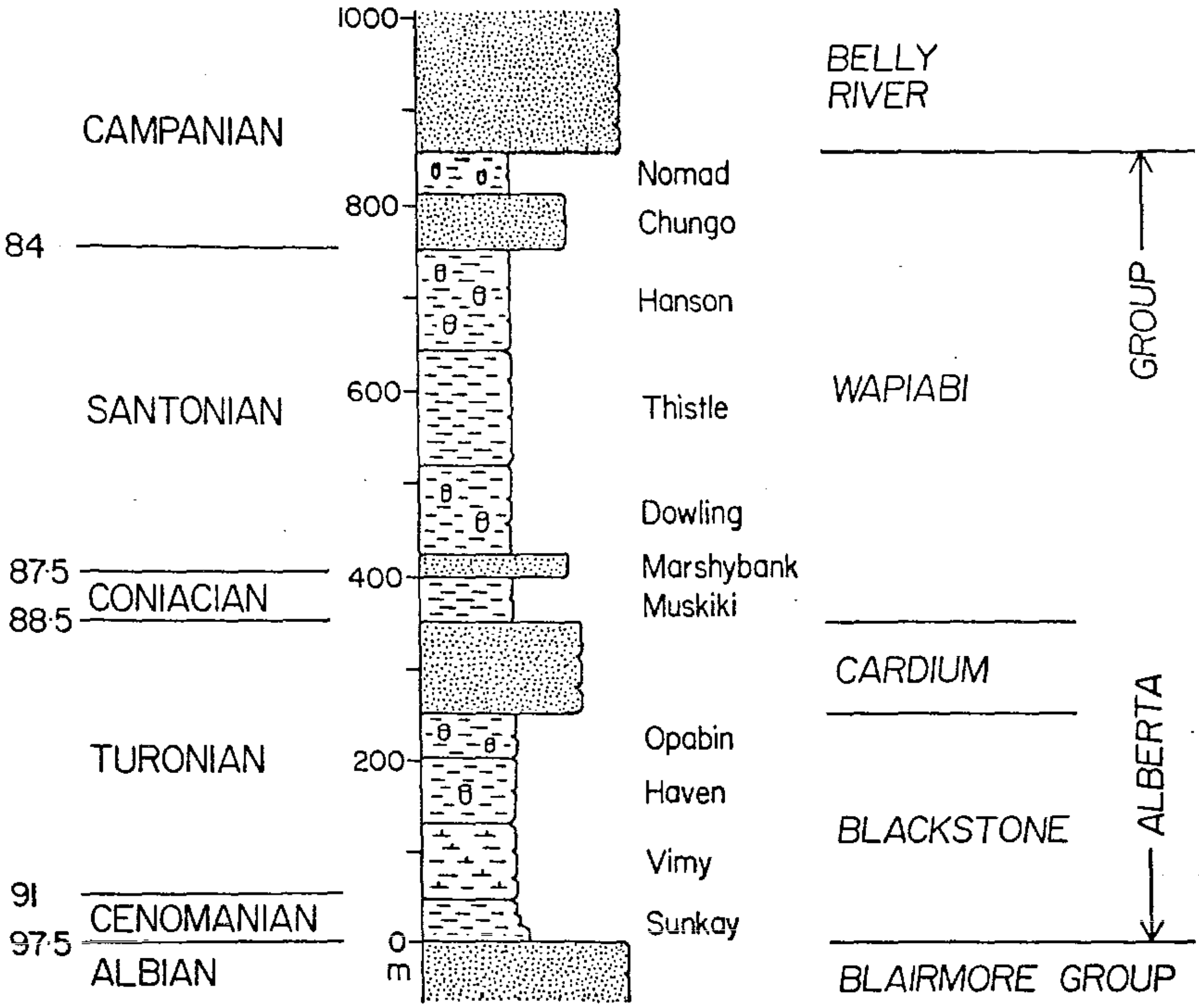

R 7
R 6
R 5
T34
T 33
T 32
T 31
T 27
T 26
R 4
R 3
R 2

Figure 1.3 Stratigraphy of Alberta Group in the Foothills of Alberta. Ages given at left are from Palmer, 1983 (from Walker, 1984c).


CAMPANIAN
84
SANTONIAN
87·5
CONIACIAN
88·5
TURONIAN
91
CENOMANIAN
97·5
ALBIAN
1000
800
600
400
200
0
m
Nomad
Chungo
Hanson
Thistle
Dowling
Marshybank
Muskiki
Opabin
Haven
Vimy
Sunkay
BELLY RIVER
WAPIABI
CARDIUM
BLACKSTONE
ALBERTA GROUP
BLAIRMORE GROUP

is still a topic on considerable debate. A sea level change would be extremely difficult to recognize in the black muds surrounding the Cardium sandstones, and the sandstones themselves show no clear cut evidence of sea level influence. However it cannot be ruled out in light of current discussion which centres around the major regression that dominated the Cretaceous seaway during the Late Turonian (Caldwell, 1975).

1.3 Previous Work

Outcrop Work

The outcrop stratigraphy of the Cardium Formation was originally described by Stott (1963) for the exposures in the Alberta Foothills. In Stott's original work, six members were defined in the formation. This member scheme was modified by Duke (in prep) after inconsistencies in Stott's divisions were noted by Walker in 1979.

There has been no success with the detailed correlation of the Cardium from outcrop to subsurface. This is due not only to the complex thrust faulting in the Alberta Foothills but also because there are more coarsening upwards cycles recognized in Cardium outcrop than there are recognized in the subsurface. In outcrop there may be between 2 to 8 coarsening upward sequences, while in the subsurface there are normally 1 to 3 major coarsening upward sequences (Keith, 1985).

Subcrop Work

The first of a series of papers by Walker (1983a), he reviewed the history of sedimentological interpretations for the Cardium since 1955. This paper highlights the arguments presented by various authors and traces the turbidity current hypothesis through its original "suggestion, its refection and its resurrection" particularly as a mechanism to explain deposition of the Ricinus field.

Berven's (1966) study led him to the conclusion, based largely on the geometry of the fields, that these "en echelon sand bodies at Crossfield and Garrington represent offshore bars." Furthermore, he suggests that the gradational base implies a slowly regressing sea and the sharp top may indicate a rapid transgression.

Michaelis and Dixon (1969) introduced the idea of storm generated currents as an important offshore transport mechanism.

Krause (1982) suggested the Upper Cardium sandstones of Pembina were deposited episodically and in 1983, after studying the lower Pembina sandstone, concluded that the Cardium at Pembina was deposited as a "tempestite". Krause and Nelson (1984) suggest additional sediments may have been supplied to Pembina during changes in sea level and reworked during periods with a stable sea level.

In the second of his series of papers Walker (1983b) details the sand body geometry and stratigraphy of the Caroline, Garrington and Ricinus area. Walker describes a "raggedly continuous" sandstone distribution of the upper Cardium sand between Caroline and Garrington, the term "ragged" implying a non-systematic thickness change in the sandstones (Walker, 1983b). The lower Cardium sequence is distributed as a "ragged blanket" but is not continuous between Caroline and Garrington. The lower sand in the Garrington field occurs as a descrete "long, thin strip" (Walker, 1983c).

Current Work

The importance of sea level changes with respect to the coarsening upwards cycles in the Cardium for the whole of the Alberta region is a topic of considerable discussion and is undergoing rapid modification daily (Plint, Walker, pers comm. 1985).

Additional subsurface Cardium studies include a detailed conglomerate study at Carrot Creek by Bergman (Ph.D. in prep).

1.4 SUBCROP NOMENCLATURE

Walker (1983c) emphasized the necessity of a formal stratigraphic terminology and stresses the importance of its use throughout regional studies and correlations between Cardium fields.

Walker identified the A sand at Caroline and Garrington, west of Ricinus as the Raven River Member. The B sand at Garrington, correlative with the B sand at Caroline extending west below Ricinus as the Burnstick Member.

An informal addition to this nomenclature identified the upper-most part of the Blackstone Formation which coarsens into the Burnstick Member as the Burnstick Sequence and similarly the coarsening upward sequence from the top of the Burnstick Member to the top of the Raven River Member to be termed the Raven River Sequence.

This formal terminology is easily extended to the Lochend study and is therefore used throughout this report.

The third coarsening upward cycle recognized in the overall

Cardium sequence has not been (legitimately) formally named. A recent suggestion to name this the "Cardium Zone Member" (Krause, 1984) contradicts two rules set by the North American Commission on Stratigraphic Nomenclature (NACSN, 1983). Firstly, Article 19 Revision, section (f) states that "in changing the rank of a unit, the same name may not be applied both to the unit as a whole and to part of it" (NACSN, 1983, p.855). Therefore the use of the name Cardium as a formation name disallows its use as a member name within the same formation.

Secondly, Article 22 Nature of Lithostratigraphic Units, section (i) states "as applied to the designation of lithostratigraphic units, the term "zone" is informal" (NACSN, 1983, p.855). Thus the formalization of this term is not permitted.

Therefore the third coarsening upwards cycle in the overall Cardium sequence has been incorrectly named. Throughout this thesis the informal use of the term Cardium "zone" will be used in reference to the pronounced petrophysical log kick and its associated conglomerates at the top of the coarsening upwards cycle.

It is the intention of Walker et al. to formally define this unit as the Dismal Rat Member (in prep).

1.5 Thesis Format

Following the first chapter which includes a brief introduction of the Lochend field, the geologic setting, a discussion of previous work and the nomenclature to be used throughout the thesis, the rest of the thesis is organized into 5 chapters.

Chapter 2 describes the individual facies recognized in the study area. In chapter 3 the facies are arranged into the three sequences (or cycles) as they occur in the core, and the representative "type" sections of the sequences are illustrated. Chapter 4 presents correlations of the formally recognized sequences between Lochend, Crossfield and Caroline. Chapter 5 presents possible interpretations of the facies in terms of depositional environment. The final chapter summarizes the findings of the previous four chapters as well as describes the problems associated with the interpretation of the Cardium in this region.

CHAPTER 2: FACIES

2.1 Definition of Facies

The definition of individual facies is basd on the identification of distinguishable lithologies, sedimentary structures and intensity of bioturbation (Walker, 1984).

2.2 Methodology

When working with drill core, the first step in a detailed description requires the identification of separate units. Units can be defined simply by the change from one facies to another, or by the identification of some obvious depositional break.

Once the units have been established, the core is measured from the bottom of the core to the top of the first unit. This unit is then described in detail noting first the overall lithologic characteristics. Grain sizes are estimated using a Can-Strat card. By this method sand sized particles can be subdivided into lower and upper divisions of each of the very fine, fine, medium, coarse and very coarse categories. Facies descriptions will include grain size estimates as read off the Can-Strat card. Example: mU is medium (upper) sand division and vfL is very fine (lower) sand division.

Minor, but distinguishable beds within a unit were then measured and described, followed by the description of any preserved sedimentary structures.

The bioturbation intensity or lack there of was noted including the names of any recognizable burrow forms.

Each subsequent unit is described in the same detail.

2.3 Introduction of the Facies Scheme

In the Lochend area nine distinct facies can be recognized. The facies that occur repeatedly throughout this study area are very similar to those at Caroline and Garrington (Walker, 1983c) and hence the same numbering and terminology will be used. Any minor variations between features of facies observed in the Caroline, Garrington region and those observed in the Lochend region will be identified as subfacies to simplify correlations between the facies.

The complete facies scheme as described by Walker is presented in order with the exception of facies 7. The facies described as 7A in this chapter is not equivalent to facies 7 of Walker's scheme. The facies described as 7A is named as such for two reasons, firstly, to maintain the facies in sequential order and secondly because the non-bioturbated sand designated as facies 7 by Walker for the Caroline, Garrington fields does not exist in the Lochend region and this confusion must be avoided.

An additional change in Walker's terminology results from the formal use of subfacies 8A and 8B. In Walker's scheme all conglomeratic facies were described as facies 8.

2.4 Facies 1. Massive Dark Mudstone (Fig. 2.1 A & B)

This facies comprises dark gray to black unbioturbated mudstone. A faint overall "stirring" or "mottling" is detectable in slabbed core, suggesting bioturbation by organisms that leave no distinct burrow forms. The maximum observed thickness of this facies is 10.41 m.

2.4.2 Facies 2 Laminated Dark Mudstones (Fig. 2.1 C & D)

This facies comprises bioturbated mudstones with silty beds. The average thickness of this unit is 7.66 m. Preserved siltstone beds have a maximum thickness of 2 cm., with sharp bases and bioturbated tops. These beds can rarely be traced across the full width of the core. The remnant silt beds show horizontal, or more rarely, ripple cross laminations.

Distinct burrow forms are not recognizable but some silty burrow fills have been pyritized. The mud stones between the silty beds have an overall dark grey well "stirred" appearance.

This facies might be considered to differ slightly from that described by Walker (1983c) due to the degree of bioturbation and presence of silt beds which are thicker and ripple cross laminated. This facies however does occur at the same stratigraphic horizon as facies 2, described by Walker and hence is interpreted as a stratigraphic equivalent.

2.4.3 Facies 3 Dark Bioturbated Muddy Siltstones (Fig. 2.2 A)

This facies has a gradational contact with facies 1 and occurs only in the Raven River Sequence. Facies 3 comprises dark grey mudstones with a well "stirred" texture, as a result of thorough bioturbation. Horizontal to slightly undulatory silt laminations of 2 cm maximum thickness occur but are generally disrupted by bioturbation. The overall silt content does not exceed approximately 10%. The silt remnants are often preferentially pyritized. Terebellina is the only recognizable burrow form. The upper most regions of this unit have sideritic concretion development.

2.4.4 Facies 4 Bioturbated Muddy Sandstone (Fig. 2.2 B)

This facies comprises an intensely bioturbated muddy sandstone. The sands and muds are thoroughly bioturbated together leaving very few preserved sandstone/siltstone beds. The remnant sand beds are a maximum 2 cm thick; they have sharp bases and show colour grading. Recognizable burrow forms include Zoophycos, Planolites, Terebelina and Skolithos.

2.4.5 Facies 5 Bioturbated Sandstones (Fig. 2.2 C)

This facies is distinguishable from facies 4 by the significant increase in sand content. The intensity of mixing of the sand and mud due to biturbation gives this facies the same general appearance as that described in facies 4. Preserved sand beds are very scarce, 2 cm. is the maximum remnant thickness. Sand grain sizes coarsen upward within the unit. Recognizable burrow forms include Chondrites, Teichichnus, Zoophycos and Planolites.

2.4.6 Facies 6 Speckled Gritty Mudstone (Fig. 2.2 D & Fig. 2.3)

This facies comprises a pervasively bioturbated mudstone, distinguishable from facies 4 by the abundance of randomly dispersed chert grains. The majority of chert grains fall in the cU to vcU range, however, a few grains range up to 3 mm. diameter. The chert grains of cU and vcL size are sometimes concentrated in pockets, particularly when associated with sideritized muds. The remnant sandy beds are of mU to mL grain size and reach 3 mm maximum thickness, but mostly the sand and mud are thoroughly bioturbated. Recognizable burrow forms include Zoophycos and Rhizocorallium. The average thickness calculated for this unit is 1.36 m.

2.4.7 Facies7A Interbedded Sandstones and Mudstones (Fig. 2.4)

This facies was not recognized by Walker (1983c) in the

Caroline and Garrington area and is not equivalent to the facies he designates as facies 7. Rather, the facies I have recognized as facies 7A in the Lochend region closely resembles facies 6, as described Keith by (1985) for the Willesden Green area. Also facies 7A is comparable to facies 15 of Plint's scheme for Kakwa (Plint pers. comm., 1985). This facies only occurs in the Raven River Sequence at Lochend.

Facies 7A comprises discrete, fine sandstone beds, 2 to 8 cm thick, having sharp bases and tops. Individual beds have well defined, horizontal or higher angle stratification. The sand beds are well preserved, lacking any significant amount of bioturbation. The mudstones show a higher degree of bioturbation. Any preserved silty laminae in the mudstones show horizontal lamination.

2.4.8 Facies 8A Clast Supported Conglomerate (Fig. 2.5)

Facies 8A comprises interbedded coarse sand and conglomerate. This facies represents the cleanest "sand" in the Lochend and Caroline region. The sandstone is of mL grain size and the conglomerates are composed of subrounded clasts of up to 4 mm in diameter. Although there appears to be a crude sorting of grain sizes no grading from coarser to finer clast sizes is apparent, nor is there any evidence of preferred fabric. The average thickness of this unit is 1.08 m.

2.4.9 Facies 8B Mud Supported Conglomerate (Fig. 2.6 & Fig. 2.7)

This facies consistently overlies facies 8A, the clast supported conglomerate. Facies 8B resembles a pebbly mudstone (Crowell, 1957) however the average clast size is within granule size range thus a better descriptor for this facies would be gravelly mudstone. The clasts are concentrated at the base of the unit where there is an estimated 20% muddy matrix. As in facies 8A there is no apparent stratification or imbrication. Towards the top of the unit granules are more dispersed in the mud, decreasing in abundance but not grain size. Within 0.26 cm. of the top of the unit the granules die out completely.

Figure 2.1 A Massive Dark Mudstone, Facies 1. Note the lack of laminations or silt patches. From above the Burnstick Member, 6-36-28-4W5, 2295.0 m. The core is 102 mm (4 inches) across.

Figure 2.1 B Massive Dark Mudstone, Facies 1. Note the absence of significant lamination and rare occurence of silty patches disrupted by bioturbation. This section of core occurs above the Burnstick Member, stratigraphically higher than that of Fig 2.1 A, 6-36-28-4W5, 2288.8 m. The core is 102 mm across.

Figure 2.1 C Laminated Dark Mudstones, Facies 2. Note the sharply based siltsone laminations (mm to cm thick). The discontinuity of the lamination suggests bioturbation. This occurs below the Burnstick Member, 8-17-28-3W5, 2197.4 m. This core is 102 mm across.

Figure 2.1 D Laminated Dark Mudstone, Facies 2. Note the sharply based delicately laminated silty layers (mm thick). The larger isolated sandy patches appear to have been thoroughly bioturbated. This facies occurs between the Burnstick and Raven River Members, 6-36-28-4W5, 2283.3 m. This core is 102 mm across.

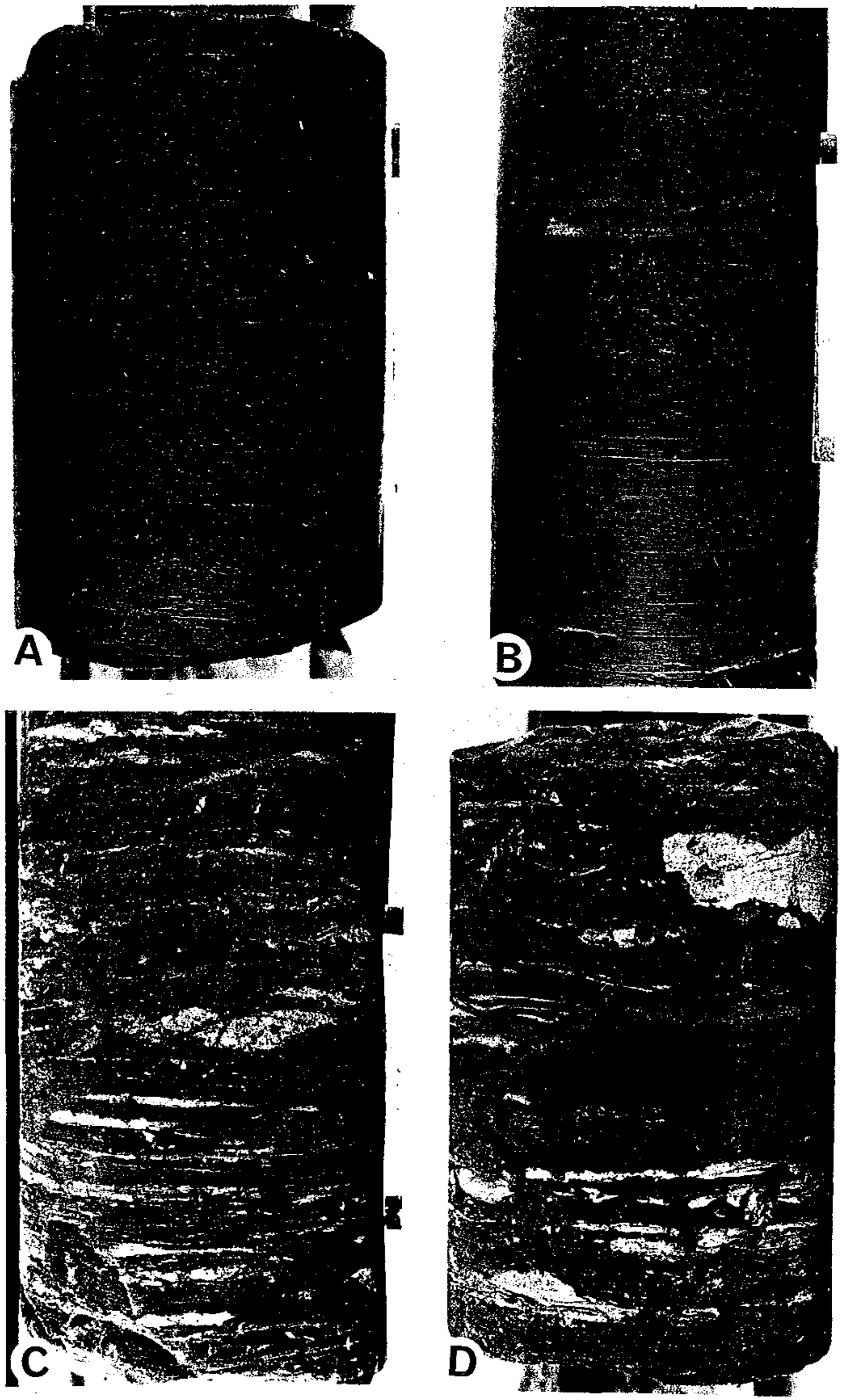

A
B
C
D

Figure 2.2 A Dark Bioturbated Muddy Siltstones, Facies 3. Distinct laminations are rarely present and the sandy patches are disrupted by bioturbation. Note the _Terebellina_ burrow forms. This facies occurs below facies 2 in the Raven River Sequence 6-36-28-4W5, 2284.0 m. This core is 102 mm (4 inches) across.

Figure 2.2 B Bioturbated Muddy Sandstone, Facies 4. This facies is sandier than facies 3 with considerably more bioturbation. Note the _Zoophycos_ burrow just below the centre of the photo. This facies occurs in the Raven River Sequence, 6-36-28-4W5, 2281.8 m. The core is 102 mm across.

Figure 2.2 C Bioturbated Sandstone, Facies 5. This facies is much sandier than facies 4 and is thoroughly bioturbated. Both vertical and horizontal burrows are present as well as _Inoceramus_ fragments. From the Raven River Sequence, 6-36-28-4W5, 2269.4 m. This core is 102 mm across.

Figure 2.2 D Speckled Gritty Mudstone, Facies 6. This photo illustrates the similarity between facies 6 and facies 5. Facies 6 however, has the speckled testure of coarse and very coarse sand grains randomly dispersed throughout. This facies occurs below the Burnstick Member, 8-7-28-3W5, 2255.8 m. This core is 76 mm (3 inches) across.

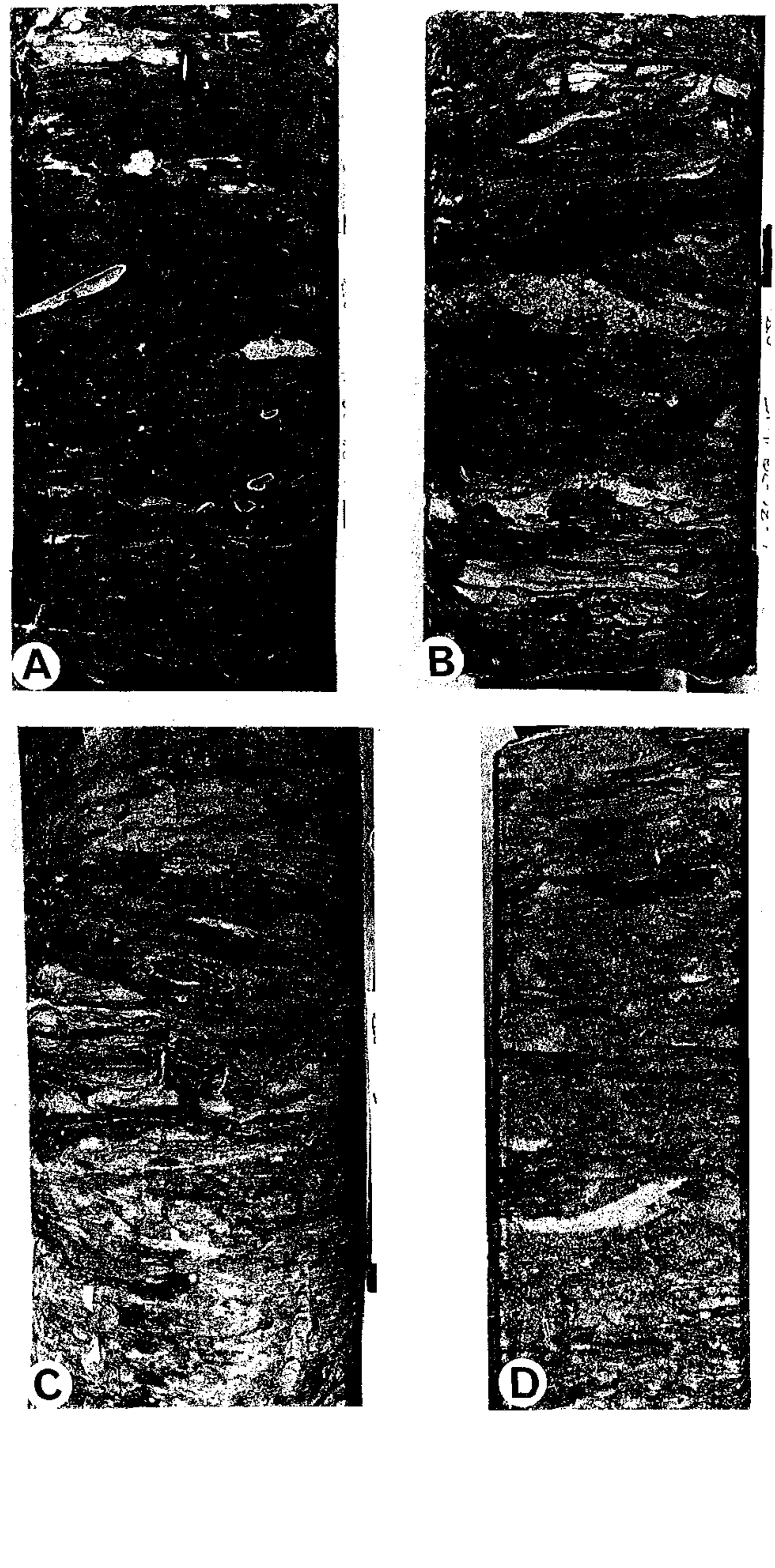

A
B
C
D

Figure 2.3 A Bioturbated Sandstone, Facies 5, overlain by Speckled Gritty Mudstone, Facies 6. Note the relatively sharp contact between the two facies. From the Burnstick Sequence, 6-36-28-4W5, 2285.0 m. This core is 102 mm (4 inches) across.

Figure 2.3 B Speckled Gritty Mudstone, Facies 6. Note the randomly dispersed coarse sand to granules size grains. From the Burnstick Sequence, 6-36-28-4W5, 2299.8 m. This core is 102 mm across.

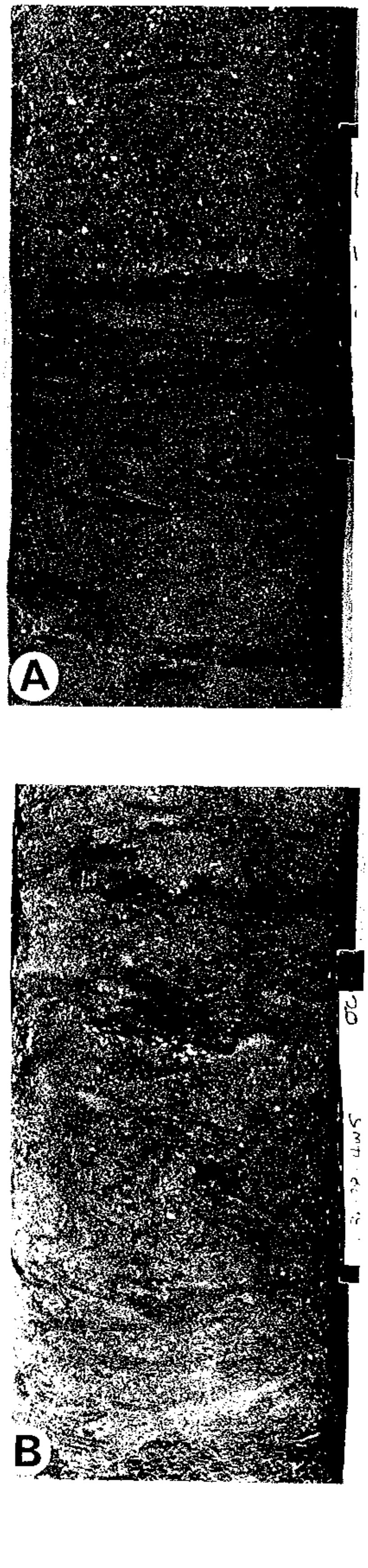

A
B
20

Figure 2.4 A Interbedded Sandstone and Mud, Facies 7A. Note the ripple cross laminated sand layers separated by mudstone, and the preserved symmetrical ripple topography of the sand beds. This occurs in the Raven River Sequence, 6-36-28-4W5, 2282.5 m. This core is 102 mm (4 inches) across.

Figure 2.4 B Interbedded Sandstone and Mud, Facies 7A. This section of core occurs further up the core than Fig. 2.4 A. The ripple cross laminated sand beds are thinner than those further down the core and have sharp bases and tops. The lower half of the core is considerably more bioturbated however few organisms could penetrate the 3 cm sand bed in the bottom section of the photo. From well 6-36-28-4W5, 2281.8 m. This core is 102 mm across.

Figure 2.4 C Interbedded Sandstone and Mud, Facies 7A. The sand is much coarser than Fig 2.4 A & 2.4 B. The mud in this core is sideritized. Note the sharp base and top of the sandstone bed. This core is from the Raven River Sequence, 8-7-28-3W5, 2255.4 m. This core is 76 mm (3 inches) across.

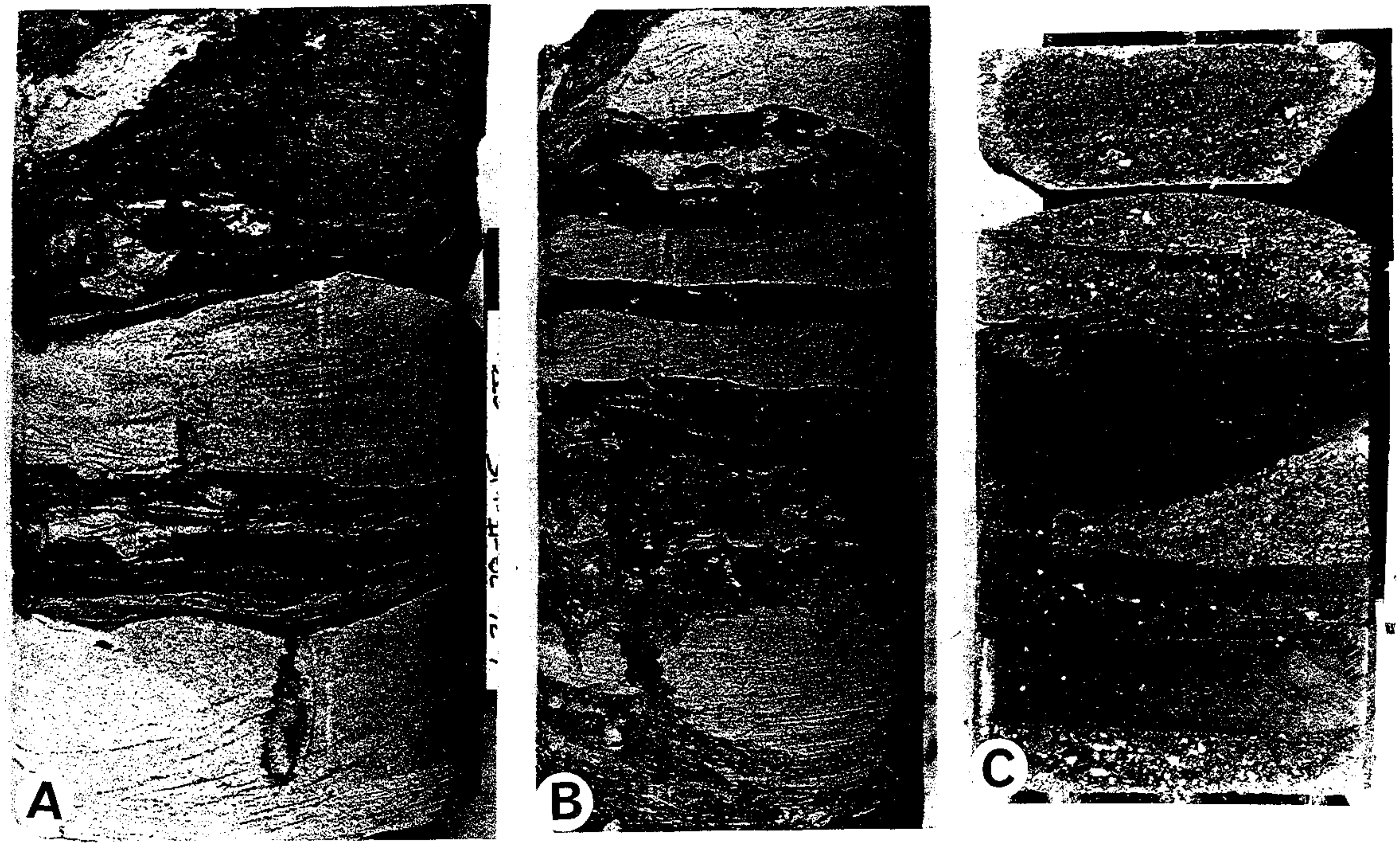
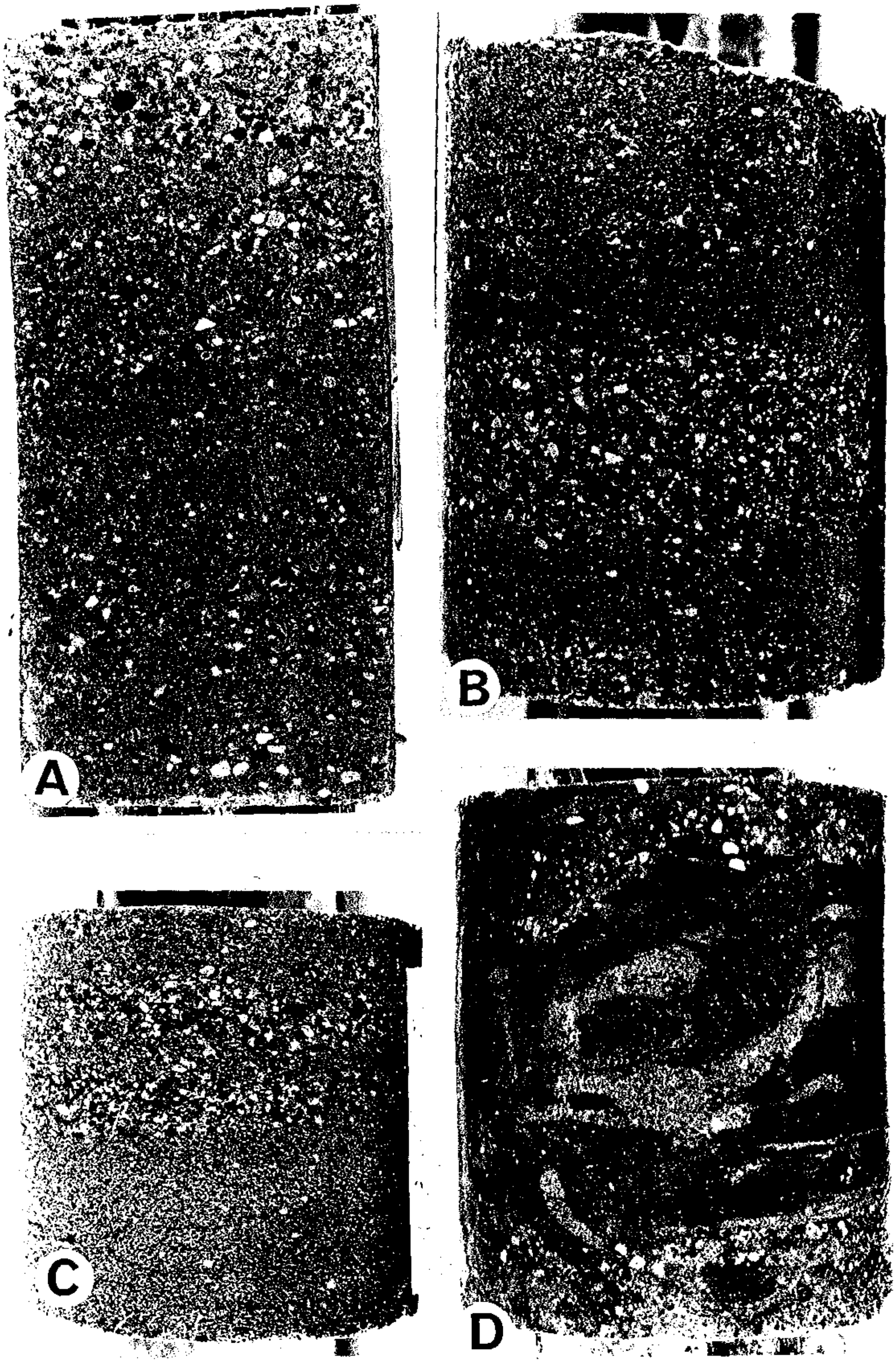

A
B
C

Figure 2.5 A Clast Supported Conglomerate, Facies 8A. Note the lack of preferred orientation, imbrication but the crude sorting of the grains into coarser and finer bands. From the Burnstick Member, 4-22-27-3W5, 2259.5 m. The core is 76 mm (3 inches) across.

Figure 2.5 B Clast Supported Conglomerate, Facies 8A. Note the only significant sedimentary feature is the crude sorting into coarser and finer bands. From the Burnstick Member, 14-8-28-3W5, 2217.0 m. This core is 102 mm (4 inches) across.

Figure 2.5 C Clast Supported Conglomerate, Facies 8A. Note the crude sorting into coarser and finer grain sizes. The coarse bands 1 to 2 cm thick. From the Burnstick Member 6-36-26-4W5, 2298.2 m. The core is 102 mm across.

Figure 2.5 D Clast Supported Conglomerate, Facies 8A. This is a muddy break in facies 8A. Note the sideritized Zoophycos burrow. From the Burnstick Member,10-5-28-3W5, 2283.5 m. This core is 76mm across.


A
B
C
D

Figures 2.6 A, B and C illustrate the sequence of gravel ribs associated with the southern-most "off-field" Raven River Sequence, 10-36-26-3W5.

Figure 2.6 A Granule pockets within the mudstone at a depth of 2135.7 m.

Figure 2.6 B Conglomerate banding within laminated mudstones. Clast supported conglomerates show considerable size range from mm size chert grains to cm scale siderite nodules. Depth of 2136.5 m.

Figure 2.6 C Sharp based clast supported conglomerate band within laminated mudstone. Note the large 2 cm siderite nodule and delicate silt laminations within the overlying mud. Depth of 2137.4 m.

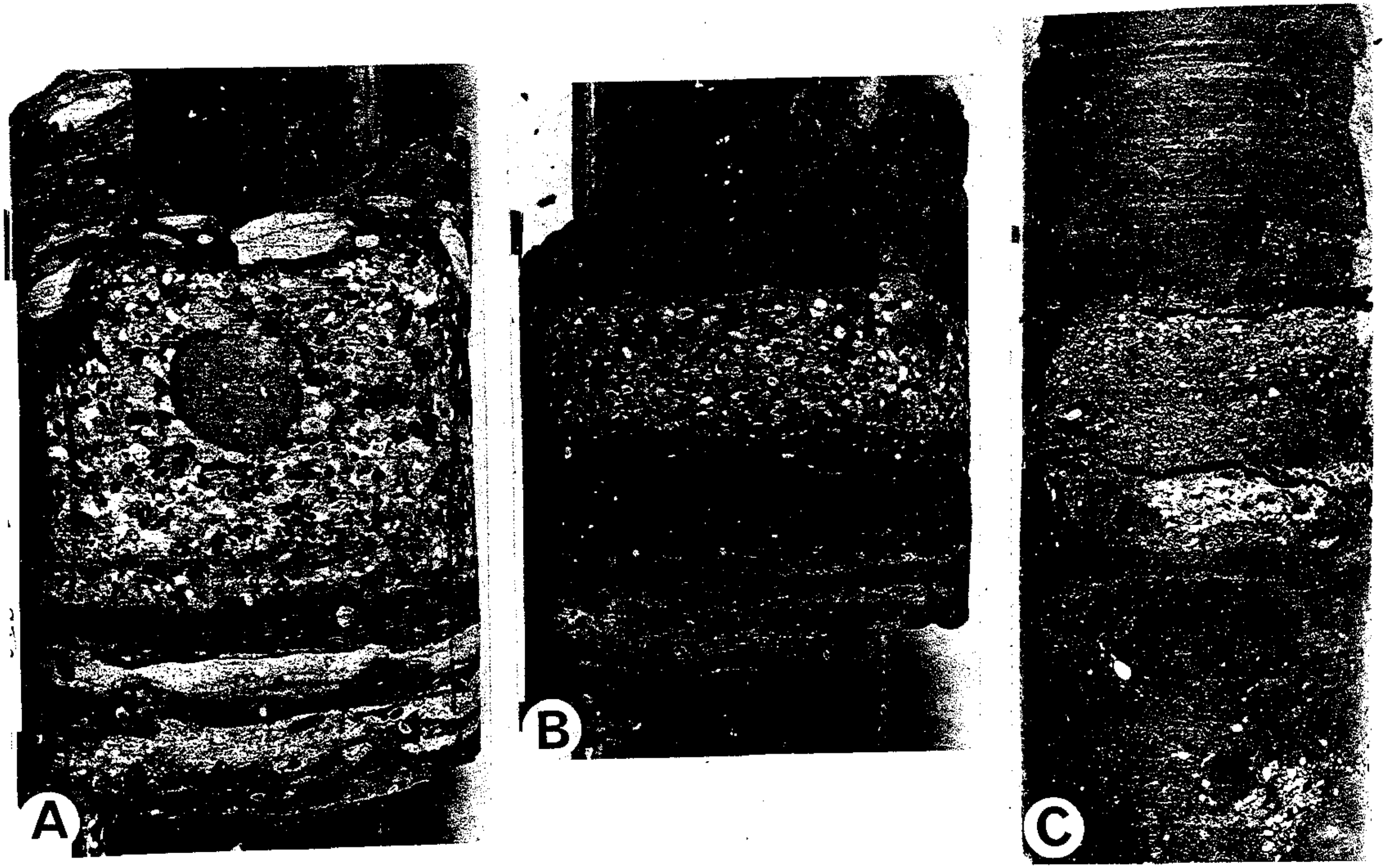
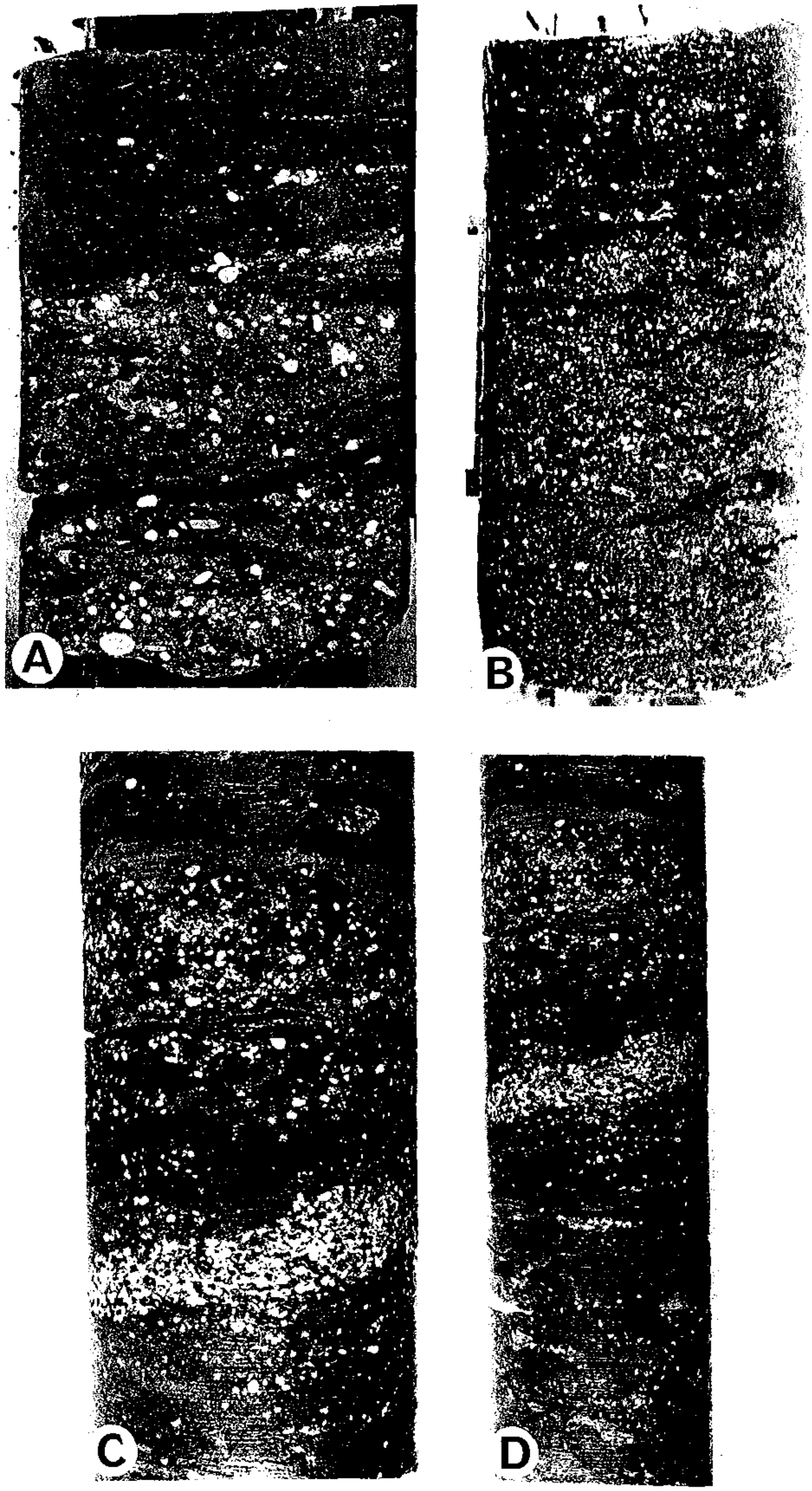

A
B
C

Figure 2.7 A Mud Supported Conglomerate, Facies 8B. Note the concentration of granules at the base. This facies consistently overlies the Burnstick Member, the clast supported conglomerate of facies 8A, 8-7-28-3W5, 2182.7 m. This core is 76 mm (3 inches) across.

Figure 2.7 B Mud Supported Conglomerate, Facies 8B. Note the gradational contact with the underlying facies 8A, 8-17-28-3W5, 2182.7 m. This core is 76 mm across.

Figure 2.7 C & D Figure C is a close up of Figure D. This shows clast supported conglomerate banding within the faintly laminated mudstone. The discontinuity of the laminations may be indicative of bioturbation. This banding is associated with the Raven River Sequence, 6-36-28-4W5, 2277.9 m. This core is 102 mm (4 inches) across.


A
B
C
D

CHAPTER 3: SEQUENCES

3.1 Introduction

The recurrence of consistent facies assemblages throughout the Lochend study area made it possible to construct typical facies sequences. The descriptions of the facies sequences permitted confirmation of the log data that the sequences in Lochend were correlative with the Burnstick Sequence and the Raven River Sequence at Caroline and Garrington. There exists a single core which penetrates the third coarsening upward cycle known as the "zone" of the Cardium Formation. This section is very infrequently cored and therefore the detailed core description is documented in its entirety.

Typical facies thicknesses have been calculated by averaging the thickness values from every available core. Table 3.1 gives the average thickness, the thickness range and the number of data points used in establishing the average. The maximum cored thickness of the upper and lower most units are the representative thickness values for these units. It is important to note that these values represent a minimum thickness, in that these units could in fact be thicker than the cored segment.

Table 3.1 Burnstick Sequence Facies Thickness

Top Unit	Facies 1	Maximum 10.41 m
Unit 2	Facies 8B	0.26 m (0.05 m - 0.38 m) 14 data points
Unit 3	Facies 8A	1.08 m (0.55 m - 1.69 m) 13 data points
Unit 4	Facies 6	1.36 m (0.44 m - 1.83 m) 10 data points
Basal Unit	Facies 2A	Maximum 7.66 m

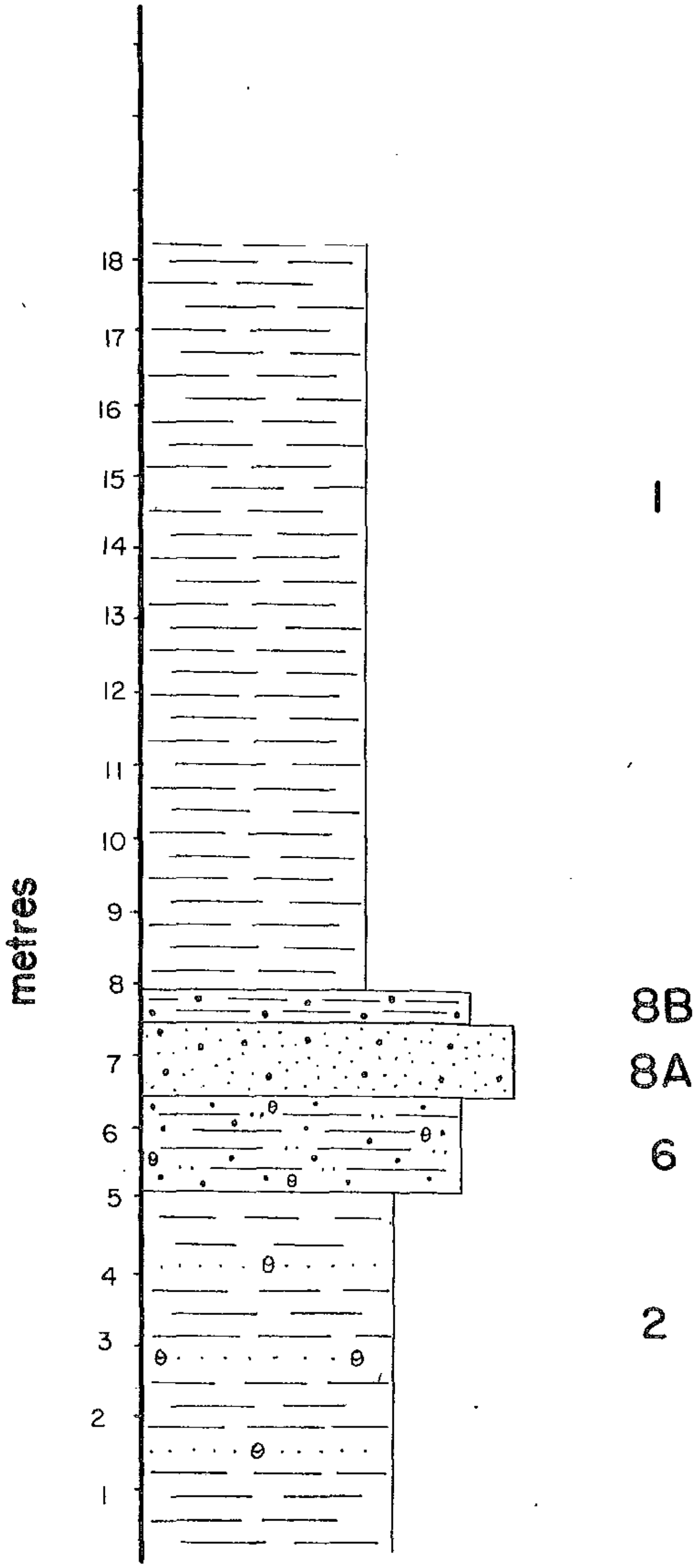
3.2 Burnstick Sequence

From the 14 cores measured in the Lochend field, a reasonably consistent facies sequence can be identified for the Burnstick Sequence. A "type" section along with calculated average thicknesses for each facies is illustrated in Fig 3.1.

This sequence comprises five distinct facies, comparable to those described by Walker (1983c) in the Caroline and Garrington area. The Burnstick Sequence begins with laminated mudstones of facies 2. These are consistently overlain by the thoroughly bioturbated speckled mudstone, facies 6. This facies in turn grades into the sandstone/conglomerate facies 8A. Facies 8A is commonly interbedded with muddy beds. These muddy beds are a sideritized version of the speckled mudstone. The conglomeratic unit 8A sharply overlies the various lower muddy/sandy facies. It is overlain abruptly by a gravelly mudstone, facies 8B. The gravelly mudstone is only about 20 cm thick and where the gravels dies out, it grades into the black blanket of facies 1. Up to 10 m of this facies can be seen in

Figure 3.1 Burnstick Sequence "Type" Section. This lithologic section illustrates a typical Burnstick Sequence in the Lochend region. This section is to scale, the facies thicknesses are based on average value calculations, see Table 3.1. The facies are labelled to the right of the section.

BURNSTICK SEQUENCE TYPE SECTION



core.

3.3 Raven River Sequence

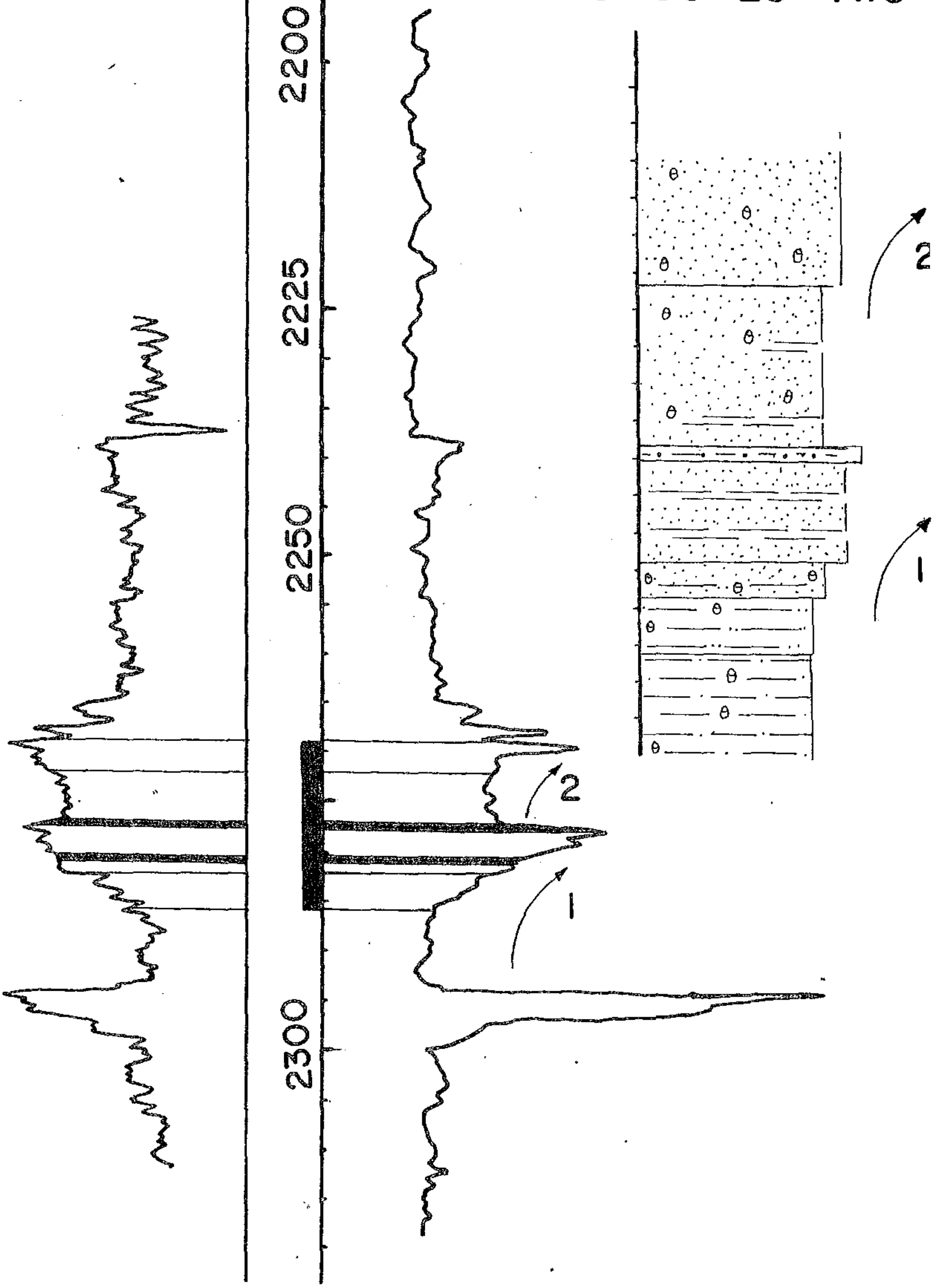
The facies descriptions of the Raven River Sequence in the Lochend field are based on the only three available cores. Two of these core 6-36-28-4W5 (all subsequent well addresses correspond to locations west of the 5th meridian), and 10-36-26-3 represent an "on-field" location and 6-4-27-3 represents an "off-field" position.

All gamma ray log responses for this sequence in the Lochend area show relatively consistent responses. This suggests that the sequences are very similar at all well locations, unfortunately limited core data prevents confirmation of this.

Only one well in the Lochend area, 6-36-28-4, provides a continuous core from the Burnstick sequence up into the Raven River Sequence. This well ties the top of the Burnstick Sequence to the base of the Raven River sequence by facies 1, the massive dark mudstone. This facies grades into the laminated dark mudstones of facies 2. A gradual increase in silt content upward defines the beginning of the overlying pervasively bioturbated muddy sandstone, of facies 4. This facies is gradationally overlain by facies 5, bioturbated sandstones. An abrupt contact generally marked by the incoming of the conglomerates defines the next unit in the sequence. This unit typically consists of interbedded sandstones, conglomerates and mudstones of facies 7A. All of the logs indicate a double coarsening upward cycle associated with the Raven River Sequence. Upon careful examination of well 6-36-28-4 the corresponding coarsening upward lithologies could be identified (Fig. 3.2).

Figure 3.2 Raven River Double Coarsening Upward Cycles. Careful examination of well 6-36-28-4W5 showed the lithologies which corresponded to the double coarsening upward cycle that is recognizable in both the gamma-ray and resistivity logs. The numbered arrows illustrate the coarsening upward units in the core and the corresponding positions on the logs. The stratigraphic section is drawn to scale. The black bar on the log shows the cored interval.

6-36-28-4W5



The first cycle coarsens upward from the bioturbated mudstone of facies 4 into bioturbated sandstones, facies 5 and then into the interbedded sandstone and mudstone facies of 7A. This first cycle is capped by a gravelly mudstone, facies 8B. Facies 8B is overlain by the muddier and bioturbated facies 4 which marks the beginning of the second coarsening upward cycle of the sequence. Facies 4 "cleans" upwards into facies 5 before returning to the black blanket, facies 1. Based on the three cores viewed no consistent "type" sequence could be identified, therefore all three are illustrated in Fig. 3.3. The Raven River Sequence is capped by the laminated mudstones of facies 2.

3.4 Cardium "Zone"

The third coarsening upwards cycle recognized in the overall Cardium sequence has not been formally named.

The Cardium "zone" is infrequently cored at any location in southern Alberta, therefore the single occurence of the "zone" core in the Lochend region at 6-21-26-3 deserves documentation. The position of the core relative to the gamma ray and resistivity log is shown in Fig 3.4. The corresponding stratigraphic section is illustrated in Fig 3.5.

At the base of the core is the laminated mudstone, facies 2. This is gradationally overlain by massive mudstones of facies 1. Facies 1 grades into a facies which appears similar to facies 2 but the bioturbation intensity is that of facies 3. This facies is followed gradationally by a return to facies 1. The introduction of bioturbation defines the next facies change to facies 2, again with lots of bioturbation verging on facies 3.

Figure 3.3 Raven River Sequence Lochend distribution. This diagram illustrates the cored interval for all three of the Raven River Sequence cores that were available in the Lochend region. The inconsistency of this sequence throughout the field made it impossible to construct a "type" section, therefore all three lithologs are included for comparison.

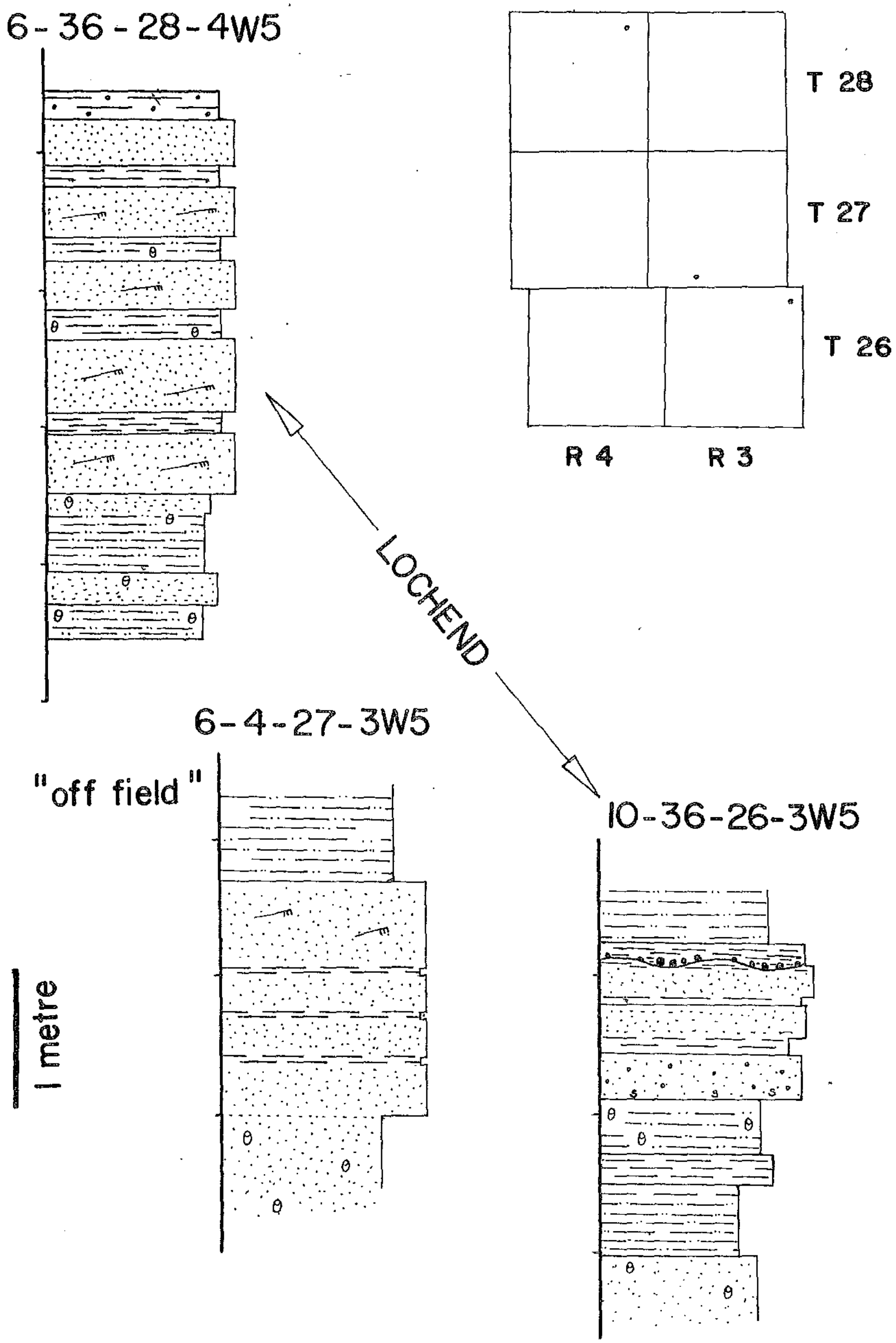

6-36-28-4W5
T 28
T 27
T 26
R 4
R 3
LOCHEND
6-4-27-3W5
"off field"
10-36-26-3W5
1 metre

Figure 3.4 Position of the "Zone" cored section. This diagram illustrates the position of the cored section of the "zone" sequence relative to the corresponding gamma-ray and resistivity logs for well 6-21-26-3W5. Note also the nature of the "inter-field Burnstick equivalent" signature, discussed in Chapter 4.

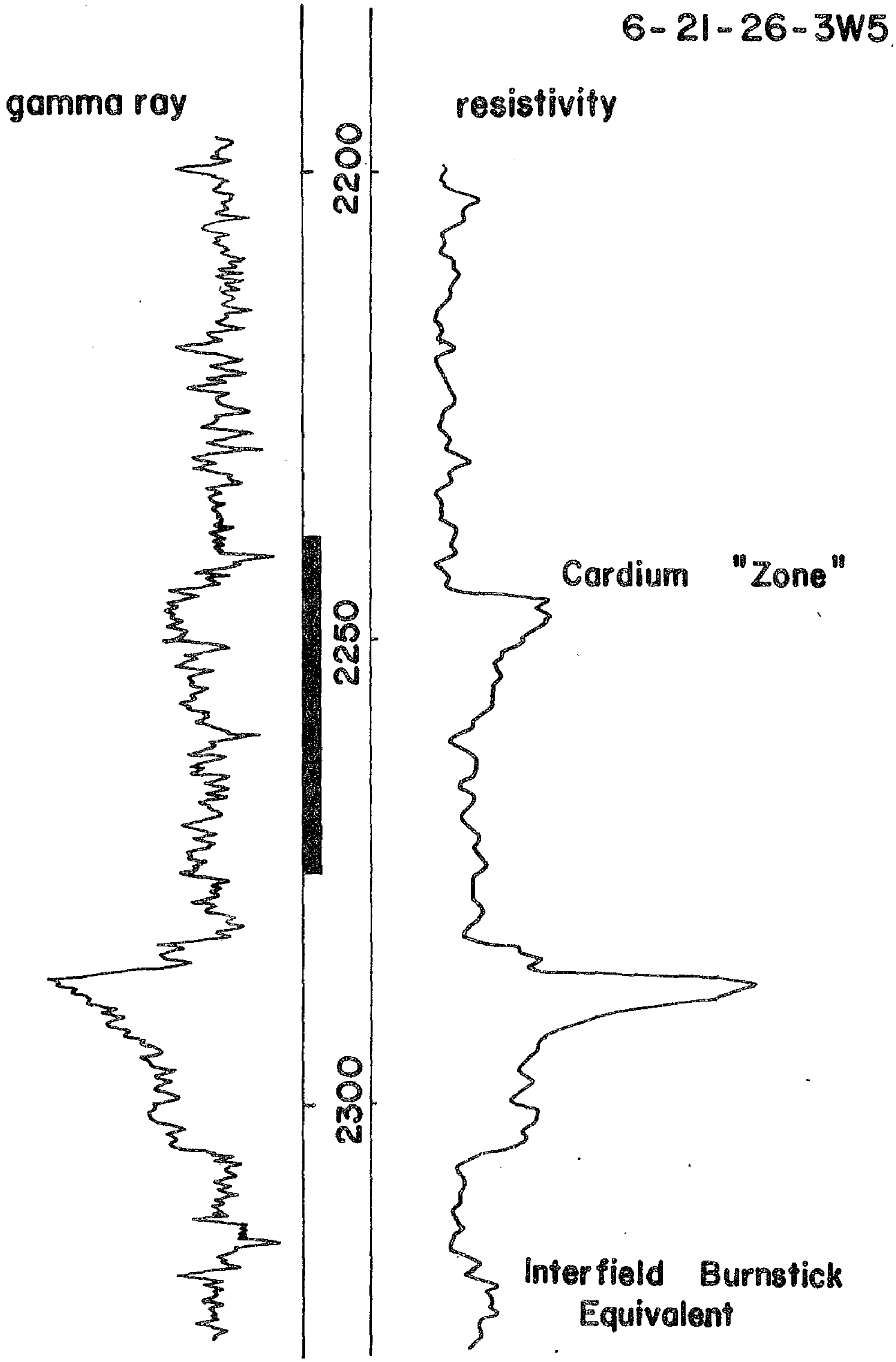
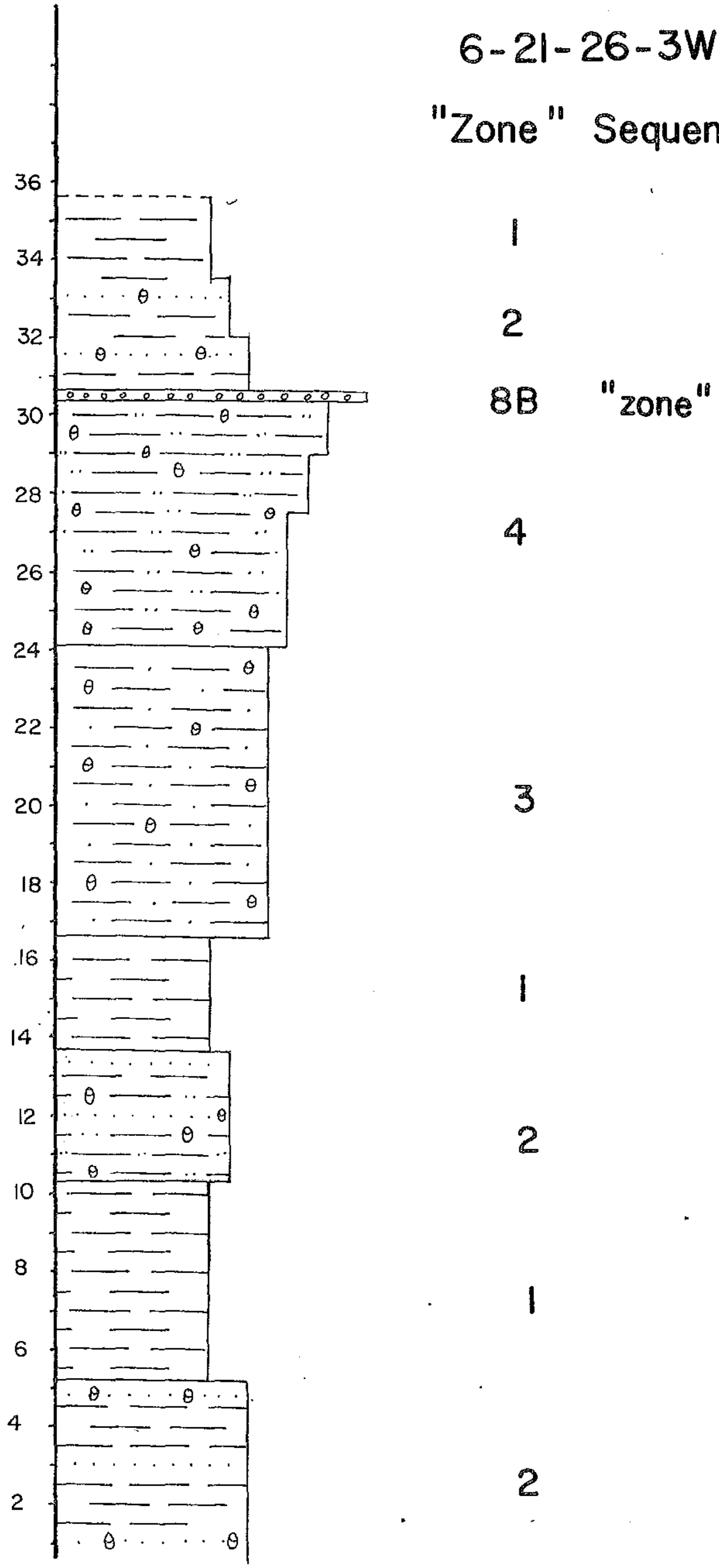

6-21-26-3W5
gamma ray
resistivity
2200
2250
2300
Cardium "Zone"
Interfield Burnstick
Equivalent

Figure 3.5 "Zone" Stratigraphy. This stratigraphic section represents the stratigraphy of the "zone" sequence as logged from well 6-21-26-3W5. This section is drawn to scale and the facies are labelled to the right of the sequence.

6-21-26-3W5

"Zone" Sequence



This facies grades into facies 4, pervasively bioturbated mudstone, which increases silt content upward. _Paleophycus_ burrows are present in this unit. Facies 4 is followed sharply by a pebble bed, facies 8A. The base is sharp but bioturbated. The main pebbly layer is about 5 cm thick, the rest of the unit consists of horizontal pebble layers alternating with mudstones, chert and siderite, as well as _Inoceramus_ fragments. This unit is gradationally overlain by the black mudstones of facies 1, with a few silty laminations at the base. A continuous photo log for the entire cored sequence is illustrated in Figures 3.6 to 3.8.

Figure 3.6 A Cardium "Zone" Sequence, Basal Unit 1. Facies 2, Laminated Dark Mudstone. Well 6-21-26-3W5, 2272.2 m. This core is 76 mm (3 inches) across.

Figure 3.6 B Cardium "Zone" Sequence, Unit 2. Facies 1, Massive Dark Mudstone. Well 6-21-26-3W5, 2267.7 m. This core is 76 mm across.

Figure 3.6 C Cardium "Zone" Sequence, Unit 3. Facies 3, Dark Bioturbated Muddy Siltstone. Well 6-21-26-3W5, 2263.7 m. This core is 76 mm across.

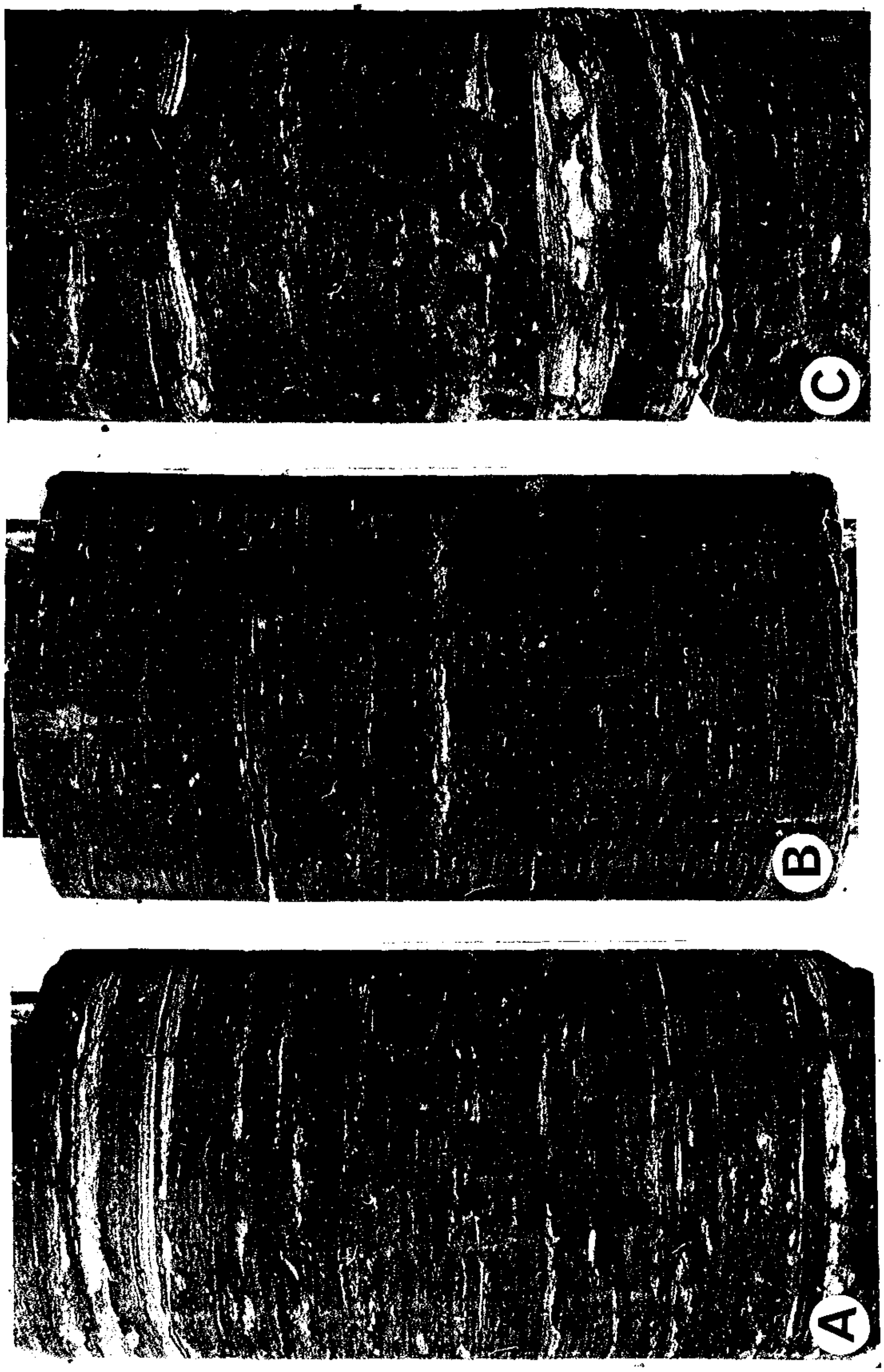

C
B
A

Figure 3.7 A Cardium "Zone" Sequence, Unit 5. Facies 3, Dark Bioturbated Muddy Siltstone. Note the complete *Inoceramus* shell. Well 6-21-26-3W5, 2253.6 m. This core is 76 mm (3 inches) across.

Figure 3.7 B Cardium "Zone" Sequence, Unit 5. Facies 3, Dark Bioturbated Muddy Siltstone. Well 6-21-26-3W5, 2253.6 m. This core is 76 mm across.

Figure 3.7 C Cardium "Zone" Sequence, Unit 6. Facies 4, Bioturbated Muddy Sandstone. Well 6-21-26-3W5, 2246.4 m.

Figure 3.7 D Cardium "Zone" Sequence, Unit 6. Facies 4, Bioturbated Muddy Sandstone. Well 6-21-26-3W5, 2249.6 m. This core is 76 mm across.

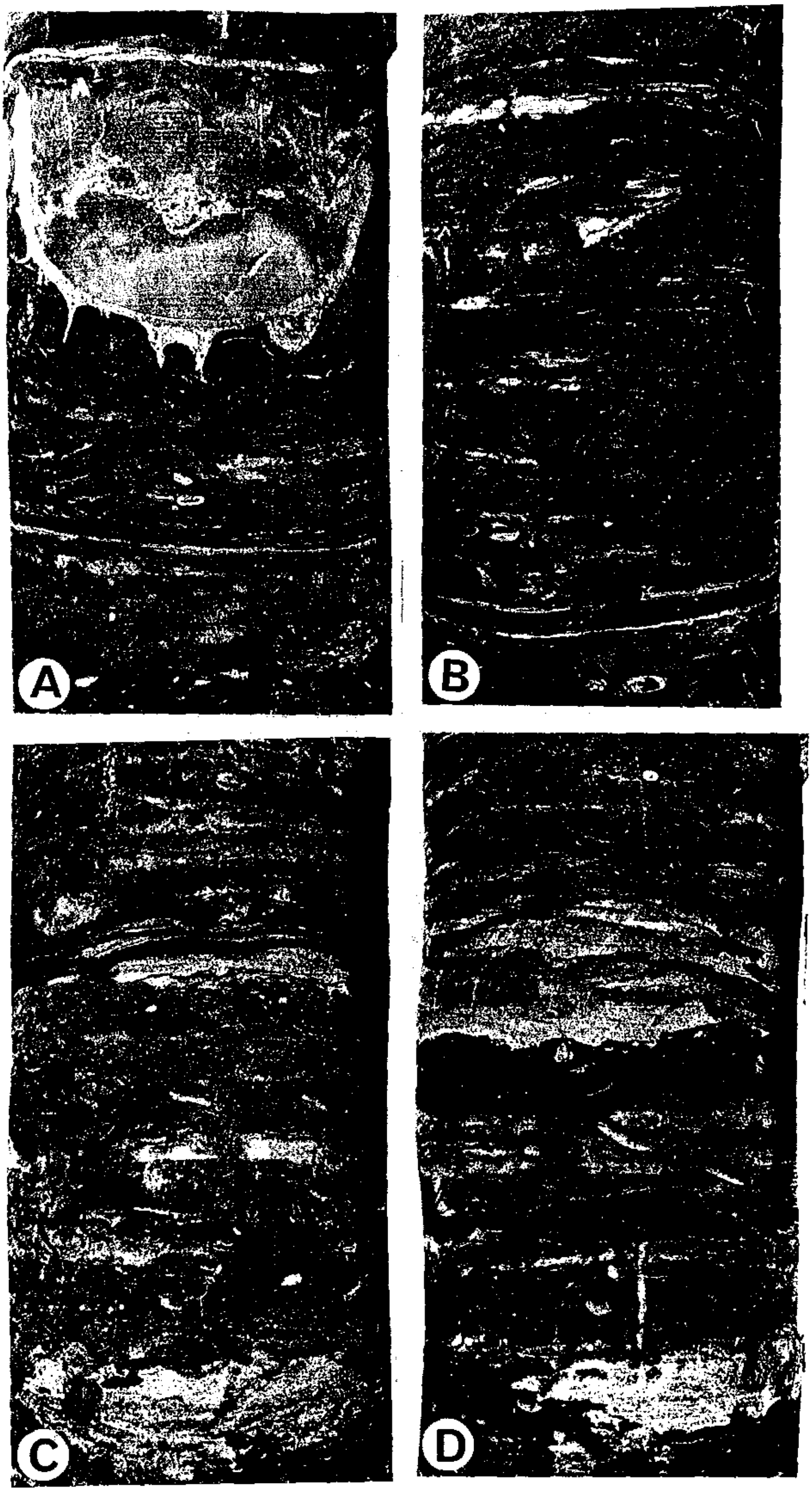
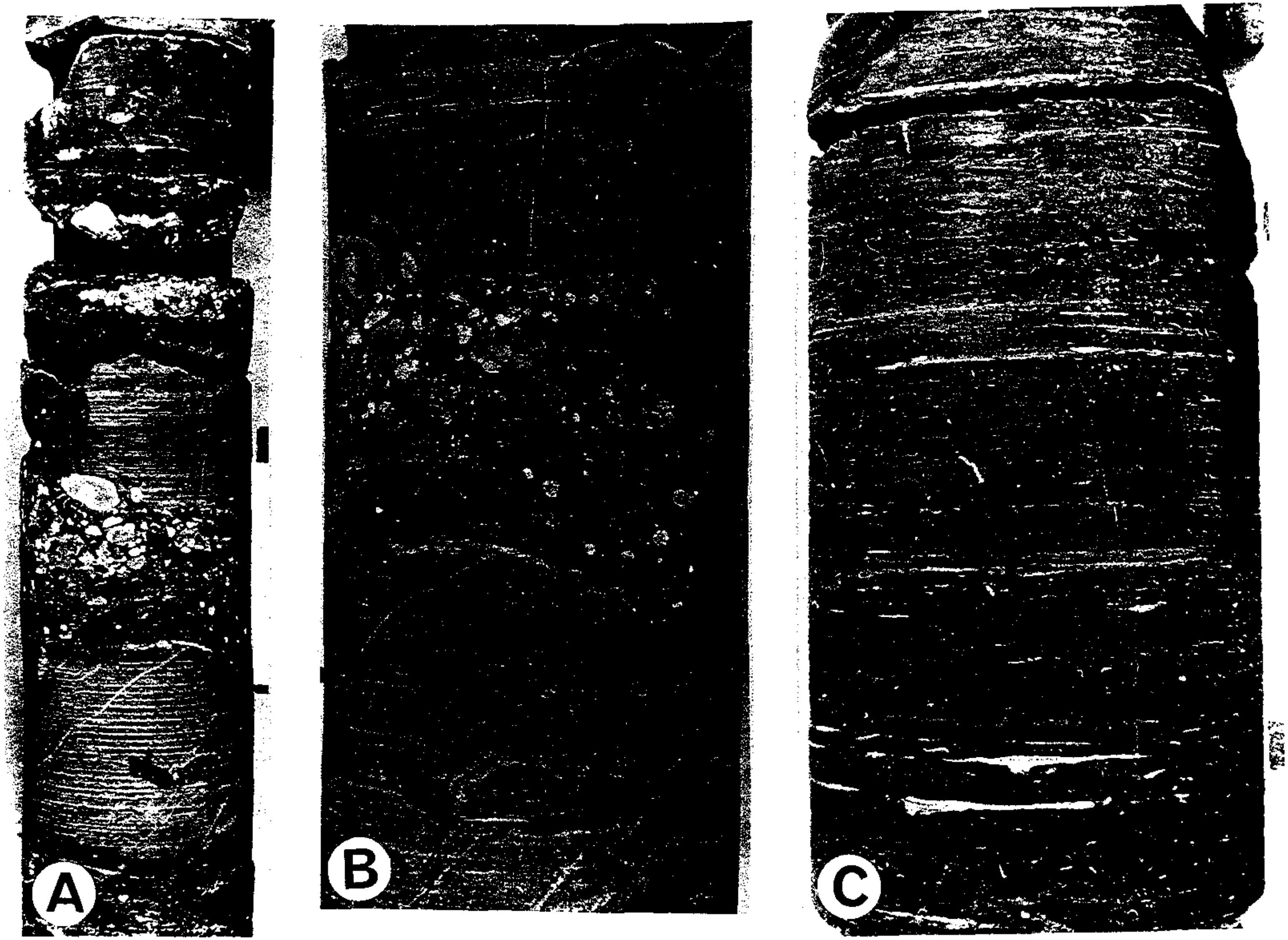

A
B
C
D

Figure 3.8 A Cardium "Zone" Sequence, Unit 7. Facies 8B, Mud Supported Conglomerate. This is the "zone" conglomerate which produces the pronounced log kick. Note the poorly sorted, subrounded clasts supported in a mud matrix. The conglomerate is surrounded by siderite. Well 6-21-26-3W5, 2244.1 m. This core is 76 mm (3 inches) across.

Figure 3.8 B Cardium "Zone" Sequence, Unit 7. Facies 8B, Mud Supported Conglomerate. The "zone" conglomerate, 6-21-26-3W5, 2244.1 m. This core is 76 mm across.

Figure 3.8 C Cardium "Zone" Sequence, Unit 8. Facies 1, Massive Dark Mudstone. This facies overlies the "zone" conglomerate. Well 6-21-26-3W5, 2239.2 m. This core is 76 mm across.


A
B
C

CHAPTER 4: CORRELATIONS

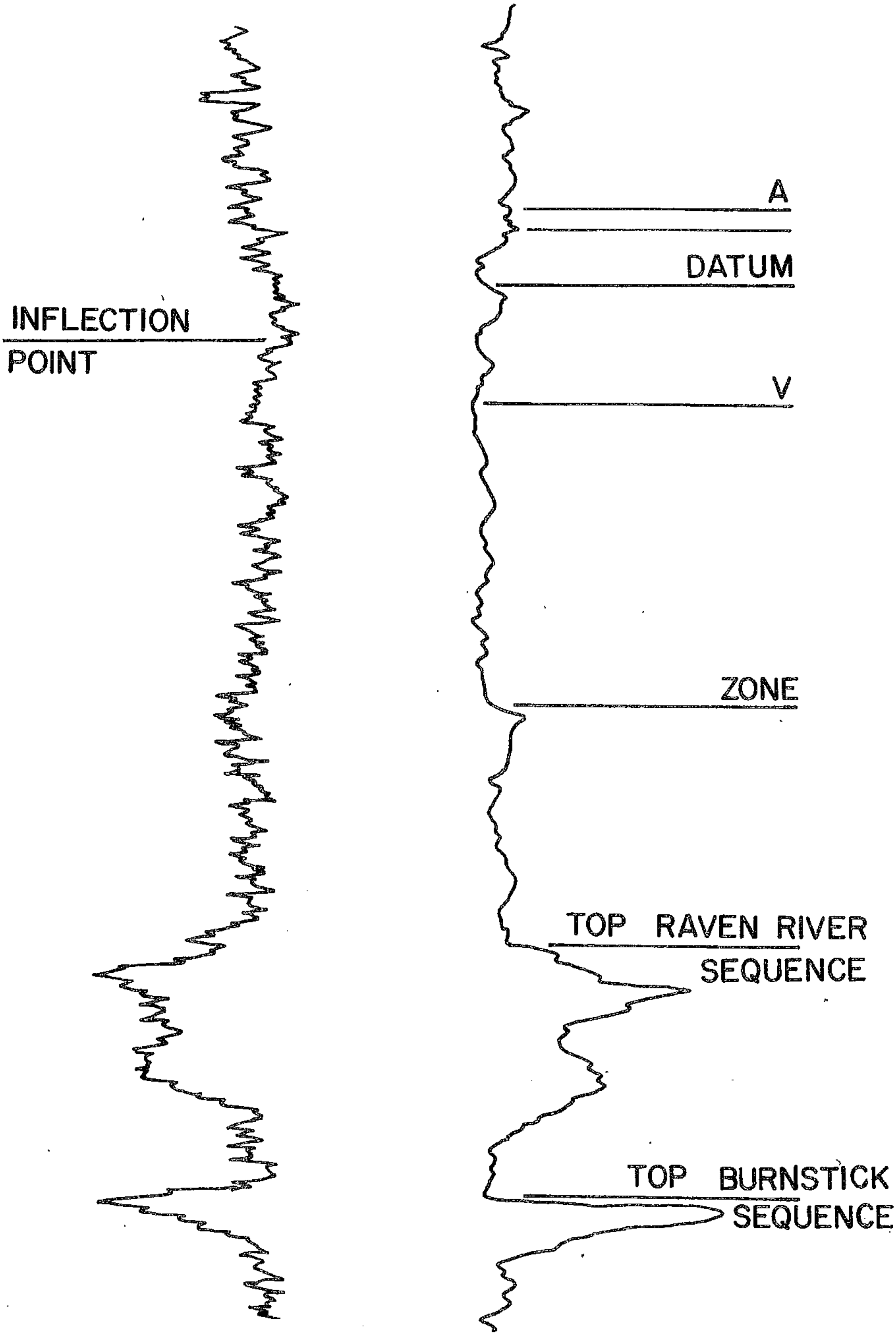
4.1 Introduction

The abundance of data provided by both cores and logs permits correlation between Lochend and Crossfield (to the west) and Caroline (to the north). These correlations illustrate the overall distribution of the Burnstick, Raven River and "zone" Sequences. Unfortunately the rather elongate, narrow nature of the productive sands at Lochend provides only enough data to construct one meaningful cross section through the length of the Lochend field. This section is extended to Caroline approximately 50 km to the north-west. Most of the logs through the this northern region were considerably older and more difficult to interpret than the logs closer to the field boundaries; however correlations were still made to give an overall view of the continuity of the sand sequences.

4.2 Log Marker Identification

The correlated cross sections are based on all available resistivity logs and gamma ray logs. The most obvious markers are identifiable on the resistivity logs. These have been named A, DATUM, V and ZONE (Fig 4.1). In the absence of resistivity logs, the overall pattern of the gamma ray log based on an "inflection point" and the ZONE marker has been used for correlation. The inflection point is identified on the gamma log as the change from a gradually increasing gamma ray response to a gradually decreasing gamma ray response. The position of the ZONE marker is readily identified on the gamma log but can be confirmed using the corresponding sonic log.

Figure 4.1 Log Marker Identification. This diagram depicts a typical log signature of the Cardium Formation in the Lochend Region. Labled are the marker horizons used for correlation A, DATUM, V, ZONE, as well as the inflection point which is represented on the gamma-ray log only.


INFLECTION
POINT
A
DATUM
V
ZONE
TOP RAVEN RIVER
SEQUENCE
TOP BURNSTICK
SEQUENCE

All sections are hung on the DATUM marker, which is a well defined feature on the resistivity log. The DATUM marker extends a considerable distance north of Lochend, at least as far a Caroline as well as eastward into Crossfield.

4.3 Cross Section No. 1

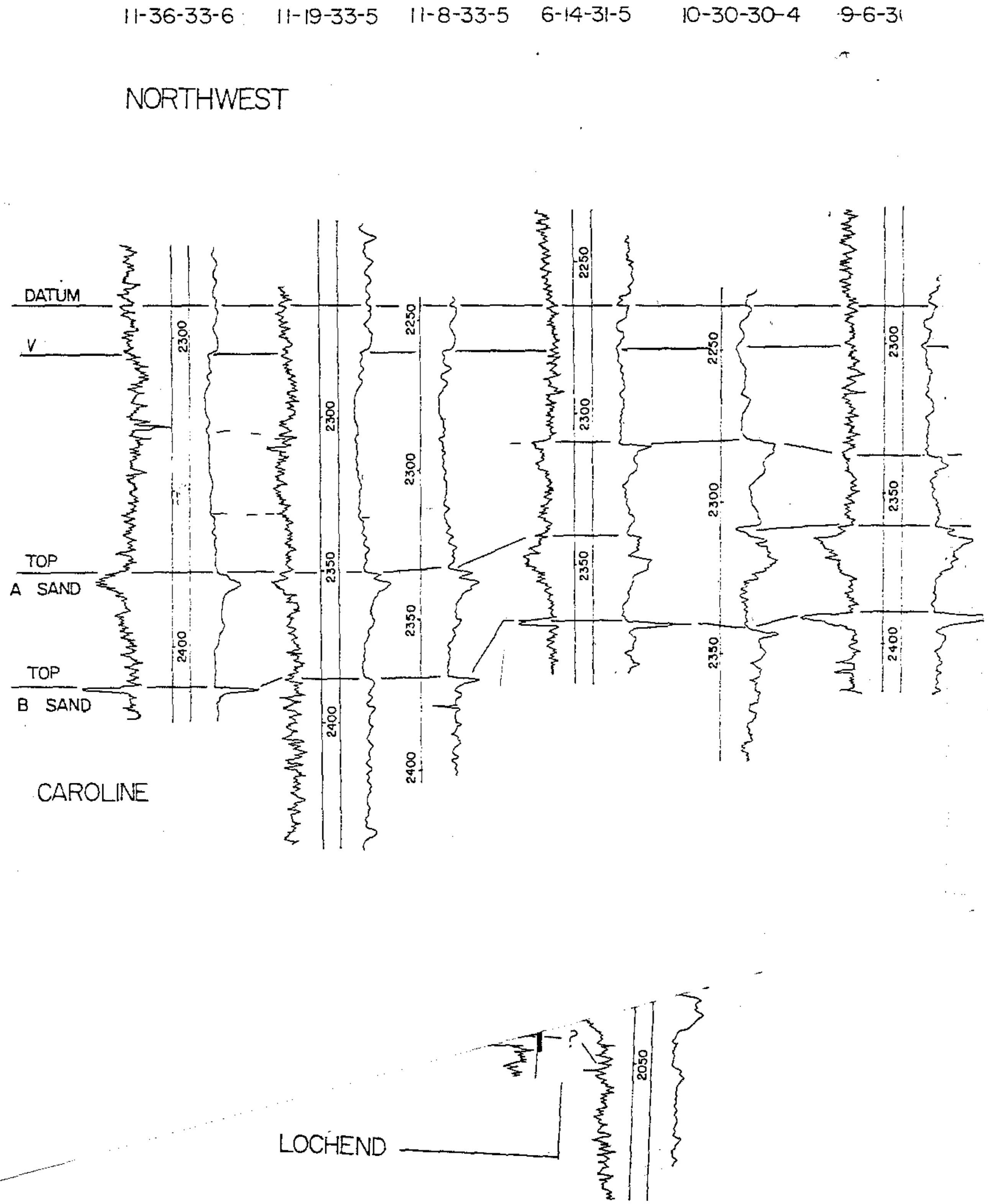
Cross section 1 parallels the north-west/south-east trend of the Lochend field. Well 10-36-26-3, the southern-most Lochend well, to 10-5-28-3 illustrates the relationship between the wells within the established Lochend field boundaries (according to ERCB, 1984). More recent data permits the extension of the Lochend field to the north, including wells 8-7-28-3 north-west to 11-36-33-6, to investigate the relationship between Lochend and Caroline.

The correlations shown in this cross section deserve considerable comment due to the relative subtlety of the log responses as well as the limited availability of data. The DATUM marker on the resistivity log is the most prominent feature and is consistent throughout the entire length of section. Where resistivity logs were unavailable (particularly in the older area within the original Lochend field boundaries), correlations are dependent on the overall pattern of the gamma ray logs and the ZONE. In order to confirm correlative gamma ray log patterns or trends, it was necessary to superimpose the tracing of one gamma ray log onto that of another well and directly match up the peaks and troughs of the gamma ray response.

Correlation (Figure 4.2)

Well 6-16-26-2 is considered to lie south of the established limit of Lochend in an "off-field" position. It has been

Figure 4.2 Correlation No. 1. This cross section parallels the northwest-southeast trend of the Lochend field. This section includes the Lochend field (10-36-26-3W5 to 10-5-28-3W5), the Lochend Extension (8-7-28-3W5 to 10-15-29-4W5) and continues northward to correlate with the southern-most tip of the Caroline field (11-36-33-6W5). This cross section is hung horizontally on the DATUM marker. The ZONE and the top of the Raven River and Burnstick Sequences have been correlated.



11-36-33-6
11-19-33-5
11-8-33-5
6-14-31-5
10-30-30-4
9-6-3
NORTHWEST
DATUM
V
TOP
A SAND
TOP
B SAND
CAROLINE
LOCHEND
2250
2300
2350
2400
2050
?

correlated with 10-36-26-3, the southern-most "on-field" well by superimposing the gamma ray log patterns. The ZONE marker was confirmed by the 10-36-26-3 sonic log. The gamma ray trends of the two wells match through the entire thickness above the Raven River Sequence to the top of the "zone". Correlations between 10-2-27-3 and 4-22-27-3 are straightforward. Well 4-27-27-3 lacks a resistivity log, hence correlation with adjacent wells is based on the position of the ZONE marker and superimposition of the gamma ray patterns. Well 10-32-27-3 has been correlated by superimposition of the gamma ray log with those of 10-5-28-3 and 4-27-27-3, as well as the position of the ZONE marker. Wells 10-5-28-3 to 9-6-30-4 can be correlated easily using the standard set of markers. Correlations of 10-30-30-4 northward to 11-36-33-6 is most easily achieved using the DATUM and V marker. The ZONE however is far less prominent.

4.4 Cross Section No. 2 and 3 (Figures 4.3 and 4.4)

Cross sections 2 and 3 run perpendicular to the northwest-southeast trend of the Lochend field. These cross sections run parallel to each other, extending northeastward from Lochend to include Crossfield. Both gamma ray logs and resistivity logs are used when available. The DATUM and markers A and V are easily recognized on the resistivity logs and therefore are used to correlate both cross sections for consistency.

4.5 Discussion

All Lochend logs clearly exhibit three major coarsening upwards cycles. That which is termed the B sand in industry terminology is the lowest-most stratigraphic coarsening upward

Figure 4.3 Correlation No. 2. This cross section runs perpendicular to the northwest-southeast trend of the Lochend field. This section runs northeastward from Lochend to include Crossfield. Correlation No. 2 parallels Correlation No. 3 which lies to the south. The DATUM marker is set horizontally. Markers A, V, and ZONE and the Raven River and Burnstick Sequences are correlated.

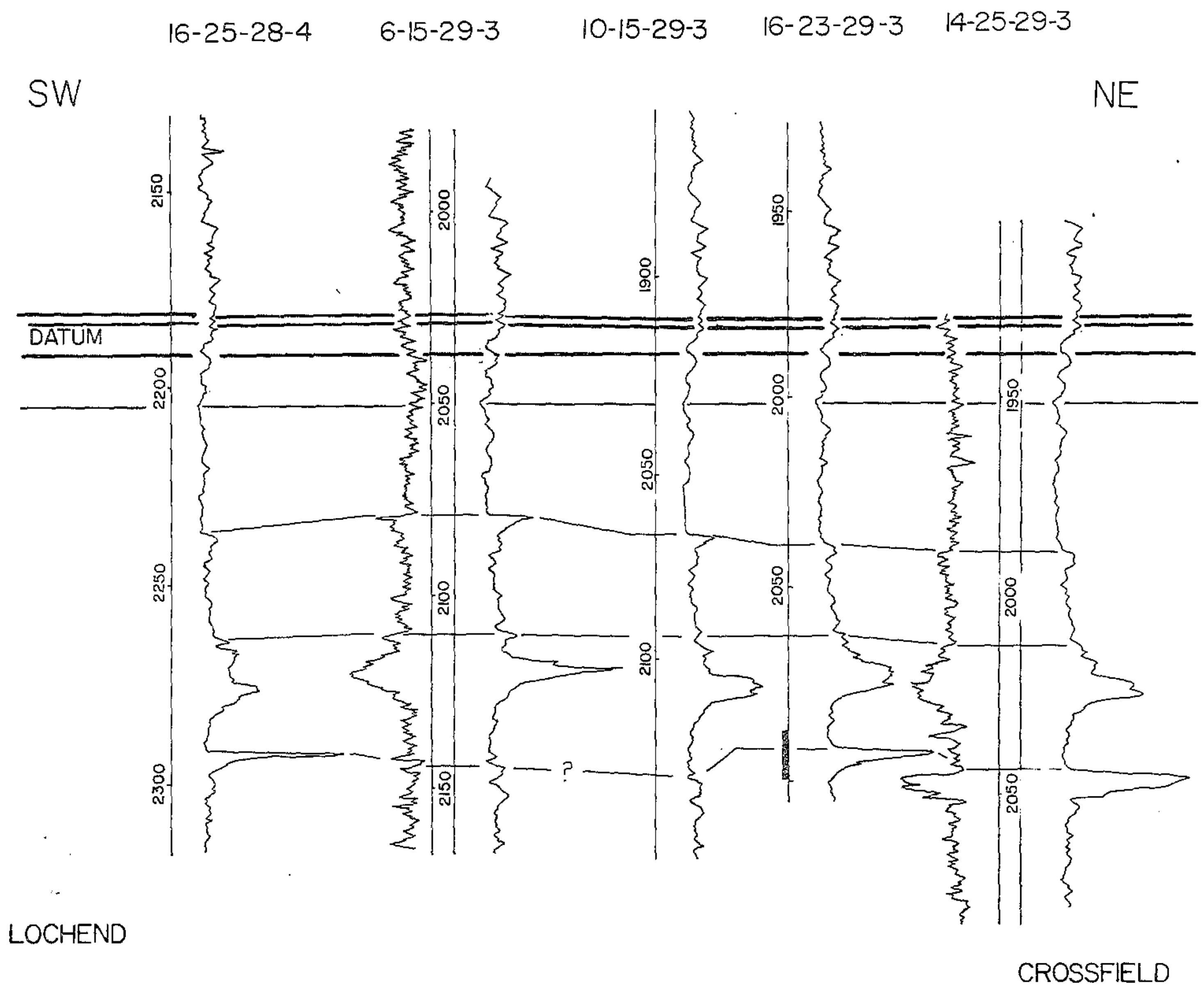
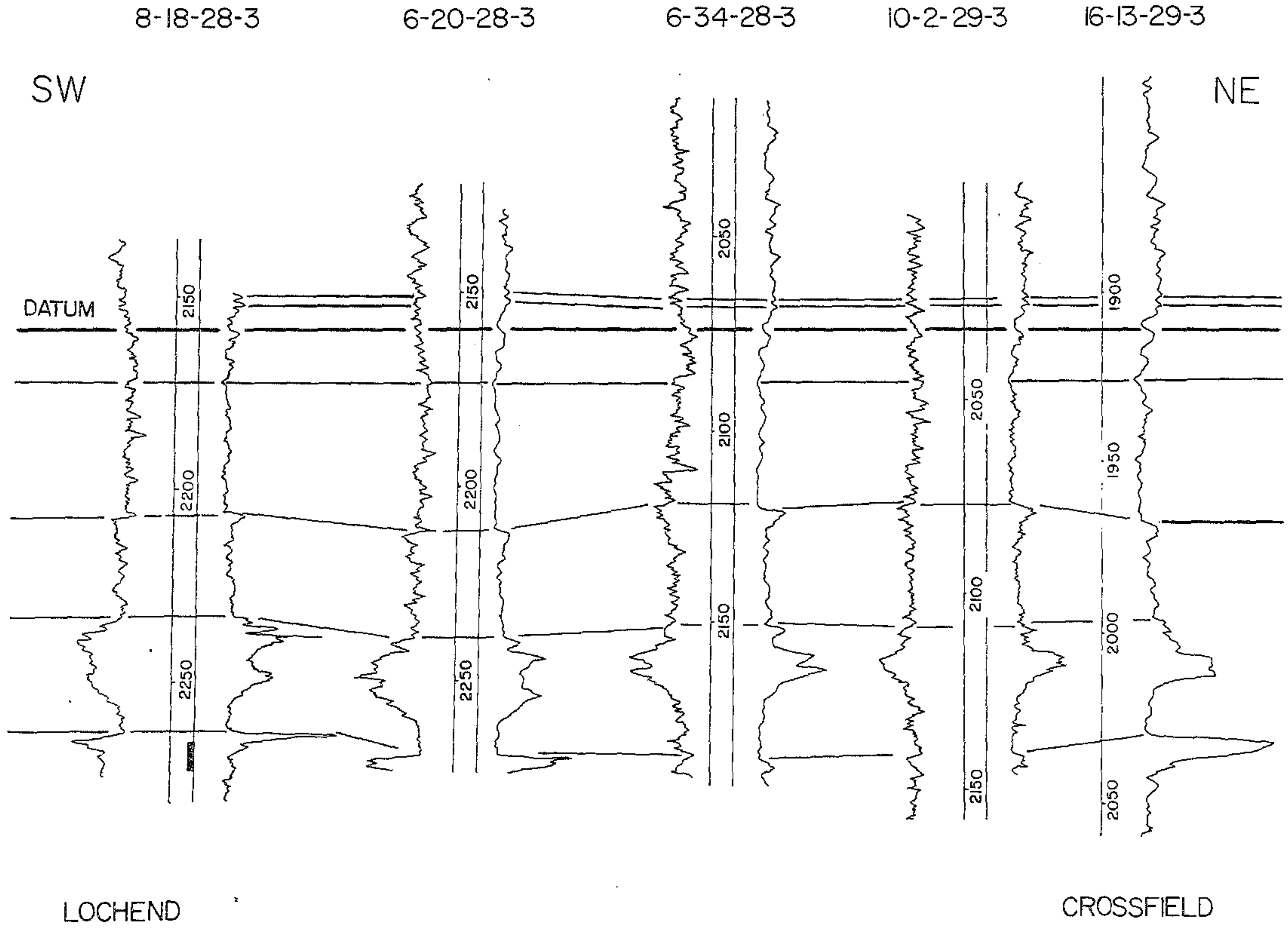

16-25-28-4
6-15-29-3
10-15-29-3
16-23-29-3
14-25-29-3
SW
NE
DATUM
2150
2200
2250
2300
2000
2050
2100
2150
1900
2050
2100
1950
2000
2050
1950
2000
2050
?
LOCHEND
CROSSFIELD

Figure 4.4 Correlation No. 3. This cross section runs perpendicular to the northwest-southeast trend of the Lochend field. This section runs northeastward from Lochend into Crossfield and lies parallel with Correlation No. 2 which is to the north. The DATUM marker is set horizontally. Markers A, V, and ZONE as well as the Raven River and Burnstick sequences have been correlated.


8-18-28-3
6-20-28-3
6-34-28-3
10-2-29-3
16-13-29-3
SW
NE
DATUM
2150
2200
2250
2150
2200
2250
2050
2100
2150
2050
2100
2150
1900
1950
2000
2050
LOCHEND
CROSSFIELD

cycle. This is directly correlative with the Burnstick Sequence as described by Walker (1983c). Stratigraphically above the Burnstick Sequence lies the second coarsening upward cycle, termed the A sand in the industry. Although the nonbioturbated sandstone facies 7 of the Raven River Member does not exist in Lochend core, the Raven River Sequence is clearly correlative with the A sand sequence from Lochend to the Caroline and Garrington region. These correlations can also be confirmed based on the DATUM on the resistivity logs. The DATUM marker extends into the Caroline field which permits confirmation of the relative stratigraphic levels of both the Burnstick Sequence and overlying Raven River Sequence with the coarsening upward cycles found at Lochend.

The overall resistivity and gamma ray log traces clearly illustrate the coarsening up nature of the Cardium sandstones. The correlated stratigraphic cross sections define the spatial distribution of the sands relative to adjacent Cardium fields.

Cross section 1 which parallels the northwest-southeast orientation of the Lochend field depicts the layer cake type stratigraphy of the Cardium sands throughout the length of the field. The prominent DATUM marker is set horizontally, markers A and V are equally horizontal from the southern-most Lochend well 10-36-26-3 northward at least as far as 9-6-30-4.

Based on original resistivity log measurements of the separation of the DATUM from the top of the "zone", it is apparent that the shales that overlie the "zone" thicken from a constant 42.5 m in the southern-most wells to 48.0 m from 10-15-28-3 northward through the Lochend extension. North of the

Lochend extension, the shales thicken at 9-6-30-4 to 50.0 m and thin to 44.0 m at 10-30-30-4 and 6-14-31-5 before the ZONE marker dies out such that further measurements were impossible. South of the Lochend field, both 10-36-26-3 and 6-16-26-2 wells show a marked thickening of the shales.

In the Lochend region the Burnstick Sequence provides the oil producing sands, therefore there is an abundance of core information for the Burnstick Member. Once the base and the top of a member is defined in core, this information can readily be extrapolated to the logs, making it possible to define the Burnstick Member thicknesses quite accurately. Since the Raven River Sequence is not frequently cored it was difficult to define the top and base of the sequence in the logs. Therefore the sand thickness measurements are restricted to the Burnstick Sequence.

The Burnstick Member ranges from 4.6 m to 7.0 m thick within the Lochend field. The thickness variations show no field wide trend but rather show a non-systematic thickness variation.

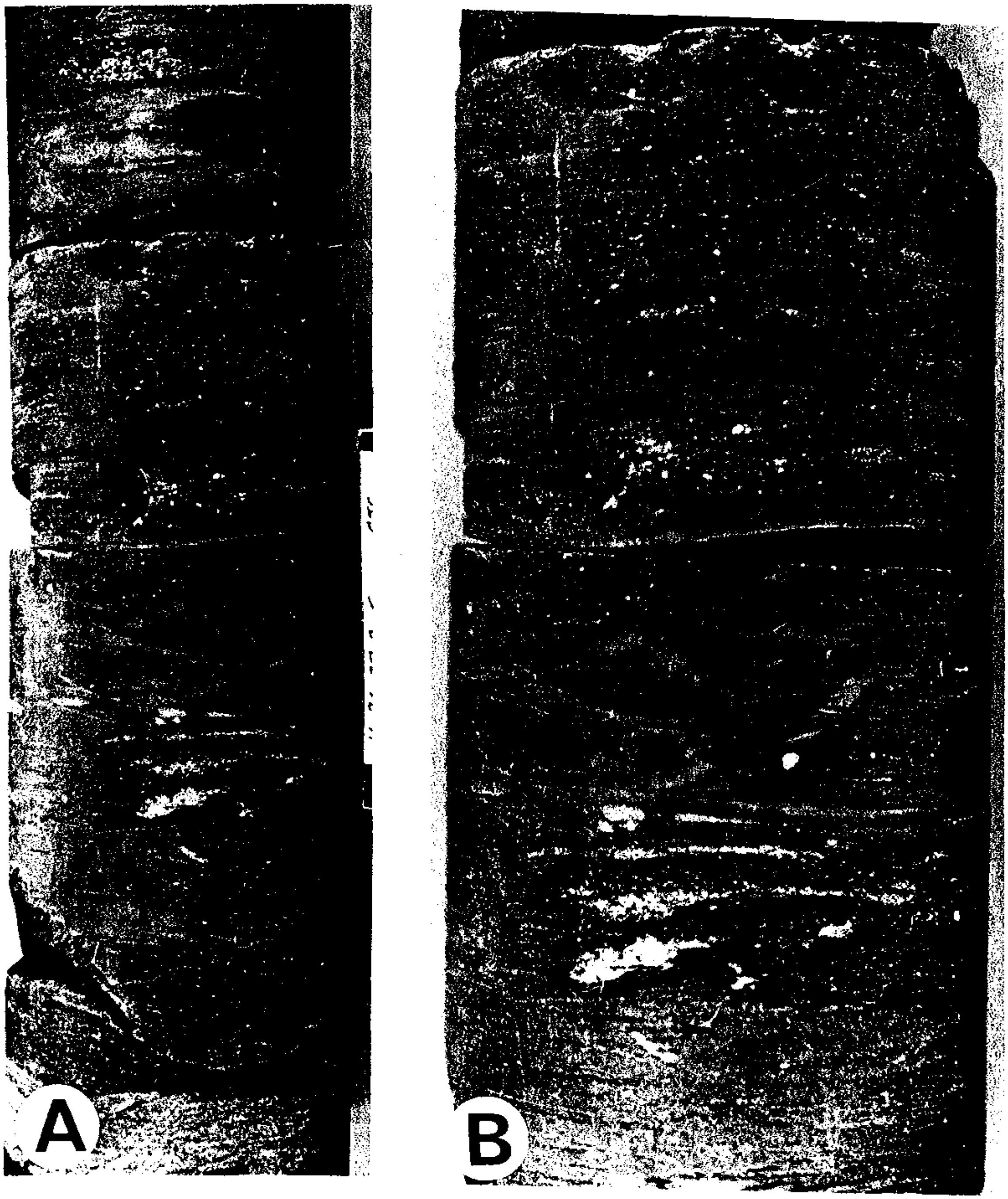
The "zone" to the top of the Burnstick Sequence separation shows a wide southerly "off-field" separation, it narrows "on-field" northwards to 10-32-27-3 before thickening by 6.0 m at 10-5-28-3. It continues at a constant 57.0 m separation northwards to 9-6-30-4 before it widens again off-field to 64.0 m.

The Raven River Member is correlative as a two cycle coarsening upwards sequence for the entire length of the cross section from south of Lochend to Caroline. The Burnstick Sequence is correlative as a single coarsening upward sequence only as far south as the Lochend field boundary at 10-36-26-3 continuously northwards to 11-8-33-5. At 11-19-33-5 the Burnstick Sequence log response is not well defined, however in the southern-most Caroline well the Burnstick Sequence reappears.

Cross sections 2 and 3 show similar sequence distribution patterns. The Raven River Sequence is continuous as two coarsening upward cycles at Lochend through to Crossfield where a third cycle might be interpreted from the logs (no core information was available).

The Burnstick Member which is well developed and productive at both Lochend and Crossfield is very poorly developed between these two fields. The log response shows a resistivity kick at the stratigraphic level equivalent to the Burnstick Member and is therefore termed the "inter-field Burnstick equivalent". This "ratty" response shows an equally "ratty" sand development composed of minor silt concentrations and granule pockets, (Fig. 4.5).

Figure 4.5 Inter-field Burnstick Equivalent. These photographs represent the "ratty" sand and silt development which lies at the same stratigraphic level as the Burnstick Member between Lochend and Crossfield. Well 16-26-27-3W5, 2329.7 m. This core is 76 mm (3 inches) wide.


A
B

CHAPTER 5: FACIES INTERPRETATIONS

5.1 Introduction

This chapter provides sedimentological interpretations for each of the facies described in Chapter 2. Although the gradational contacts between the facies suggests an interrelationship between the facies, each of the facies will be interpreted individually.

5.2 Facies 1 Massive Dark Mudstones

The massive mudstones of facies 1 contain no silt and show faint "stirring" by bioturbators, thus indicating an extremely low energy environment. This facies is a deep water indicator, probably the deepest water facies in all of the sequences described. The sediments show no sign of reworking or modification by wave or current action.

5.3 Facies 2 Laminated Dark Mudstones

The introduction of silt beds in ths facies indicates a slightly higher energy environment than that described for facies 1. The increases silt content may be indicative of a location closer to a clastic source. Alternately, the silt laminations may be representative of episodic input of sediment into a previously quiet environment similar to the one in which facies 1 was deposited.

5.4 Facies 3 Dark Bioturbated Muddy Siltstones

The most significant feature of this facies is the degree of bioturbation. Facies 3 appears to have a similar silt content to facies 2; however any silt laminae have been so thoroughly bioturbated that the remnants leave no indication of colour grading or internal lamination that would suggest original depositional processes. Presumably the environment was quiet enough and the deposition rate slow enough such that the bioturbators could completely rework the sediment.

5.5 Facies 4 and 5 Bioturbated Mudstones and Sandstones

These tow facies are very similar in terms of their high degree of bioturbation. The feature that distinguishes these facies is the increased sand content in facies 5 relative to facies 4. The sandier facies 5 very gradationally overlies facies 4.

In facies 4 the recognizable burrow traces include Zoophycos, Planolites, Terebellina and Skolithos. In the sandier facies 5 Teichicnus, Chondrites, Zoophycos and Planolites were observed.

According to Pemberton and Frey (1984), the traces occurring in facies 4 and 5 are typical of the Cruziana ichnofacies assemblage which is indicative of a moderately to low energy environment below daily wave base but above storm wave base.

5.6 Facies 6 Speckled Gritty Mudstone

This facies closely resembles that of facies 4 and facies 5 with the addition of chert granules to give it its speckled texture.

There are a number of hypotheses which could account for the occurrence of the granules within this facies. The first would assume that the granules, muds and sands flowed together as a debris flow and upon deposition was thoroughly bioturbated. A second hypothesis involves the deposition of the granules onto a very soft and wet muddy substrate. The addition of new material causes slight flowage and subsequently mixing of the granules throughout the mud (Crowell, 1957).

A final hypothesis involves the introduction of granules into a sandy mud facies. Thorough bioturbation of the sand, mud and granule mixture results in the random dispersal of the granules and the speckled texture as observed.

5.7 Facies 7A Interbedded Unbioturbated Sand and Mud

The well preserved nonbioturbated sands of this facies show very sharp bases implying sudden emplacement onto the underlying muds. The sandstone beds exhibit well defined ripple cross laminations that are often capped by a symmetrical topography. The undulatory topography of the sand bed is subsequently draped by mud. The sand beds were presumable sharply emplaced producing the unidirectional ripple cross laminations. A decrease in the flow velocity allows for the preservation of the ripple topography. Subsequently the flow dies off completely resulting in the resumption of mud deposition in a low energy environment.

5.8 Facies 8A Clast Supported Conglomerate

The conglomerates lack any stratification, imbrication or other textural clues other than crude sorting which would provide a basis on which environmental interpretations can be made. The base of the conglomerate is usually a gradational change from facies 6 which has a predominantly muddy matrix in the Burnstick Sequence and similarly gradational from facies 5 in the Raven River Sequence.

The occurrence of the conglomerates at Lochend as well as areas further north provide little sedimentary information making the interpretation of this facies difficult.

5.9 Facies 8B Mud Supported Conglomerate

The abrupt introduction of mud on top of facies 8A indicates a rapid return to a deeper environment where the deposition of marine muds is a daily occurrence. The gravels of this facies are consistently consistently concentrated at the base of the unit and diminish to nothing within 20 cm upward. Assuming that the muds represent the constant dailt sediment accumulation, the gravel distribution can be accounted for by biological reworking of the gravels from the underlying unit upwards through the mud. Alternately, the gravels could have been introduced into the soft mud environment as a debris flow. The momentum of the flow causes mixing of the gravels throughout the muddy facies similar to that described for facies 6.

CHAPTER 6: CONCLUSIONS

6.1 Sand Body Geometry

1. The B sand sequence is correlative with, although not continuous with the Burnstick Sequence at Caroline and Garrington. The Burnstick Member at Lochend is directly correlative with the same member in the northern Cardium fields.

2. The A sand sequence is both correlative and continuous with the Raven River Sequence at Caroline and Garrington. The Raven River Member defined as nonbioturbated sand in the Caroline region, is absent at Lochend. However, the continuity of the log response as well as the similarity in facies sequences confirms its correlation.

3. The Burnstick Member occurs in discrete elongate pods at Lochend, Caroline and Crossfield.

4. The Raven River Sequence is continuous as a "ragged blanket" throughout the area at least as far north as Caroline and as far east as Crossfield.

5. The "zone" sequence is continuously correlative throughout the study area as a 2 cm gravel layer which produces a consistently pronounced log signature.

6.2 Sedimentology

Most of the facies in the Lochend region are heavily bioturbated. The preservation of ripple cross lamination, the only sedimentary structure, is restricted to 4 cm beds within a single facies. This perhaps suggests a much lower depositional rate than for those fields immediately north where sedimentary structures are well preserved particularly at the northern most locations of the fields.

6.3 Discussion

The occurrence of the conglomerates in the Cardium Formation at Lochend remains problematic. There are at least three explanations that could possibly account for the existence of the clast supported conglomerates within the described stratigraphic sequences.

The first involves incremental geostrophic storm flows. The conglomerate transport is the result of flows set up by storm winds. The wind forces water on shore, creating an elevation of the water surface and hence a seaward pressure gradient. The resulting seaward flow is deflected by the Coriolis force (to the right in the northern hemisphere) resulting in a geostrophic flow parallel to the isobaths. This flow is sufficient to transport pebbles incrementally to their off shore depositional location.

A second explanation is gravel transport by storm generated turbidity currents. This hypothesis, presented by Walker (1983a,b,c) was based on the occurrence of several features in fields north of Lochend. These features included sharp based erosively emplaced sandstone beds with associated Bouma (1962) ABC sequences. There is, however, no positive evidence to support this explanation at Lochend. The sands show no evidence of scouring or eroding into the underlying units. Also, there are no sedimentary features (such as graded bedding) evident, in any of the Lochend cores.

The final possibility would be to explain the conglomerates as a transgressive lag. The conglomerates consistently lie at the top of a coarsening upwards sequence, which is overlain by vast thicknesses of marine muds. The implication of this, particularly for the "zone" conglomerates, would be the erosion of huge volumes of material at one horizon which cannot, as yet, be accounted for. Also, the uniformity of the log response implies the extension of the 2 cm of "zone" conglomerates to areas as far away as Carrot Creek some 300 km to the north of Lochend.

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