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SEDIMENTOLOGY OF THE VIKING FORMATION AT CRYSTAL FIELD, ALBERTA

Sedimentology of the Viking Formation, at Crystal Field, Alberta.

by

Elizabeth Jane Barr

A Thesis

Submitted to the Department of Geology

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ABSTRACT

The Crystal field is found in townships 45 and 46 in the ranges 3 and 4W5. The field differs from other Viking fields by being smaller, thicker, elongate in a north-south direction, and is conglomeratic.

Cross-sections of the well logs and lithologs show four extensively bioturbated, sandier-upward cycles that occur on a regional scale in the study area. The cyclic nature of these sediments may be due to distant, unknown aggrading shorefaces, possibly associated with minor relative sea level fluctuations. At Crystal, the cycles are cut out at various levels by an asymmetrical erosion surface. In the west-central area of the field there are two possible surfaces that may be equivalent to the main erosion surface. All of the erosion surfaces have been interpreted as being bases of incised shorefaces. The shoreface movement may be due to fluctuations in the relative sea level.

In the western side of the field, lithologs show the sand above these erosion surfaces as being predominantly laminated with a low-angle of inclination and/or laminated that grades into bioturbated tops. Toward the eastern side of the field, the sand gradually becomes more cross-bedded and pebble-rich. The sediment above the erosion surfaces is interpreted as preserved upper to mid shoreface deposits.

The top of the Viking at Crystal may be another erosion surface due to a major transgression.

Acknowledgements

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CHAPTER ONE

1.1 Introduction

This thesis is part of a regional study of the lower Cretaceous Viking Formation in the Western Interior Seaway. Viking sand bodies consist of long, linear sand ridges or bars encased in marine muds. These ridges have been recognized and studied in other formations such as the Cardium (Stott,1963) and the Shannon (Tillman and Martinsen,1984). These formations contain sand ridges with coarsening-upward sequences that are capped by a sandstone and conglomerate, and they appear to have formed tens of kilometers away from a time-equivalent shoreline. The time-equivalent shoreline for the Viking is unknown, but the sand ridges of this formation superficially resemble the Cardium and Shannon.

The Viking sand ridges are encased in marine muds suggesting an obvious possibility that they were initially deposited several kilometers from shore. These sand ridges also are gradationally rooted in these offshore muds and coarsen upward to a sandstone or conglomeratic cap.

If these ridges were deposited offshore :

1. how did the sediment move across the shelf? and
2. what process(es) focussed the sediment into the long, narrow ridges?

To answer these questions, a process is needed that transports and focuses the sediment on the shelf. It is also necessary to have a mechanism that can move gravel great distances and deposit it on the previously formed ridge. Thus, it is necessary to consider shelf processes and how they transport sediment.

1.2 Shelf Processes

Swift et al (1971) divided shelf currents into the following :

1. intruding oceanic currents
2. tidal currents
3. geostrophic currents
4. density currents

These processes act separately or together to move sediment on the shelf.

Intruding oceanic currents are very rare on the modern shelves and when present the oceanic currents do not introduce new sediment onto the shelf (Flemming,1978). The intruding oceanic currents do not represent a common transport mechanism in the Western Interior Seaway since the Seaway was a relatively shallow sea. Intruding oceanic currents are found on shelves that lie within oceans that would be much deeper then the cratonic seas.

Tidal currents are generated by the cyclic rise and fall of sea level due to the gravitational forces between the moon, the sun, and the earth. The sand bodies deposited by these currents are commonly dominated by medium to large scale cross-stratification.

Geostrophic currents are generated by pressure gradients which are the result of differing water elevations. In the northern hemisphere the Coriolis Force turns bottom flows to the right, and the flow moves toward being parallel to isobaths. Sediment is transported incrementally by such geostophic flows during the storms that generate the differing water levels.

Turbidity currents are the result of gravity acting on a density difference due to the suspension of sediment. The current moves sediment seaward, across isobaths, over long distances.

Although these currents do move sediment across the shelf, there are various drawbacks in using the currents to explain sand ridge creation. Geostrophic and turbidity currents probably deposit the sediment they are transporting as a sheet, and not as long, linear ridges. More importantly would be the problem of generating the turbidity current on the shelf. The slope of the cratonic shelf would be extremely low compared to the slope necessary to generate a turbidity current. Tidal currents are not known to focus sediment on the shelf, or even move it beyond fair-weather wave base. Above fair-weather wave base, the sand deposited by the tidal currents can be reworked by wave action. The sand deposit then resembles wave deposited sediment and not tidally deposited sediment.

Various interpretations of the sand ridges use these currents to explain the formation of the linear bodies, but the interpretations also involve shoreface movement due to sea level fluctuation. The currents keep the same relative position on the shoreface in each stage of movement.

Research on the Upper Cretaceous Cardium Formation has shown the effect of sea level fluctuations. With the rise or fall of the sea, there is a corresponding trangression or progradation of the shoreface. With each stage of movement, a new shoreface is established, with the previously discussed processes eroding, transporting and depositing sediment. The final result seen in the Cardium is prograding shoreline sequences, major scoured surfaces, transgressive horizons, and horizons of non-deposition marked by gritty siderite.

The idea of sea level fluctuations has recently been used in Viking research, as well as in Cardium. Although some interpretations employ sea level fluctuations to explain some of the Viking fields, the idea of sea rise and fall does not necessarily explain the creation of the Viking Crystal field. This field is approximately 30m thick, conglomeratic, and elongate in a north-south direction. Other Viking fields are areally larger and are 5m or less in thickness, and are oriented in a northwest -

southeast or westnorthwest - eastsoutheast direction.

Since the Crystal field is smaller,thicker, and oriented in a different direction then other Viking fields,previous interpretations of Crystal are controversial, as are the interpretations of the regional Viking depositional environment. Cross-sections of the Crystal field show a "channel - like" feature. The problem is to define the geometry of this feature.

1.3 Purpose

The purpose of this thesis is to study the sand geometry and facies relationships of the Viking Formation at the Crystal field. With this information a possible depositional environment of the field will be discussed. Since Crystal differs from most other Viking fields, its origin will also be discussed relative to the new ideas of sea level fluctuations and shoreface incision.

1.4 Method

During the summer of 1986, twenty-nine cores were logged at the ERCB Core Research Centre. These cores were divided into facies and facies sequences. With the cores, two hundred well logs were examined. Together, the cores and well logs were put into cross-sections of the Crystal field to show the sand geometry.

Isopach maps were also constructed to show the topography on the lowermost erosion surface.

CHAPTER 2

REGIONAL VIKING STRATIGRAPHY AND DEPOSITIONAL INTERPRETATIONS

2.1 Stratigraphy

The Early Cretaceous (Late Albian) Viking Formation is underlain by the Joli Fou Formation and overlain by the Lloydminster Formation (fig.2.1). Viking equivalents include the Newcastle and Muddy Formations of Montana and Wyoming.

The base of the Viking Formation is identified as the base of the sandstone or sandy shale overlying the Joli Fou Shale. The top of the formation is a black, chert-pebble stringer or chert-rich sandstone. The Viking Formation from central Alberta toward the east and northeast, thins and becomes finer-grained until it disappears as a sandstone unit. This also suggests Cordilleran thrust sheets as the main source of sediment for the Viking.

Within the Late Albian, the Joli Fou Formation and the Lloydminster Formation are characterized by the presence of the forams <u>Haplophragmoides gigas</u> and <u>Miliammina manitobensis</u> respectively (fig.2.2). At this time no characterizing forams have been identified in the Viking Formation.

At Crystal field, the Viking Formation lies far enough away from the thrust zone that it is undisturbed by faults and dips less than one degree to the southwest.

Figure 2.1

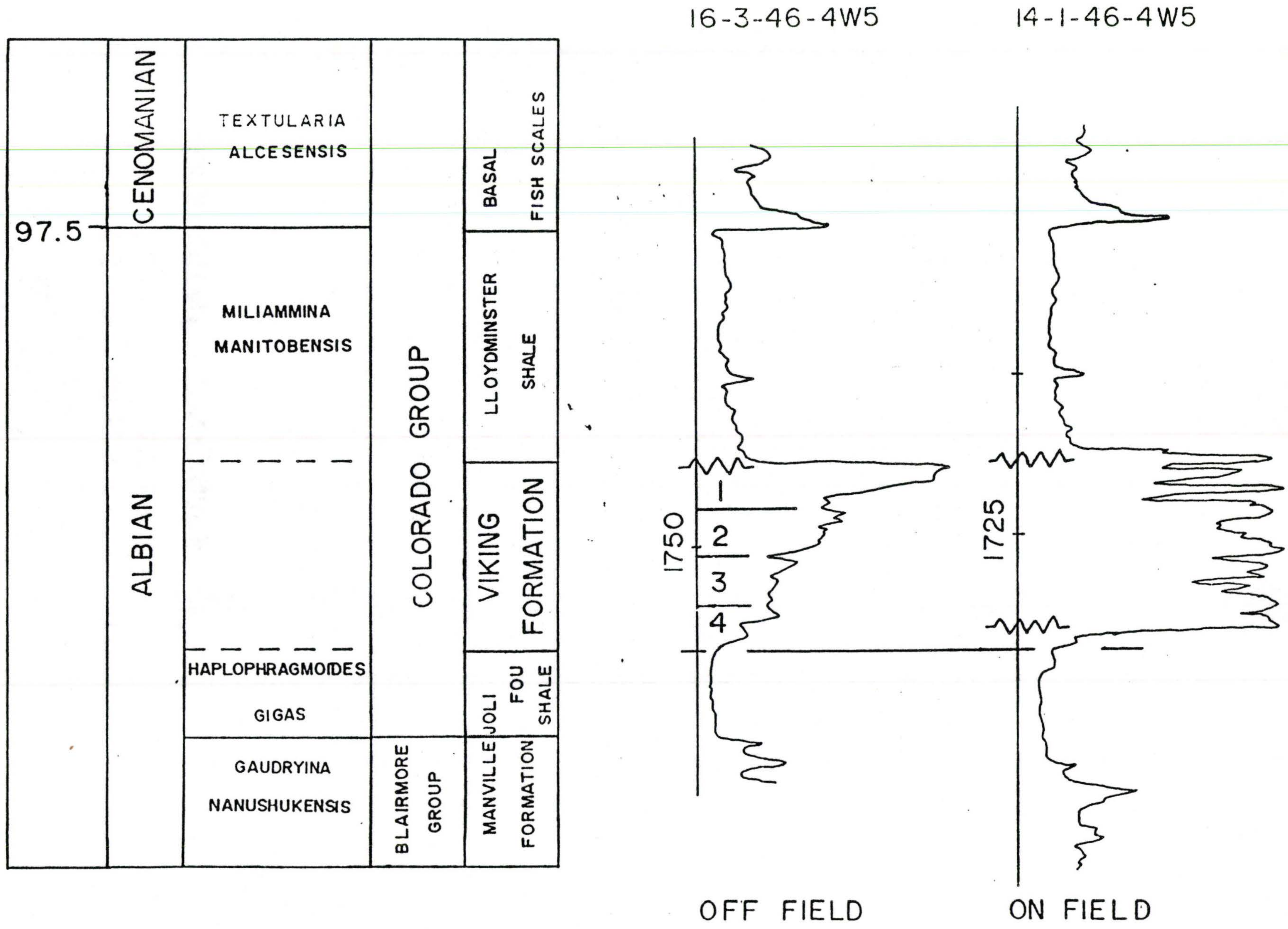
Stratigraphy of the Viking Formation of Central Alberta
The chart shows the stratigraphy of the Viking Formation in Central Alberta and its equivalents in Montana and Wyoming.

Central Alberta	Montana	Wyoming
Basal Fish Scales	Mowry Shale	Mowry Shale
Lloydminster Shale		Shell Creek Fm
Viking Fm	Newcastle Sandstone	Muddy Sandstone
Joli Fou Shale	Skull Creek Shale	Thermopolis Shale

Figure 2.2

Viking Stratigraphy at Crystal

The diagram illustrates the stratigraphy of the Viking Formation at Crystal and the relation with the well log responses on and off the field. The resistivity log response of well 16-3-46-4W5 was chosen because it represents the response of the four sandier-upward sequences that occur outside the field. The resistivity log response of well 14-1-46-4W5 was chosen to represent onfield responses since it shows the blocky nature of the log. It also shows the lower surface that represents the base of the field. This is shown as the lower jagged line. Both wells show the top of the Viking as a surface. This is the upper jagged line. Both wells also show the first deflection at the base of the Viking Formation. This deflection was used as the datum in cross-sections. The lithostratigraphy and biostratigraphy are discussed in the text.


97.5
CENOMANIAN
ALBIAN
TEXTULARIA ALCESENSIS
MILIAMMINA MANITOBENSIS
HAPLOPHRAGMOIDES GIGAS
GAUDRYINA NANUSHUKENSIS
COLORADO GROUP
BLAIRMORE GROUP
BASAL FISH SCALES
LLOYDMINSTER SHALE
VIKING FORMATION
JOLI FOU SHALE
MANVILLE FORMATION
16-3-46-4W5
14-1-46-4W5
1750
1725
1
2
3
4
OFF FIELD
ON FIELD

2.2 Interpretations of Viking Deposition

2.2.1 Turbidity Currents and Storms

In 1955, **Beach** suggested that the Viking Formation was deposited by turbidity currents as the result of the Crowsnest volcanism to the west. The same volcanic activity supplied the volcanic ash to the basin to form the bentonite layers. Beach also noted the rounded nature of the pebbles and their large size distribution. The rounded nature and size of the pebbles was explained as being due to weathering and rounding by stream and wave action acting on the sediment on the newly exposed Upper Rundle in the thrust sheets. Although Beach explains a possible method for getting the sediment onto the shelf, he fails to explain how the sediment was shaped into the linear sand ridges.

Koldijk (1976) concluded that at the Viking Gilby "B" field, the pebbles were moved as a pavement by severe storms. Koldijk postulated a shoal extention from the Joffre-Bentley-Gilby trend that localizes the pebble pavement, but he offers no explanation of the shoal's creation.

The sediment-gravity flow was introduced again in 1986 by **Hein et al.** In this interpretation of Caroline, Garrington, and Harmattan East fields, there was submarine erosion into a shoreface-attached clastic wedge and conglomeratic sedimentary-gravity flows filled in the scour. This deposit of sediment was then reworked into sandwave complexes and sheet-like deposits. This interpretation, like Beach's, offers no explanation on the currents that reworked the sediment into the linear sand bodies.

2.2.2 Tidal Currents

This interpretation was first introduced by **Evans** in 1970. He suggested the progradation of a shoreface with associated shore and offshore bars, as well as strong tidal currents. In the Dodsland-Hoosier area the shore and offshore bars form the Viking fields trending northwest - southeast and the tidal currents reworked the sediment to form the fields trending westnorthwest - eastsoutheast.

Leckie (1986) used the same idea of tidal currents to suggest the formation of tidal shelf complexes at the Caroline field. The shelf complexes are due to a shore progradation.

2.2.3 Effects of Sea Level Fluctuations

DeWiel (1956) first suggested a prograding shoreline in the formation of the Viking sand ridges. With a drop in sea level the feeders of sediment would have been shifted to the east. The ridges were formed by the supply of clastic material being distributed by longshore currents.

More recently, **Bergman and Walker** (in press) has shown the effects of sea level rise and fall in the Cardium Formation at Carrot Creek field. At the base of the Carrot Creek conglomerate is an erosion surface with topography. The topographic elements include a terrace, a bevel, then an area of bumps and hollows. These features are due to a rapid relative drop in sea level followed by a gradual rise with erosional shoreface retreat by wave scouring.

This idea of erosional shoreface retreat has been used to interpret Viking deposition at Joffre (**Downing**,1986) and at Gilby (**Raddysh**,1986). Both of these interpretations involve sea level fluctuations and the incision of a shoreface to form the fields.

Beaumont (1984,p.171) suggested that a regressive sea brought sediment out onto the shelf as deltaic deposits. With the rise in sea level "shoreface erosion of sediment...supplied sand to the shelf that was subsequently restructured into linear sand bodies, such as Joffre and Joarcam Fields, by the shelf hydraulic regime." In this interpretation, Beaumont does not explain what he means by "restructured", nor how it takes place.

2.3 Interpretations of Viking Deposition at Crystal

Reinson (1986) concluded that sea level dropped and eroded a channel in the lower shoreface - inner shelf deposits. During the following, continuous transgressive event, there were stillstands that filled the channel with four separate estuarine, tidal, channel-fill events.

2.4 Study Area

The Crystal field is found in townships 45 and 46 in the ranges 3 and 4W5 (fig 2.3). It was discovered in the fall of 1978 with a gas well at 6-7-46-3W5. In 1979, 3-8-46-3W5 was drilled and completed as an oil well. This led to a re - evaluation of 6-7-46-3W5 and it had oil reserves. In 1981, 13-5-46-3W5 was drilled and produced oil, and with its discovery, drilling began in earnest. The recoverable reserves are estimated at 5.8×10^6 m^3 from two separate pools, A and H. Ninety-six per cent of the reserves are from pool A.

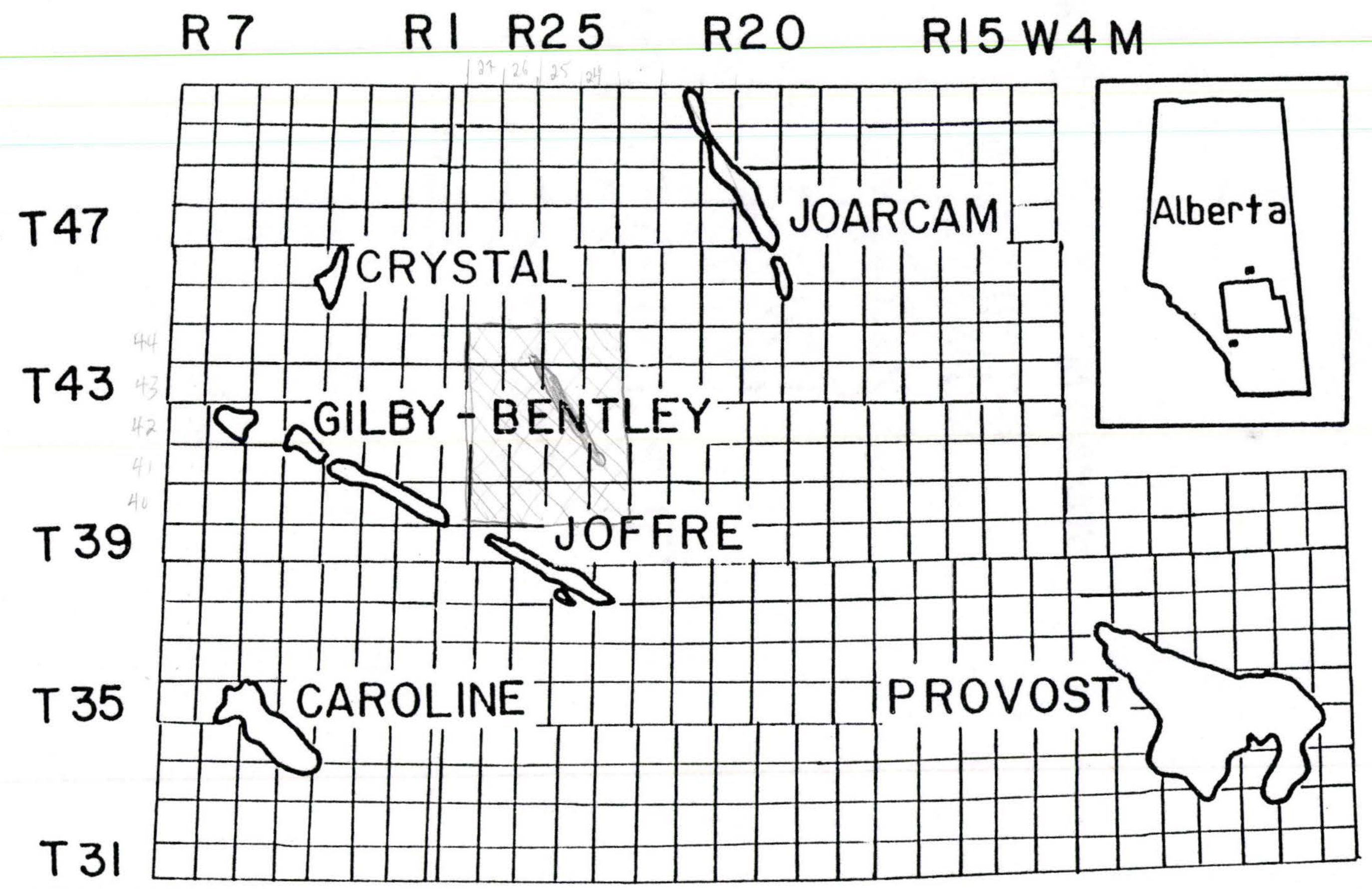
Crystal is different from other Viking fields since :

1. it is 30 m thick and elongate in a north-south direction. Other Viking fields are larger and are 5 m or less in thickness. These are oriented in a northwest - southeast or a westnorthwest - eastsoutheast direction.
2. the oil-bearing fields are two separate pools, each with its own gas cap. There is also some overlapping of the pools.
3. it is conglomeratic.

Figure 2.3

Location Map of Crystal Field

This map gives the location of Crystal field with respect to other major Viking fields in the area. Crystal is located in the upper left hand corner of the map in townships 45 and 46, ranges 3 and 4W5. The map shows one of the differences between the Viking at Crystal and the Viking at other fields. This difference is the north-south trend of the Crystal field, whereas other Viking fields trend northwest-southeast or westnorthwest and eastsoutheast. The location of the paleo-shoreline for the Viking Formation is unknown at this time.


R 7
R 1
R25
R20
R15 W4M
27
26
25
24
T47
T43
T39
T35
T31
44
43
42
41
40
JOARCAM
CRYSTAL
GILBY - BENTLEY
JOFFRE
CAROLINE
PROVOST
Alberta

CHAPTER 3

Facies Descriptions

3.1 Introduction

The measurement and description of each core studied began with the division of the rock into a series of units. These units were separated by a distinct or gradational change in the lithology. Once separated by lithology, each unit was then given a more detailed study. This involved the measurement of grain size, the identification of sedimentary structures, the degree of bioturbation, and the identification of recognizable trace fauna. This method was used for logging twenty-nine cores. The final result is the classification of ten facies based on lithology, sedimentary structures, and characteristic trace fauna. The following are the facies descriptions :

3.2 Facies 1 : HORIZONTAL TO LOW-ANGLE INCLINED LAMINATED SAND

This facies consists of clean, well-sorted, fine-grained, laminated sand. The laminations are 2-10mm thick, and occur in sets 10-75cm thick. Cosets consist of one to four sets. Within each set, the laminae are parallel to each other, and lie parallel to regional bedding or are inclined up to 5°.

The stacked sets are separated by either black mud partings 1-5cm thick or one set will scour into the one below it. In the latter case, the scour may be marked by the presence of siderite clasts 7mm-5cm, and/or thin, wispy mud clasts 2-10cm long. If these clasts are present, they will occur in structureless sand up to 11cm thick.

In the former case, where the sets are separated by mud partings, the laminated sands may show a gradation into rippled sands, up to 5cm thick. Each ripple set is on the scale 1-2cm.

Trace fossils of this facies are _Ophiomorpha_, _Diplocrateria_, _Rhizocorallium_, _Rosselia_, and _Teichichnus_ within the sand. The mud partings have the trace fossils _Skolithos_ and _Planolites_.

3.3 Facies 2 : LAMINATED SANDS TO BIOTURBATED MUDS

These are sharp based fine sands that may be structureless and/or laminated and grade into rippled sand and finally a bioturbated mud and sand. The sandstone to bioturbated mudstone units average 5-40cm in thickness.

When present, the structureless sands occur at the base of the unit and are up to 3cm thick. More commonly the units start with sand which contain parallel and flat laminations 2-5mm thick. Within the entire unit, the laminated sand ranges from 4-35cm in thickness. The rippled sands comprise 2-4cm of the unit, with each set having a scale of 2-3cm. The bioturbated mud and sand that cap the unit is 50% - 60% mud and 3-20cm thick. Trace fossils include _Skolithos_, _Teichichnus_, _Planolites_, and _Thalassinoides_ all within the

Figure 3.1

A: Facies 1 **Horizontal to low-angle inclined laminated sand**

The photo shows the thin laminations that are parallel to each other and are either flat or inclined up to 5. The core is from 11-6-46-4W5 at 1757m depth.

B: Facies 1 **Horizontal to low-angle inclined laminated sand**

The photo is an example of the low angle intersections of the laminated sands. This is not a very common feature. The core is from 8-11-46-4W5 at 1730m depth.

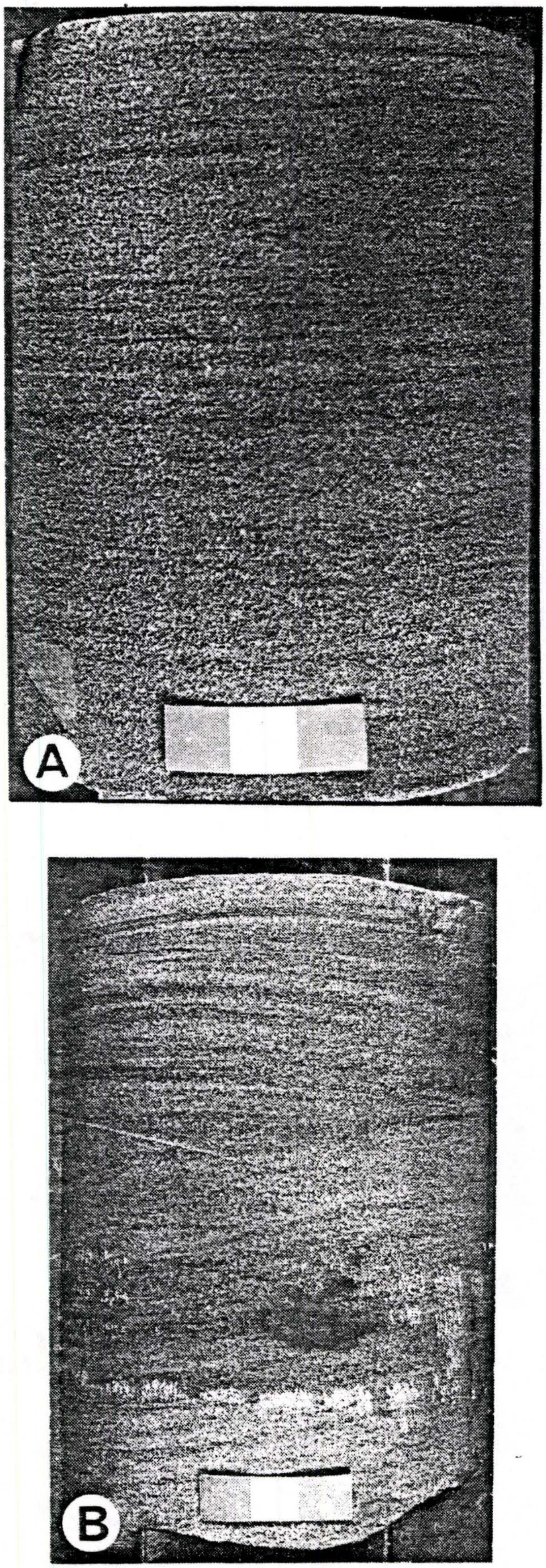
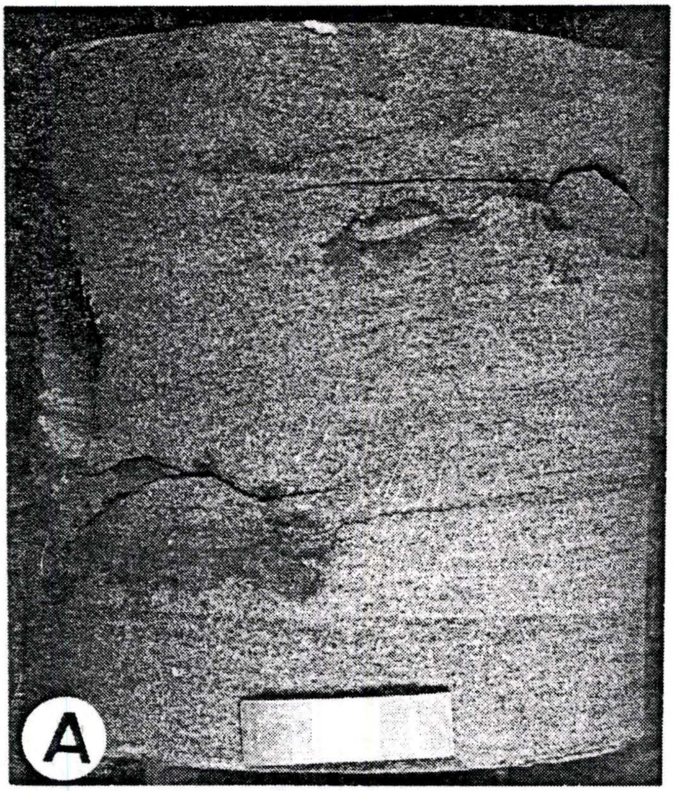

A
B

Figure 3.2 **Common Trace Fauna of Horizontal to low-angle inclined laminated sand**

A: The sand of this photo shows an example of an Ophiomorpha burrow. It recognized as the irregularly shaped, mud-lined circle that has been filled with sand. The core is from 2-31-45-3W5 at 1796m depth.

B: The sand of the photo shows an example of a Diplocraterion burrow. It is recognized as a mud-lined, U-shaped burrow. The core is from 11-12-46-4W5 at 1715m depth.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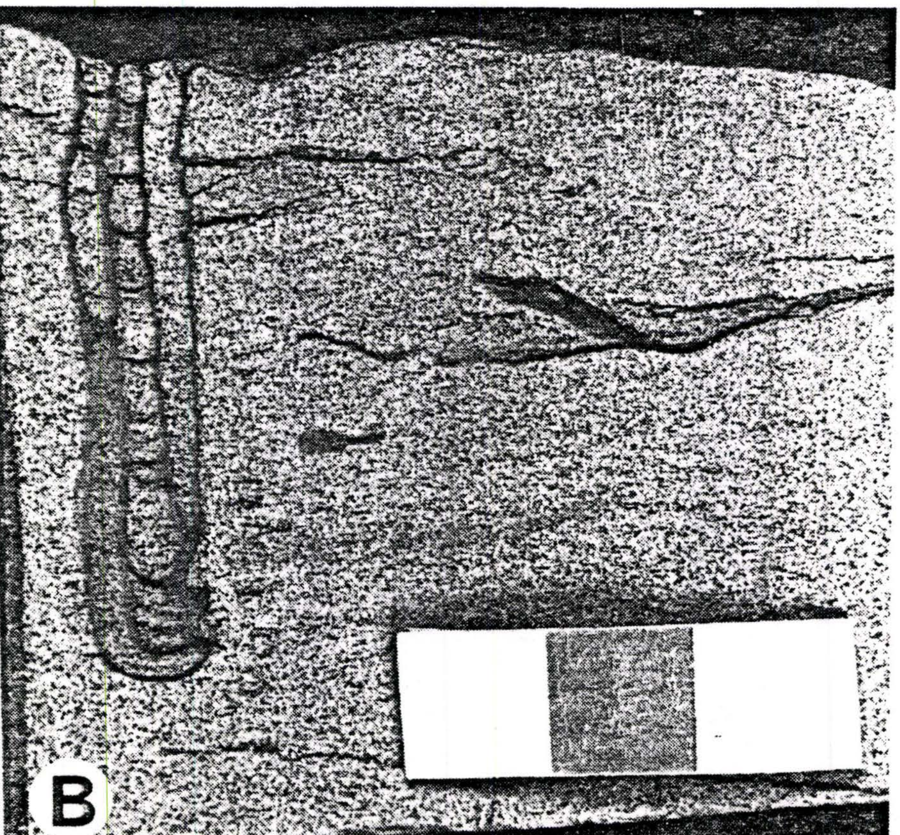

B

muds.

3.4 Facies 3 : CROSS-BEDDED SAND

This facies consists of fine to coarse-grained trough cross-bedded sand. Individual sets are 15-50cm thick and cosets consist of one to five sets. Within each set are foresets 1-2cm thick defined by grading of clean sand. Within any one set, the dip increases upward from about 10° to 33°, suggesting they are trough crossbeds rather than planar tabular crossbeds.

The stacked units are separated by either mud partings 1-5mm thick, or a scoured surface with siderite clasts 2-37mm long. This facies may stack upon itself or with the laminated sand units.

3.5 Facies 4 : CROSS-BEDDED SPECKLED SANDSTONE

This facies consists of clean, well-sorted, fine to medium-grained sand with granules. The unit ranges from 5-40cm in thickness. Bedding, dipping at 5° to 20°, is defined by layers of disc-shaped granules that are 1-15mm in diameter. From bottom to top, the granule layers increase there separation and with this there is a decrease in the granule content. This decrease is commonly from 60% granules to 20% granules.

Figure 3.3

A: Facies 2 **Laminated sand to bioturbated mud**

This photo shows the sharp base of the laminated and flat sand that occurs at the base of each unit of this facies. The laminated sand grades upward into ripple structured sand. Each unit of the facies is capped by the bioturbated mud and sand. The core is from 8-2-46-4W5 at 1778m depth.

B: Facies 4 **Cross-bedded speckled sandstone**

The photo shows the fine to medium grained sand with layers of clasts defining the bedding planes. The bedding planes are inclined $5^{\circ}-20^{\circ}$. The core is from 14-1-46-4W5 at 1726m depth.


A

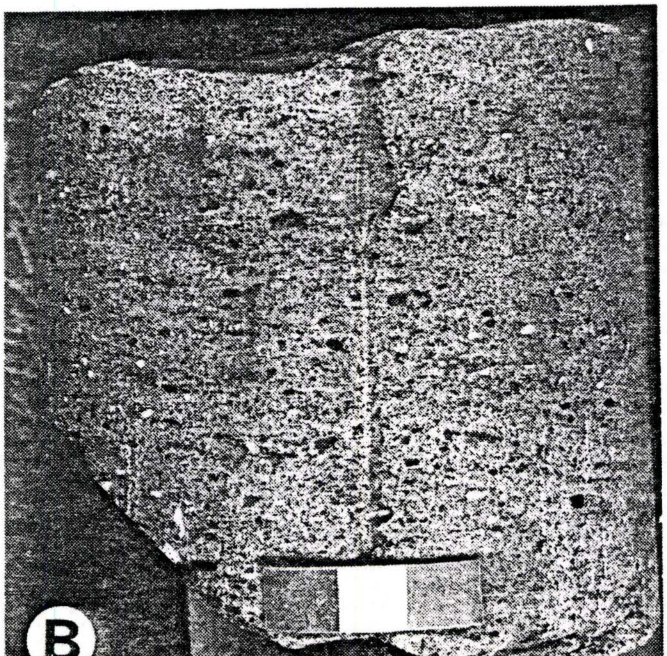

B

Figure 3.4 Facies 3 **Cross-bedded sandstone**

A: This photo of the cross-bedded sandstone is an example of the coarse-grained clasts. The foresets are defined by normal grading of the clasts. The core is from 10-18-46-3W5 at 1715m depth.

B: This photo of the cross-bedded sandstone is an example of the fine-grained clasts. The definition of foresets by normal grading is less obvious with respect to the coarser grained. The photo illustrates the increase in dip from the bottom of each unit toward the top. The increase is normally 10° to 30°. The core is from 11-6-46-3W5 at 1756m depth.


A

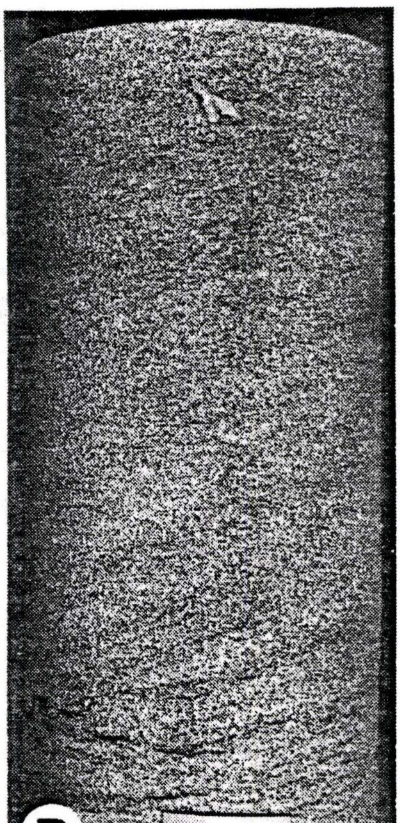

B

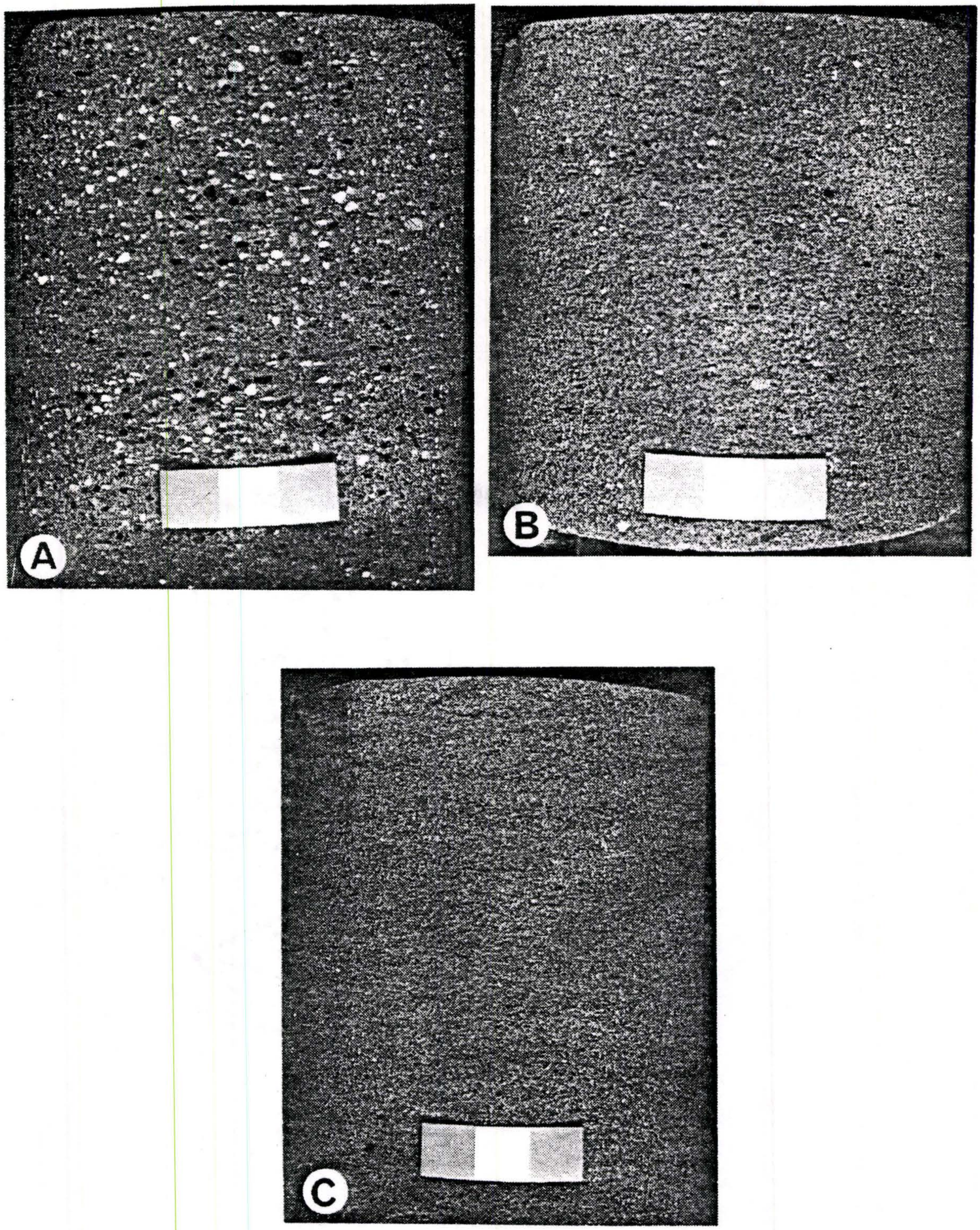
Figure 3.5

Facies 5 **Structureless speckled sandstone**
The three photos are of core from 11-6-46-3W5. They illustrate the gradational change from bottom to top within each unit of this facies.

A: This photo is of the basal part of the facies. It contains approximately 70% granules that are randomly scattered throughout the fine-grained sand. In the well this is at 1753m depth and grades into...

B: This photo is of the middle part of the facies. It contains fewer granules, but the random scattering is still recognized. In the well this is at 1750m depth and grades into...

C: This photo is of the upper part of the facies. It is structureless fine to medium-grained sand that has no granules. In the well this is at 1747m depth.


A
B
C

3.6 Facies 5 : STRUCTURELESS SPECKLED SANDSTONE

This facies is well-sorted, clean, fine to medium-grained sand with scattered granules that do not define bedding. The granules commonly occur as discs 1-11mm diameter.

Beds range in thickness from 1.4 to 3m and show a decrease in proportion of granules from about 70% at the base to 20% closer to the top. The unit commonly loses all granules and grades into a structureless sand, 0.5 to 2.4m thick.

3.7 Facies 6 : CONGLOMERATE

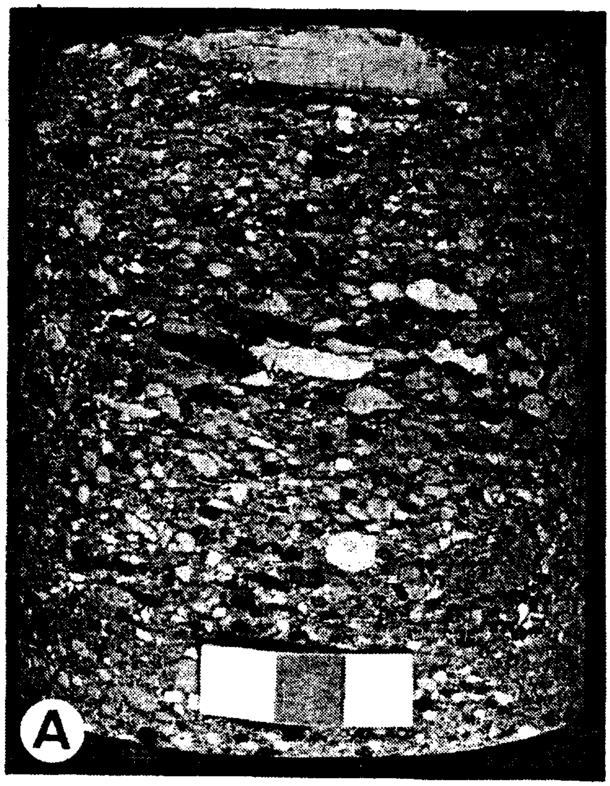
This facies consists of poorly-sorted, clast supported chert and quartz pebbles, with fine to medium-grained sand occurring interstitially. The beds are usually 0.3 to 4m in thickness and show a fining upward in the pebble size. The clasts within the beds range from 1mm to 5cm, are well-rounded, and occur disc-shaped and rarely blade-shaped. The clasts usually define bedding planes at 15° to 20° in units 1-2m thick, but the beds also occur structureless and/or chaotic in units 2-4m thick. There is also the rare occurrence of an inversely graded unit that is 0.5-0.8m thick. The facies is usually associated with facies 7.

The rare blade-shaped clast lies oblique or parallel to the dip direction.

Figure 3.6

A: Facies 6 **Conglomerate**
This facies is clast supported discs with fine to medium-grained sand occurring interstitially. The photo shows the clasts defining bedding planes at 15° -20°. In other cases the conglomerate is chaotic and structureless. The core is from 11-6-46-3W5 at 1751m depth.

B: Facies 7 **Conglomerate and sand**
This facies is interbedded layers of sandstone and conglomerate. It should be noted that the clasts define bedding planes at 15°-20°. This is in both the conglomeratic and sand layers. The core is from 16-1-46-4W5 at 1719m depth.


A


B

3.8 Facies 7 : SANDSTONE AND CONGLOMERATE

This facies consists of clean, well-sorted, fine-grained sand interbedded with 4-15cm thick pebble beds. The total thickness of the beds ranges from 0.7 to 2m.

The pebble beds consist of disc-shaped clasts, 1-11mm in diameter, that are clast-supported with fine to medium sand occurring interstitially. These pebble beds define bedding planes that either lie horizontal or are inclined up to 15° to 20°.

The sand interbeds generally look structureless, but occasionally there is a slight appearance of being laminated.

There is no evidence of dish structures or fluid escape structures suggesting dewatering of these sands.

3.9 Facies 8 : BLT SANDWICH

This sandwich of three beds marks the top of the Viking Formation in this area. From bottom to top, the sandwich is composed of :

B : BASAL CONGLOMERATE

This is a fine to medium-grain sand supporting chert and quartz pebbles 2-30mm in size. These pebbles may be discs or blades. The bed is 3-50cm thick and appears structureless. In two cores, the pebbles were mud-supported.

L : LAMINATED SHALE BLANKET

This layer consists of fine sand and mud that occur in

Figure 3.7

Facies 8 **BLT sandwich**
The three photos are of core from 14-1-46-4W5 and show the three layers that lie at the top of the Viking Formation in the study area.

A: <u>B= Basal conglomerate</u>
The photo shows the lowermost layer of the sandwich. It is poorly-sorted and structureless. In two cores this conglomerate is mud-supported (fig.3.8). In the well this is at 1712m depth.

B: <u>L= Laminated shale blanket</u>
The photo shows the intermediate layer of the sandwich. Note the lenticular nature of the layers of mud and sand. In the well this is at 1711.5m depth.

C: <u>T= Top sandstone</u>
The photo shows the uppermost layer of the sandwich. It shows the poorly-sorted nature and trough cross-beds that characterize the layer. In the well this is at 1711m depth.

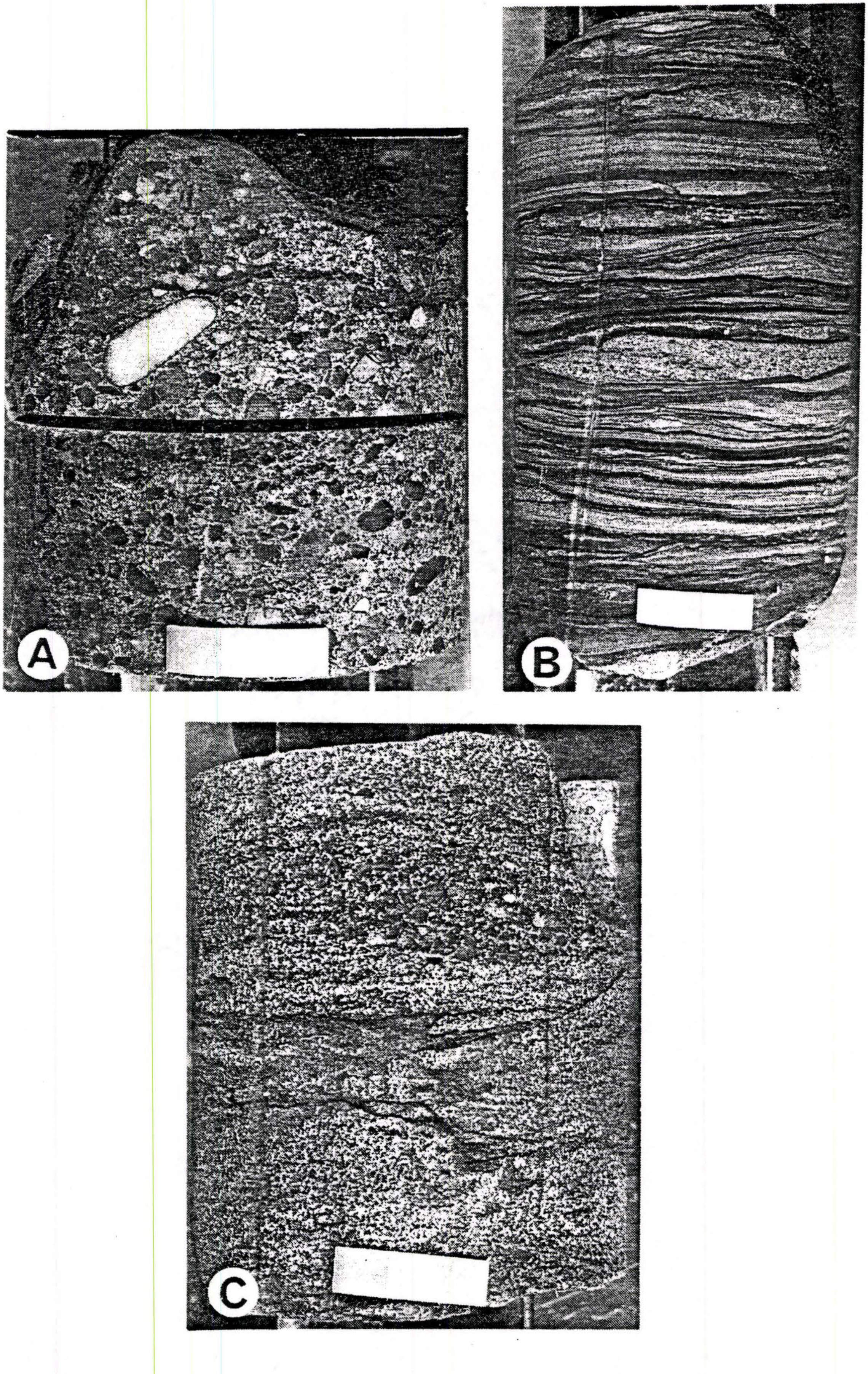
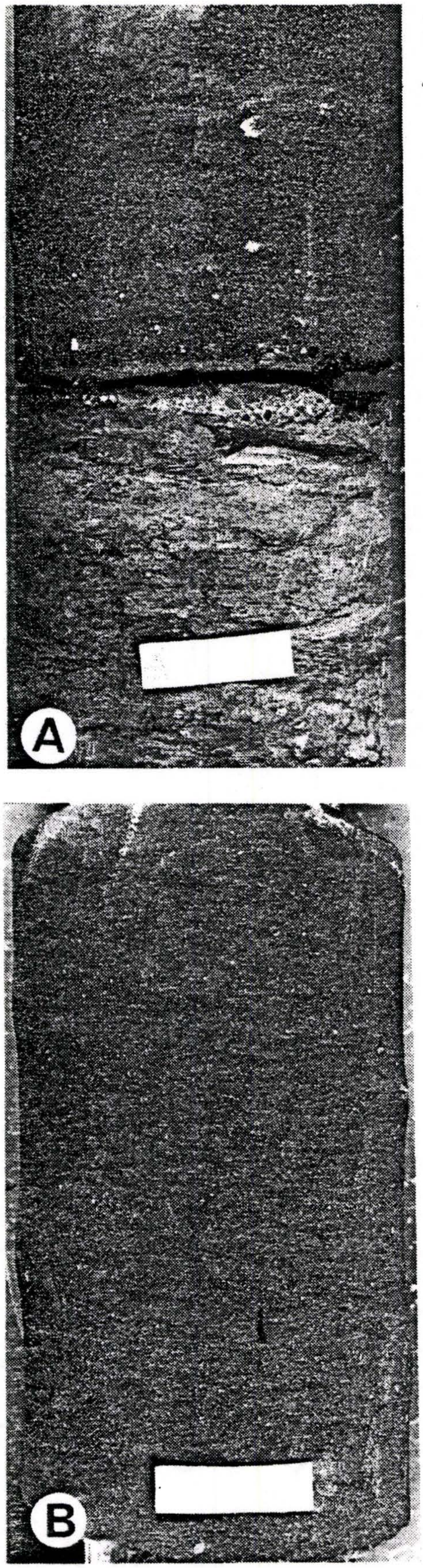

A
B
C

Figure 3.8 Facies 8 **BLT sandwich**

A: This photo shows the contact of the mud-supported lower basal conglomerate of the BLT sandwich. This occurrence of the facies is to the east of the field where the A surface is eroding out entire sandier-upward cycles. The core is from 6-30-45-2W5 at 1681m depth.

B: This photo is illustrating how the basal conglomerate of the BLT sandwich occurs to the east of the field. This is as mud-supported grit and granules. The core is from 6-30-45-2W5 at 1680m depth.


A
B

lenticular beds 1mm to 3cm thick. The silt comprises 30% to 50% of the unit and occasionally shows preserved wave structures on the scale 1-2cm. In some cores the silt beds contain granules up to 7mm diameter.

T : TOP SANDSTONE

This bed marks the top of the sandwich and underlies the Lloydminster Shale or subfacies 9A. It is a poorly-sorted, coarse, trough cross-bedded sand. The beds 2-5cm thick appear structureless, but the thicker (5-30cm) beds show cross-bedding, with foreset dips of 20° to 30°.

3.10 Facies 9 : **BLACK MUDSTONE**

This facies is a black mud with thin layers of silt up to 3cm thick and 1-3cm apart. The silt layers have a sharp base and a fuzzy gradational top, and some have preserved wave structures.

Within the mud is carbonaceous material, coal fragments, and fish scales. The fish scales also occur as concentrated layers up to 1mm thick.

3.11 Facies 9A : **BLACK MUDSTONE WITH GRANULES**

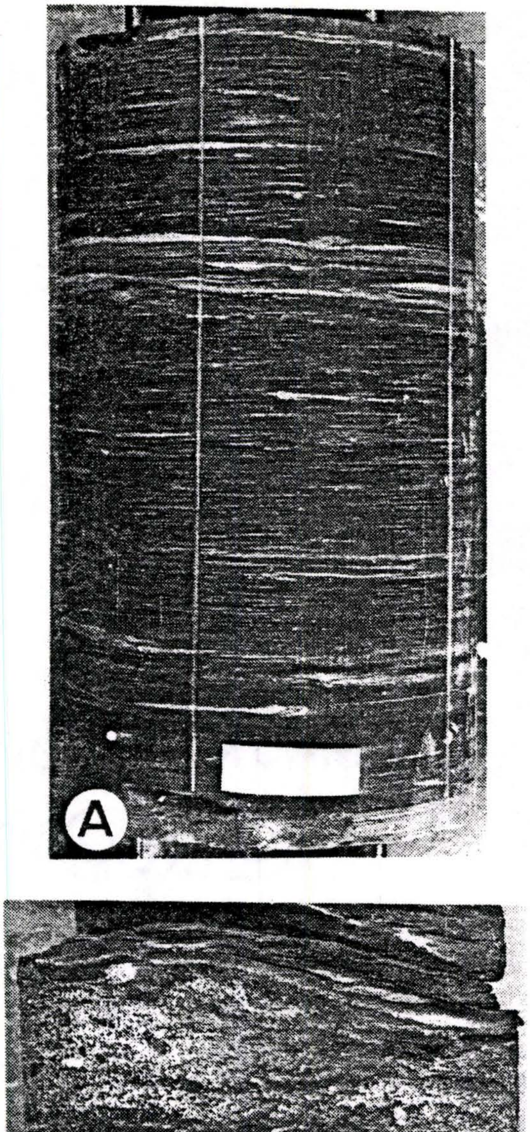
When present this facies directly overlies the BLT sandwich. It is similar to the black mudstone facies, but differs by the presence of granules 1mm to 3cm diameter.

The granules can occur in beds 1-3cm thick or as random scatterings within the mud. The facies ranges 15-130cm in

Figure 3.9

A: Facies 9 **Black Mudstone**
This photo is of the black mudatone that is above the BLT sandwich. It represents the Lloydminster shale. The core is from 10-18-46-3W5 at 1712m depth.

B: Facies 9A **Black Mudstone with granules**
This is the same as facies 9 except that there are coarse clasts present. The facies onlaps the A surface and occurs to the east of the field. The core is from 6-30-45-2W5 at 1679m depth.


A
B

thickness, with coarser beds occurring every 5-14cm.

3.12 Facies 10 : BIOTURBATED MUD AND SAND

This facies consists of extensively bioturbated mud and fine sand. It has two occurrences, one outside the channel feature and the other inside.

In the first occurrence the sand content increases from 5% to 90% in four separate cleaning upward cycles. These cycles occur regionally and are cut out at various levels by the previously described facies. The cycles are numbered one to four from the top downward. Each cycle usually shows the same trace fauna. There is the rare case of cycles one and two gradationally loosing their trace fauna and primary sedimentary structures are preserved. Usually this is the laminated to bioturbated mud facies and the laminated sand facies.

The bioturbated mud and sand facies also occurs above the lowermost erosion surface, within the channel feature. The beds range from 0.5 to 8m in thickness. Each bed may have either a constant mud proportion (70% to 80%) from the bottom to top or there may be a gradational change to more mud, followed by a decrease in mud.

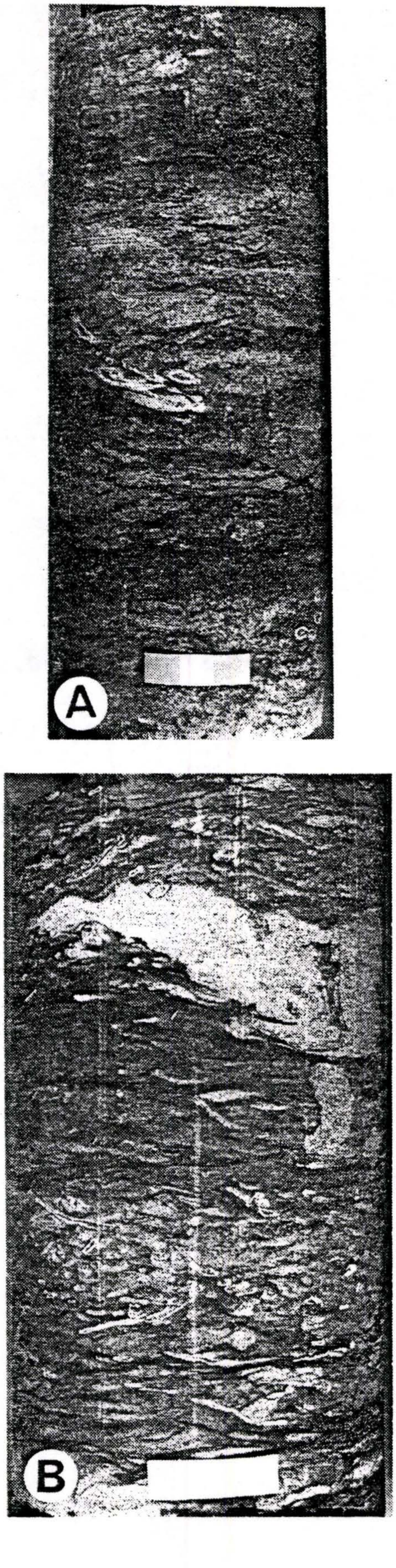
The beds of this occurrence are usually extensively bioturbated, but in some cases there is preservation of horizontal lamination and/or wave structures within sand layers,4-9cm thick. With increasing sand content there is a

Figure 3.10 Facies 10 **Bioturbated mud and sand**

This figure is showing two examples of the bioturbated mud and sand. One is from inside the field between the B1 and B2 surfaces. The other is from outside the field.

A: This photo is of a core outside the field, or below the B surface. It is from 14-28-45-4W5 at 1811m depth.

B: This photo is of a core inside the field, or above the B2 surface. It is from 8-11-46-4W5 at 1745m depth.


A
B

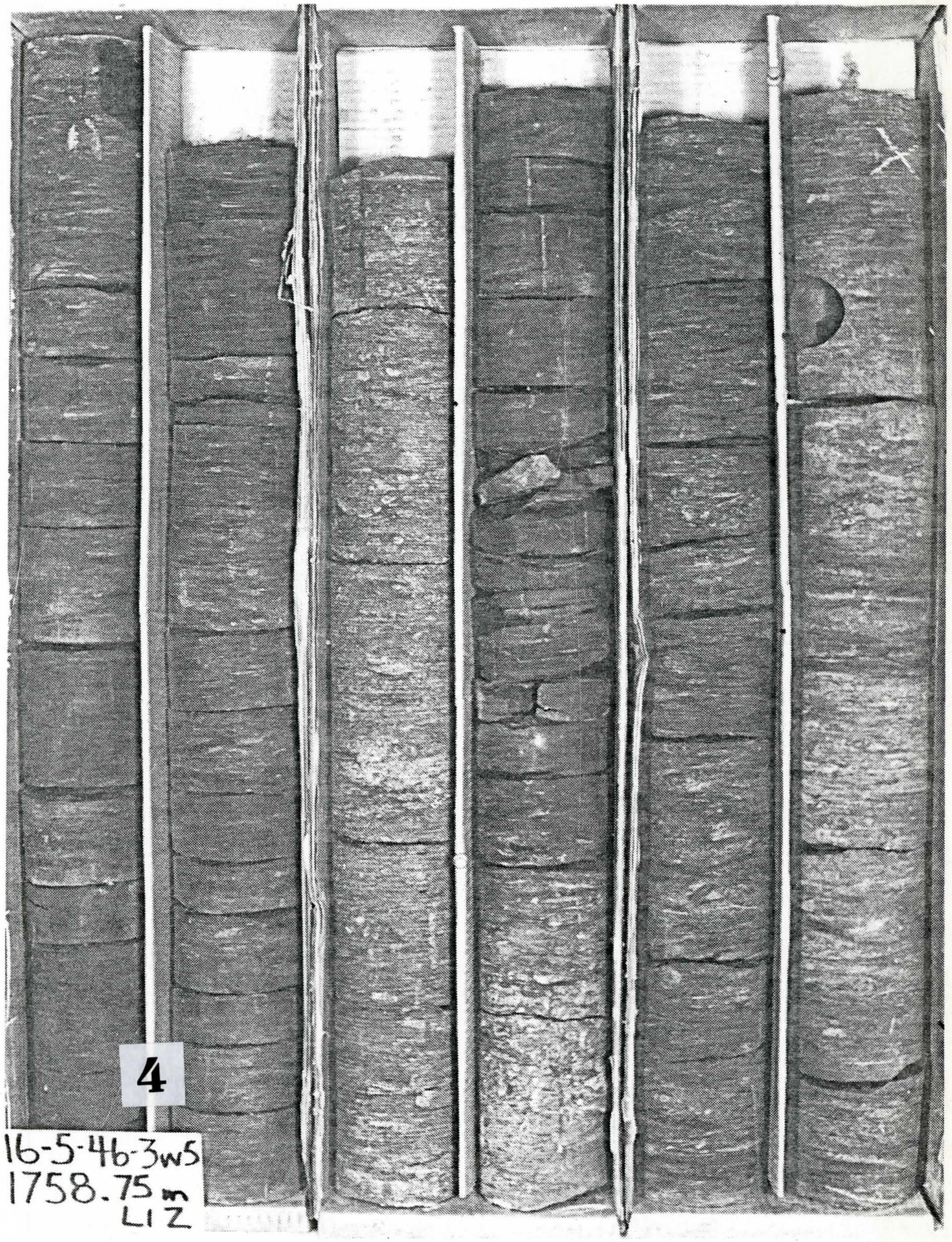
transition at 50% sand to other facies. These are the laminated sand to bioturbated mud facies and the laminated sand facies.

The distinguishing feature between the two occurrences is the presence of clast-stringers. Within the channel feature, the bioturbated mud and sand contains clasts 1-14mm in size in the mud.

Similar trace fossils are found in both occurrences. This includes Planolites, Skolithos, Terebellina, and Chrondrites. Within the four cycles Teichichnus, Helminthopsis, and Zoophycos also occur.

Figure 3.11 Facies 10 **Core 16-5-46-3W5**

In the box photos the lower lefthand corner is the stratigraphic base and the upper righthand corner is the stratigraphic top. This core represents the some of the cyclic bioturbated mud and sand of facies 10. These sandier-upward cycles occur on a regional scale in the study area. The numbers on the core correspond to the cycle number referred to in the text. To the left of the number 4, is the lower part of cycle 4. In the east, cycle 4 splits into two distinct sandier-upward cycles. These two cycles can be recognized in this core. The contact between the cycle 3 and 4 has been broken. However, to the left of the number 3 is the basal portion of the cycle 3 of bioturbated mud and sand. This core is part of the cross-section C-C' (fig.4.4).


4
16-5-46-3w5
1758.75 m
LIZ

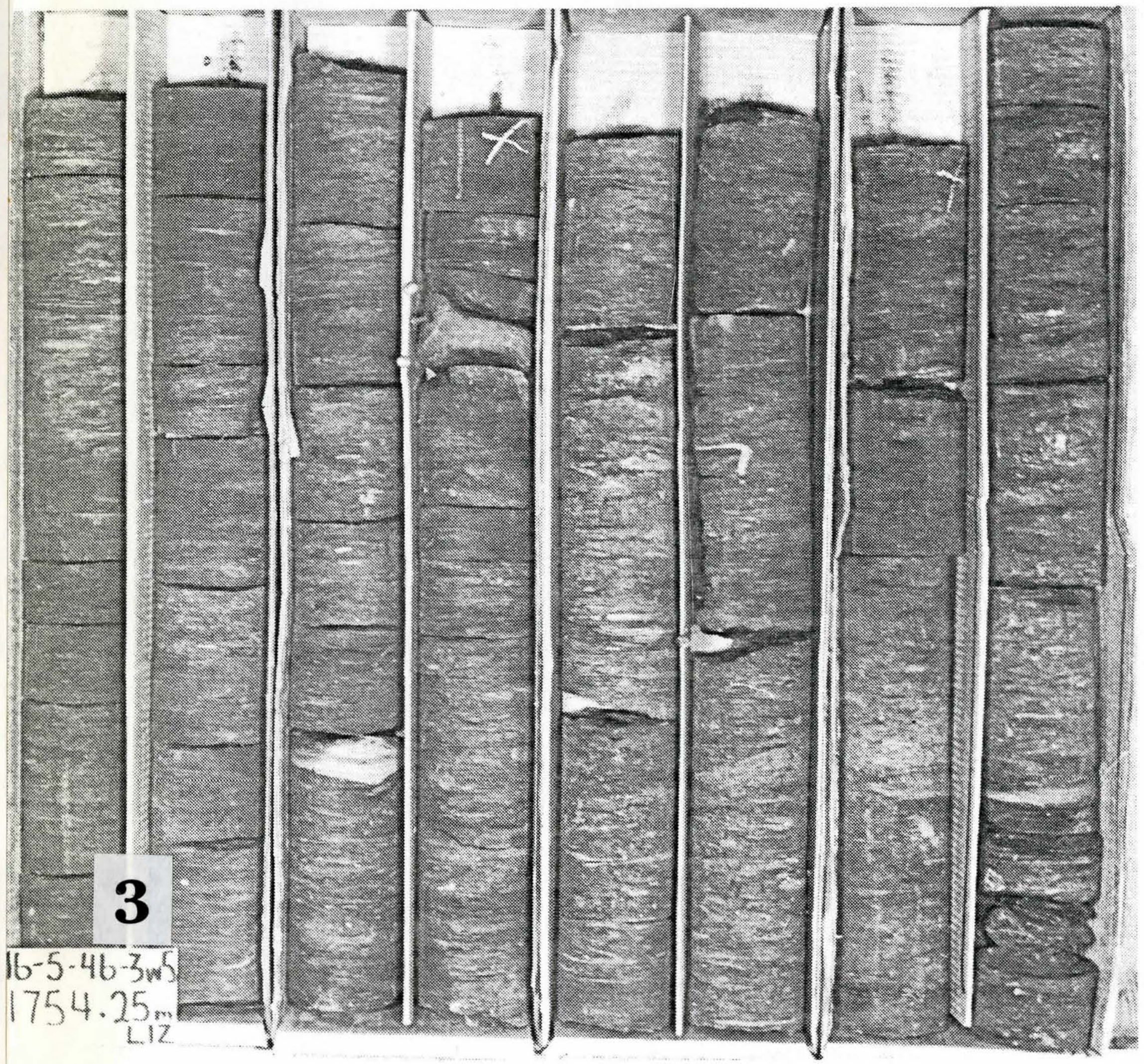
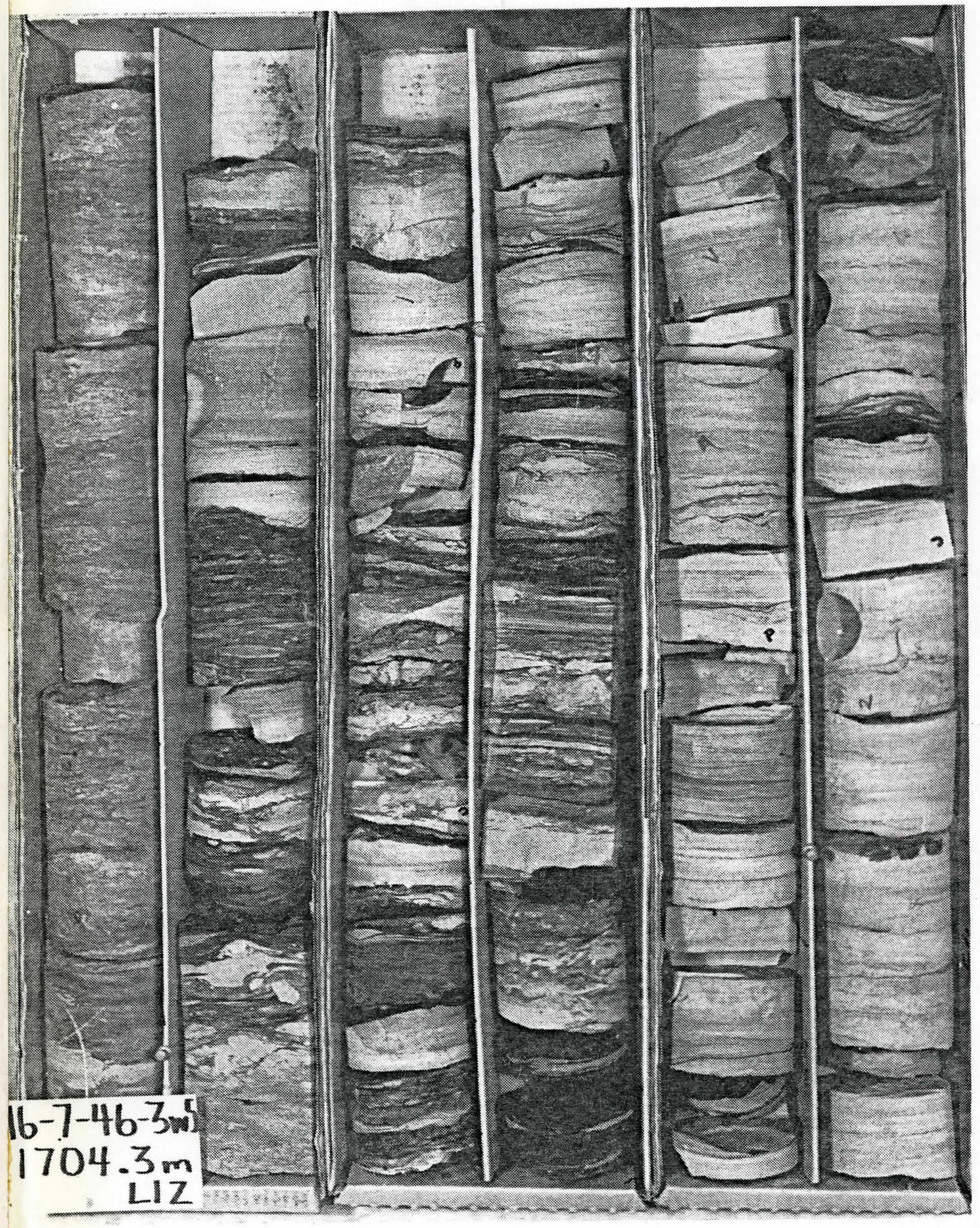
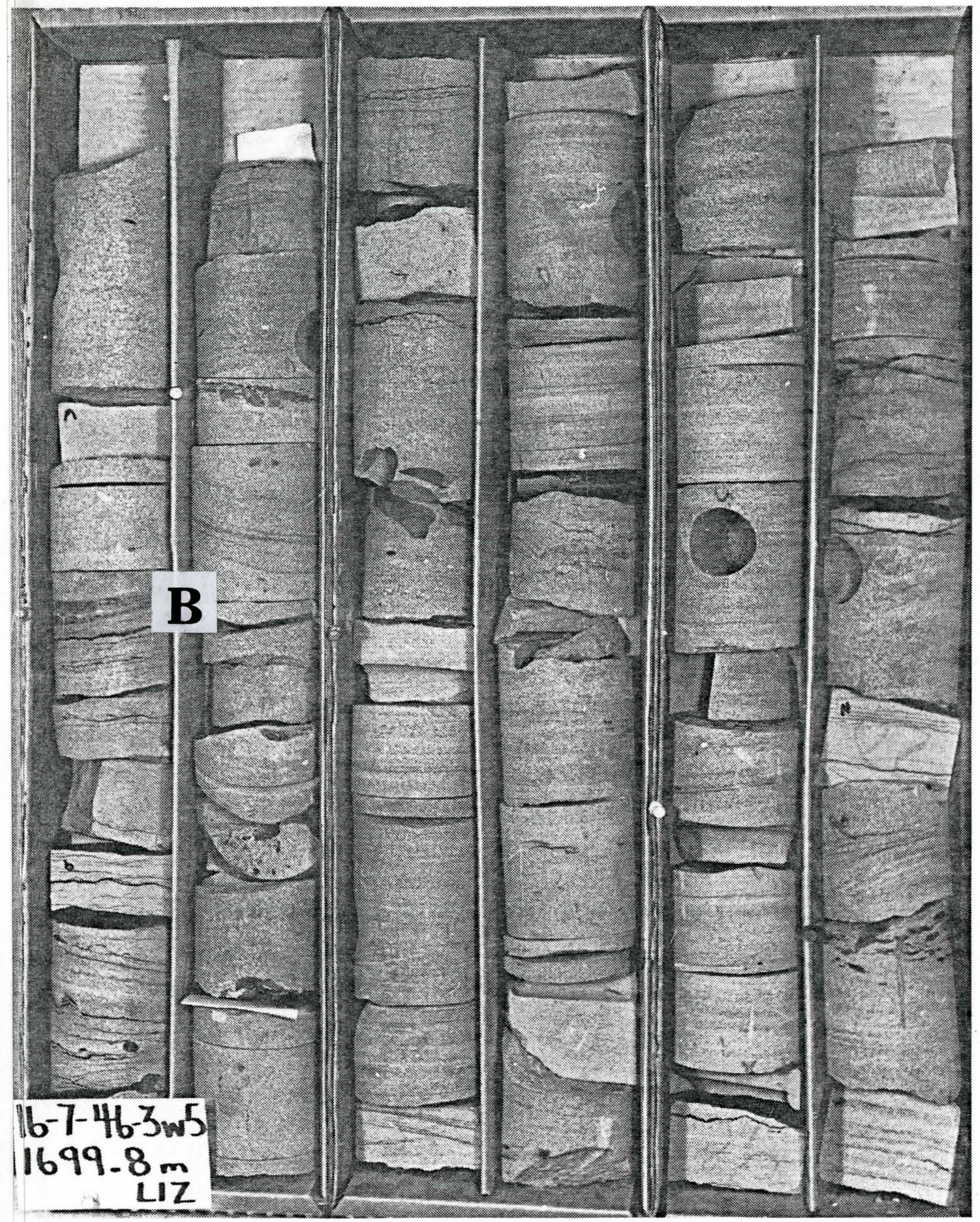

3
16-5-46-3w5
1754.25 m
LIZ

Figure 3.12 Facies 10 **Core 16-7-46-3W5**

In the box photos the lower lefthand corner is the stratigraphic bottom and the upper righthand corner is the stratigraphic top. The core illustrates two of the sandier-upward cycles of facies 10 and how they are scoured out by the erosion surface labelled B. To the left of the number 3, is the regionally occurring cycle 3 of bioturbated mud and sand. The contact between the cycles 2 and 3 is marked by a bentonite layer;seen below the lefthand corner of the number 2 in the box photos. The cycle 2 is seen to get sandier-upward. It loses the bioturbation and grades into laminated sand to bioturbated mud (facies 2) and laminated sand (facies 1). To the left of the letter B is the erosion surface. It has cross-bedded sand (facies 3) overlying it. The core stratigraphically above the B surface is predominantly very clean laminated sand (facies 1). This core is part of the cross-section B-B′ (fig.4.3).


16-7-46-3w5
1704.3m
LIZ


B
16-7-46-3w5
1699.8 m
LIZ

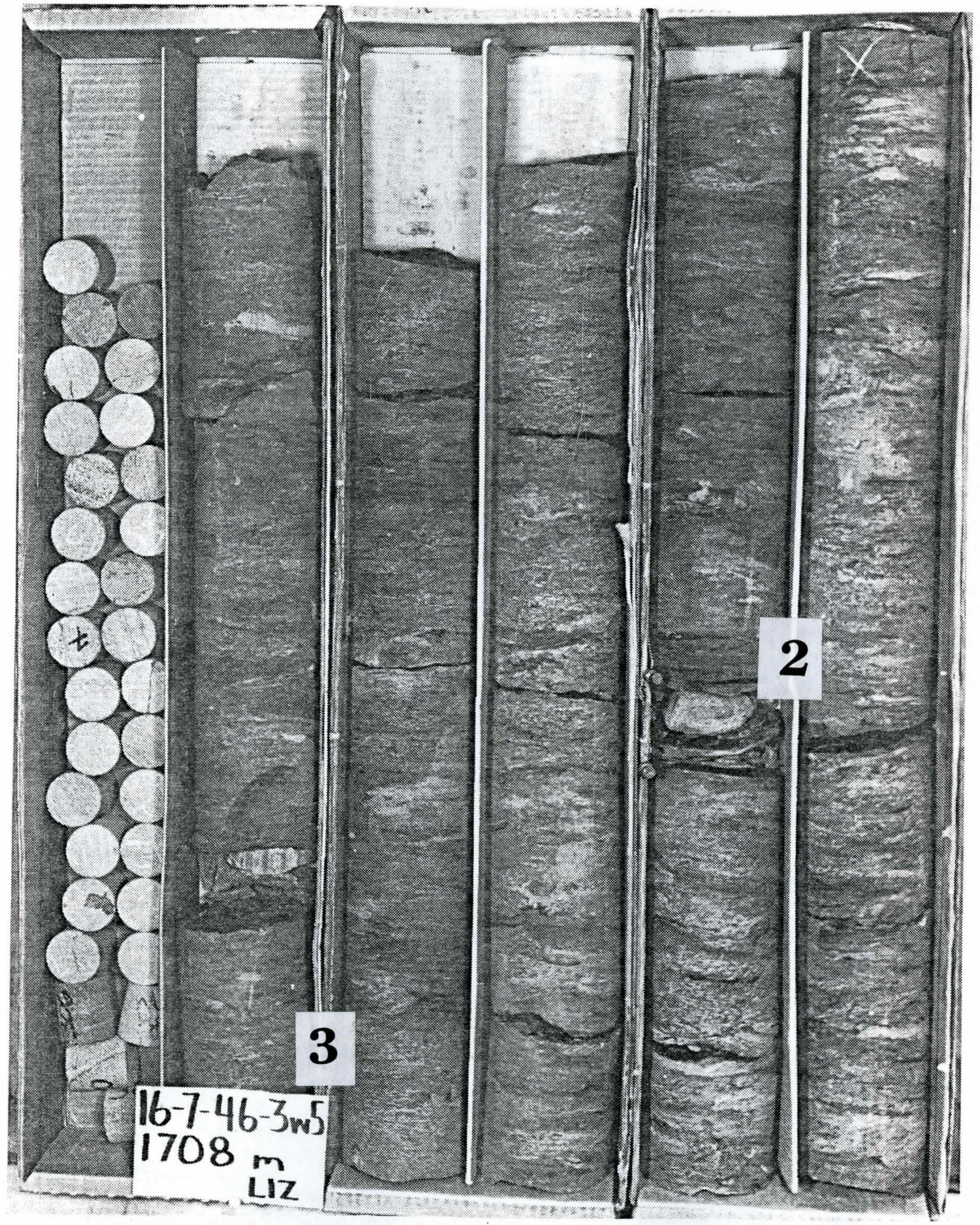

2
3
16-7-46-3w5
1708 m
LIZ

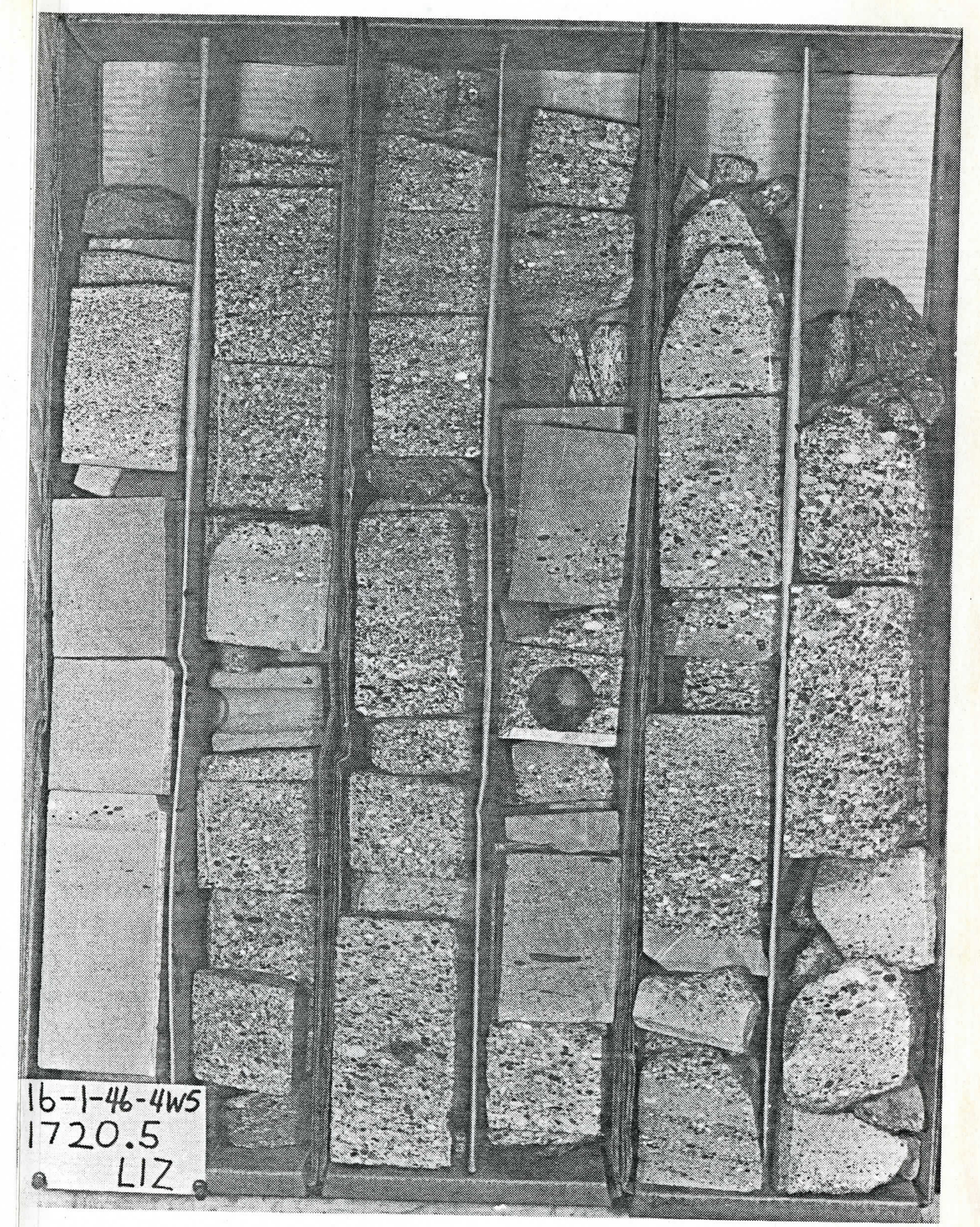
Figure 3.13 Facies 6 Core 16-1-46-4W5

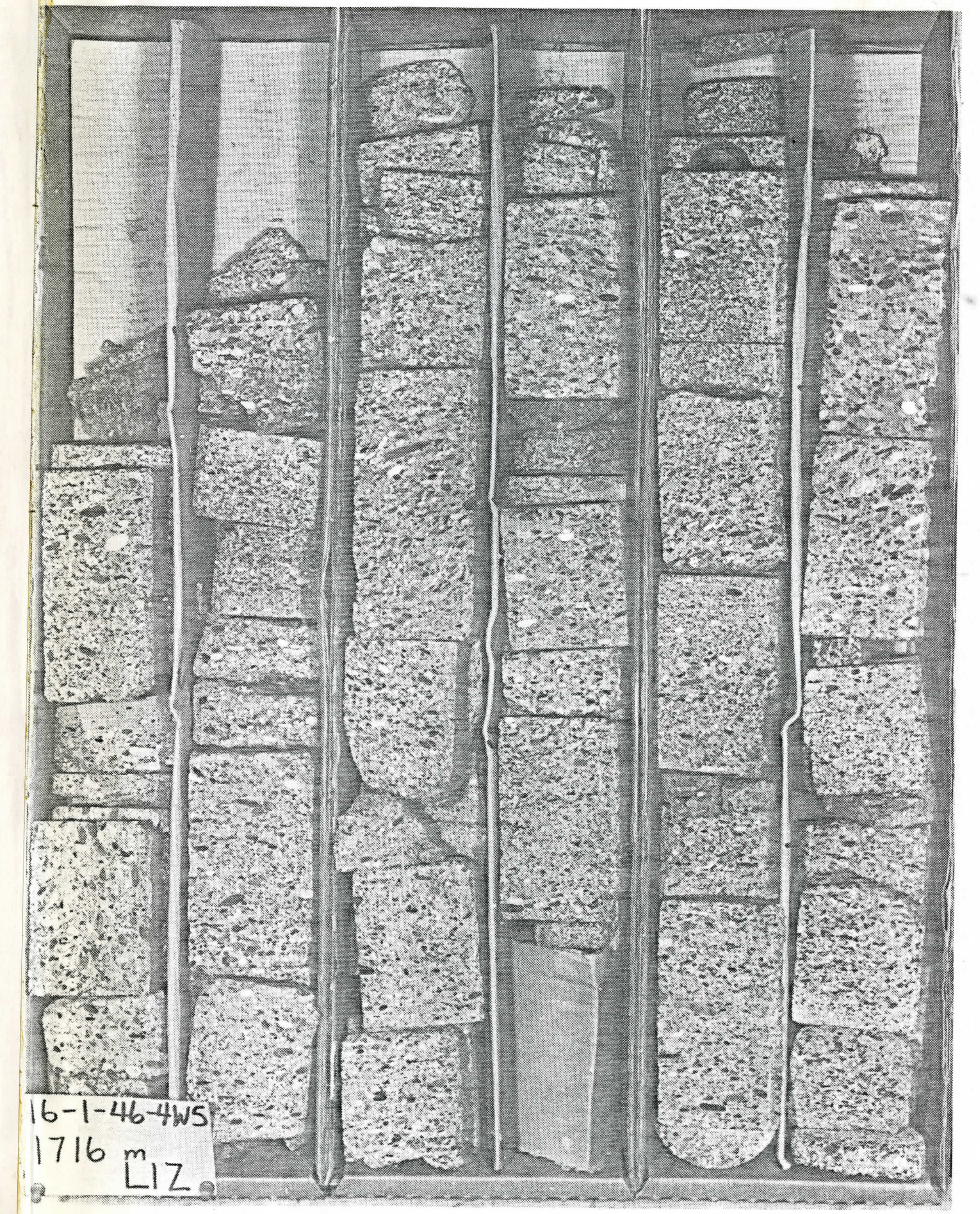
In the box photos the lower lefthand corner is the stratigraphic bottom and the upper righthand corner is the stratigraphic top. The core shows thw outer bioturbated mud and sand with an erosion surface to the left of the letter B. Above the erosion surface is 27m of preserved conglomerate (facies 6) and conglomerate and sand (facies 7). The top of the Viking Formation is marked by the erosion surface A. This surface is to the left of the letter A. Preserved on the surface is the basal conglomerate of the BLT sandwich (facies 8).

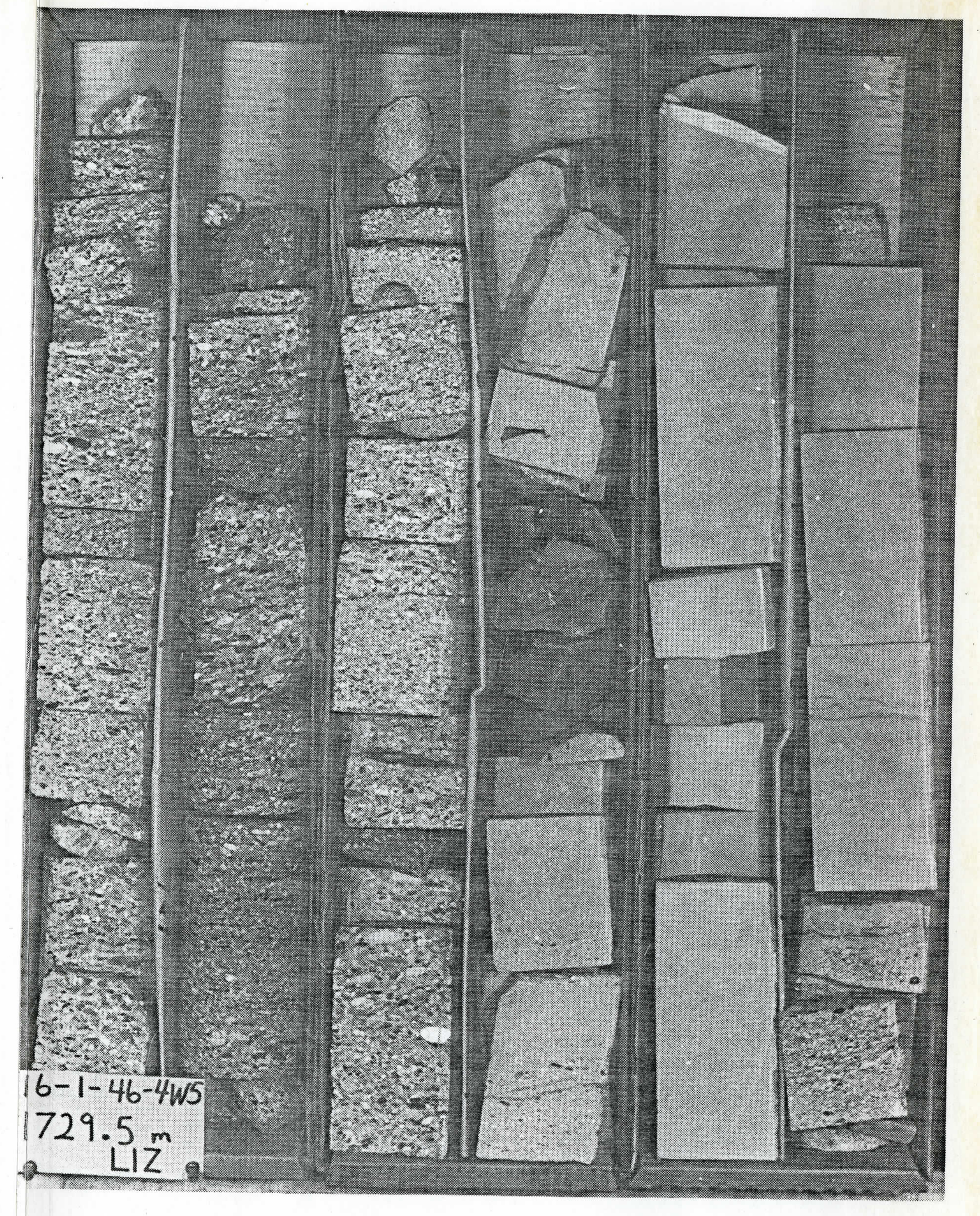

16-1-46-4WS
1711.5 m
LIZ

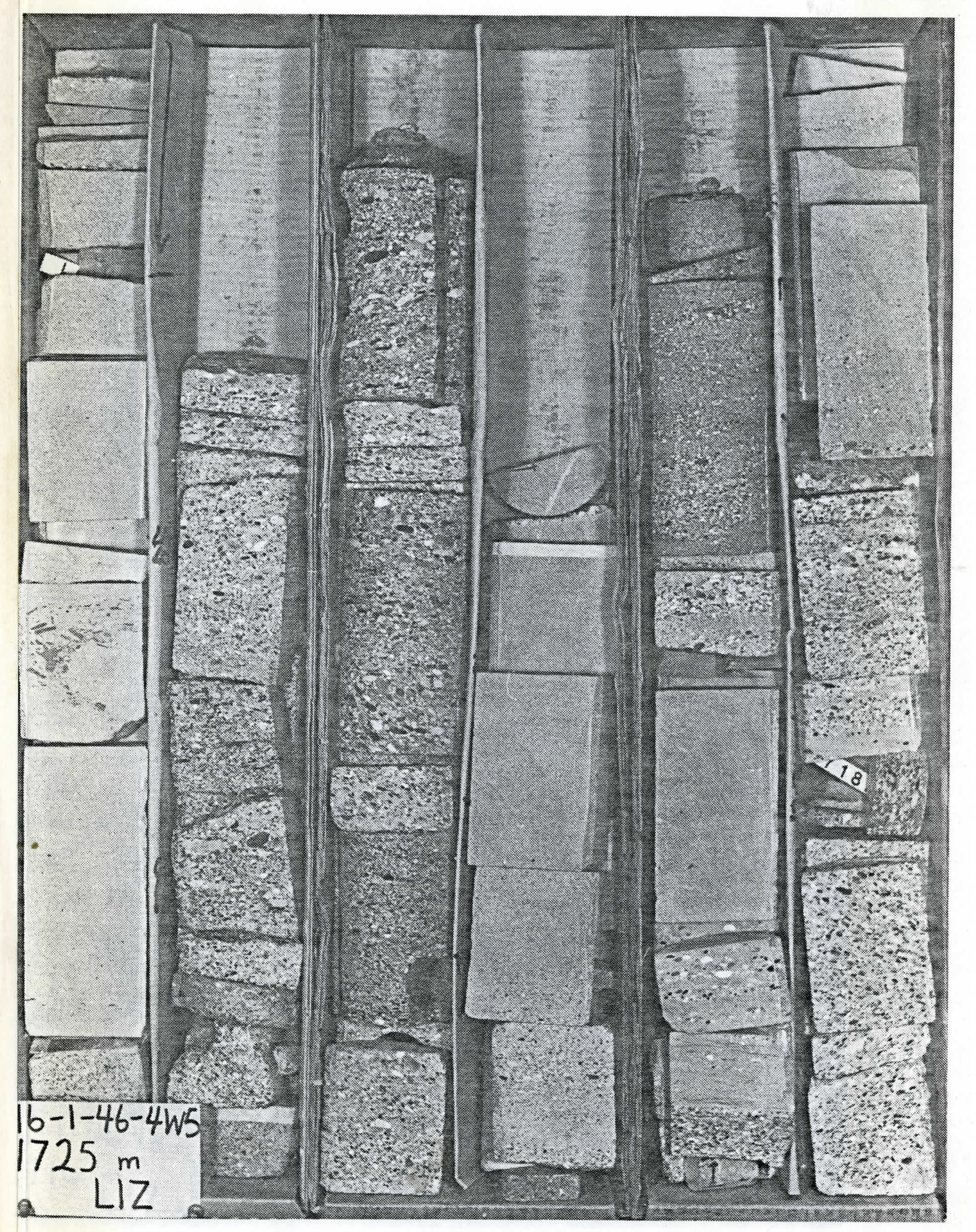

16-1-46-4WS
1707.0 m
LIZ

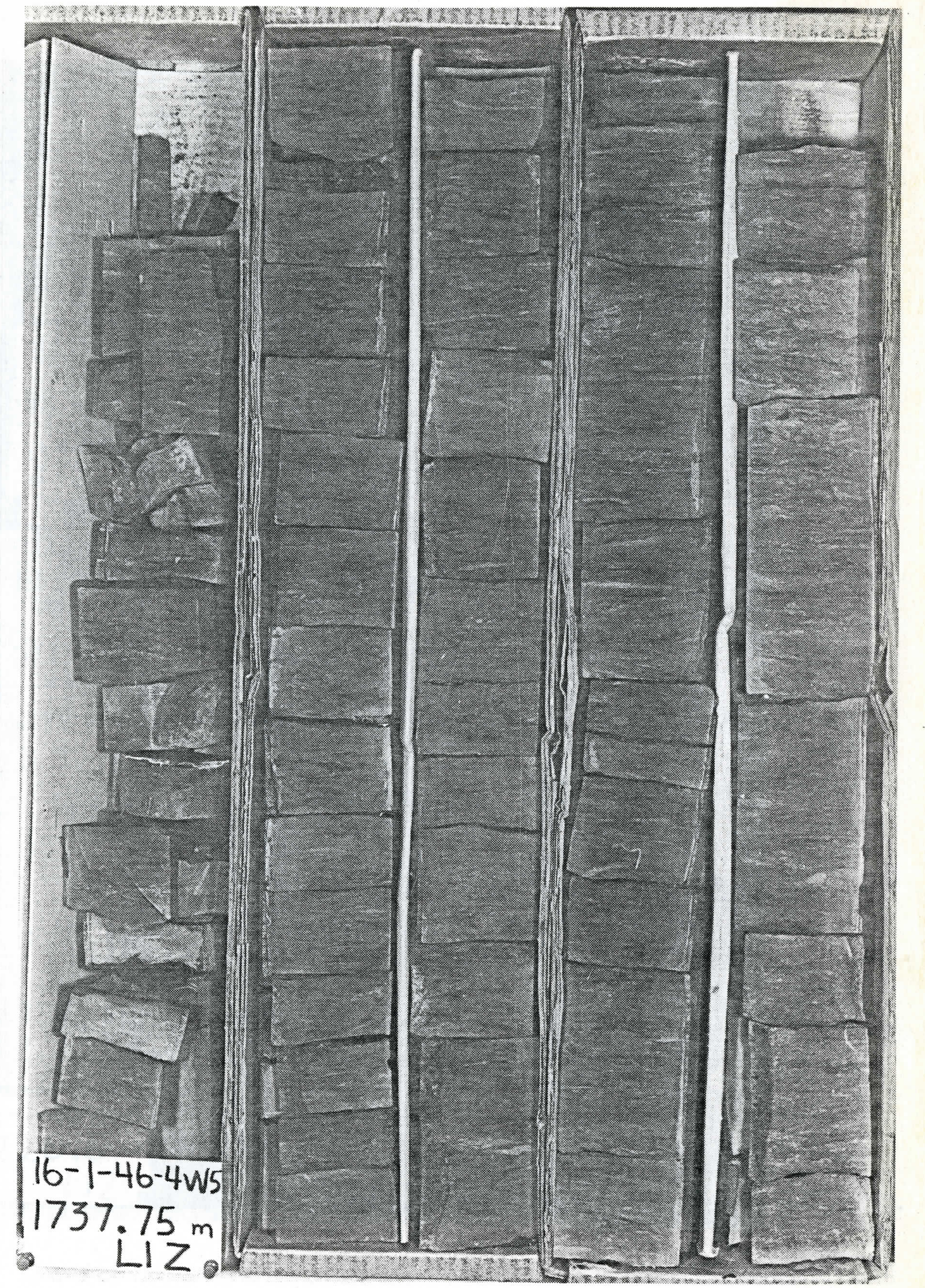
A

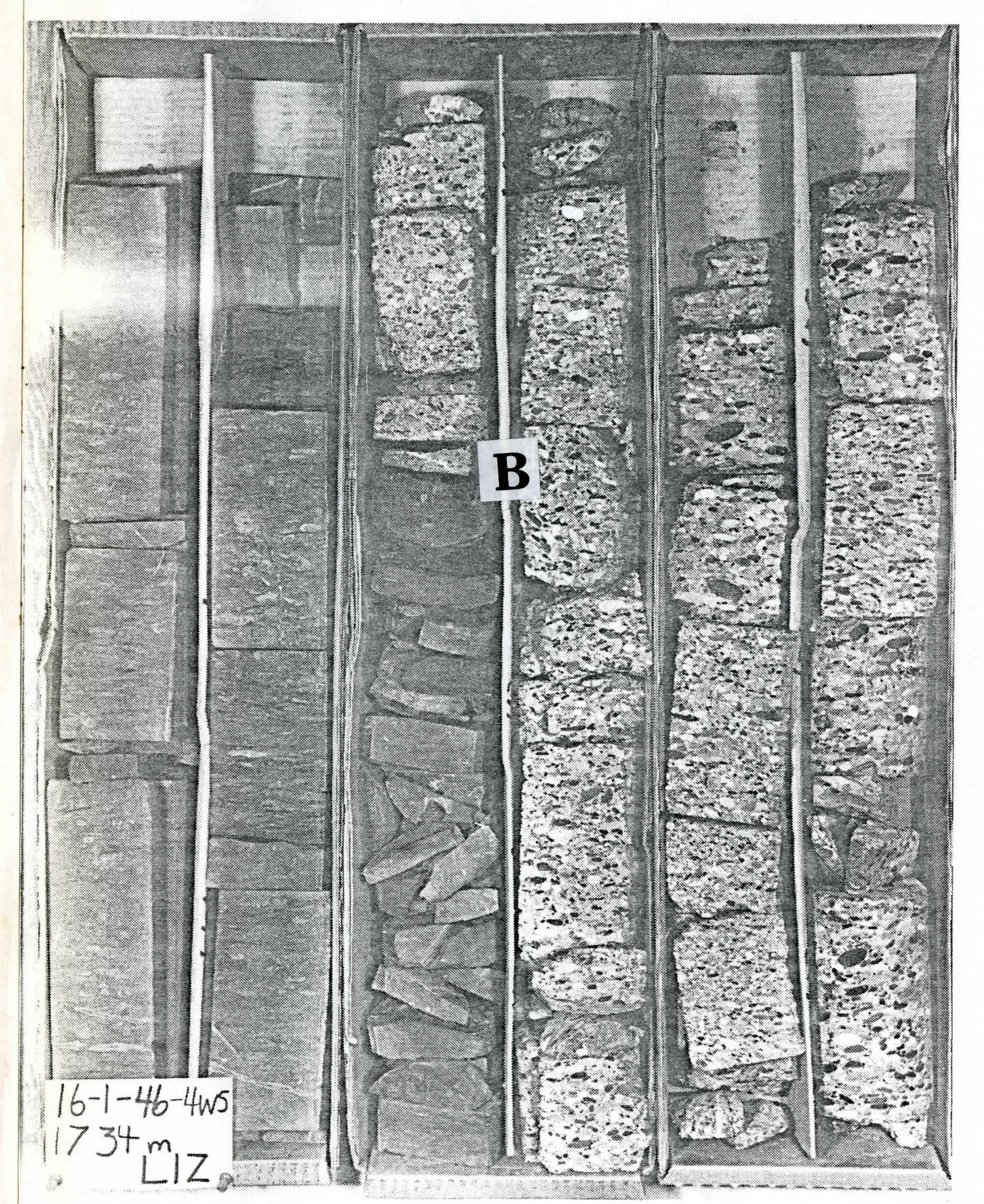

16-1-46-4WS
1720.5
LIZ


16-1-46-4WS
1716 m
LIZ


16-1-46-4WS
1729.5 m
LIZ


16-1-46-4WS
1725 m
LIZ


16-1-46-4WS
1737.75 m
LIZ


B
16-1-46-4WS
1734 m
LIZ

CHAPTER 4

SAND GEOMETRY

4.1 Introduction

Four cross-sections were drawn from west to east across the Crystal field (fig 4.1). They show gamma ray and resistivity logs. The core intervals studied are shown as black bars, and are presented below the well logs as lithologs. The separation between the wells on the cross-sections does not represent the true distance between the wells.

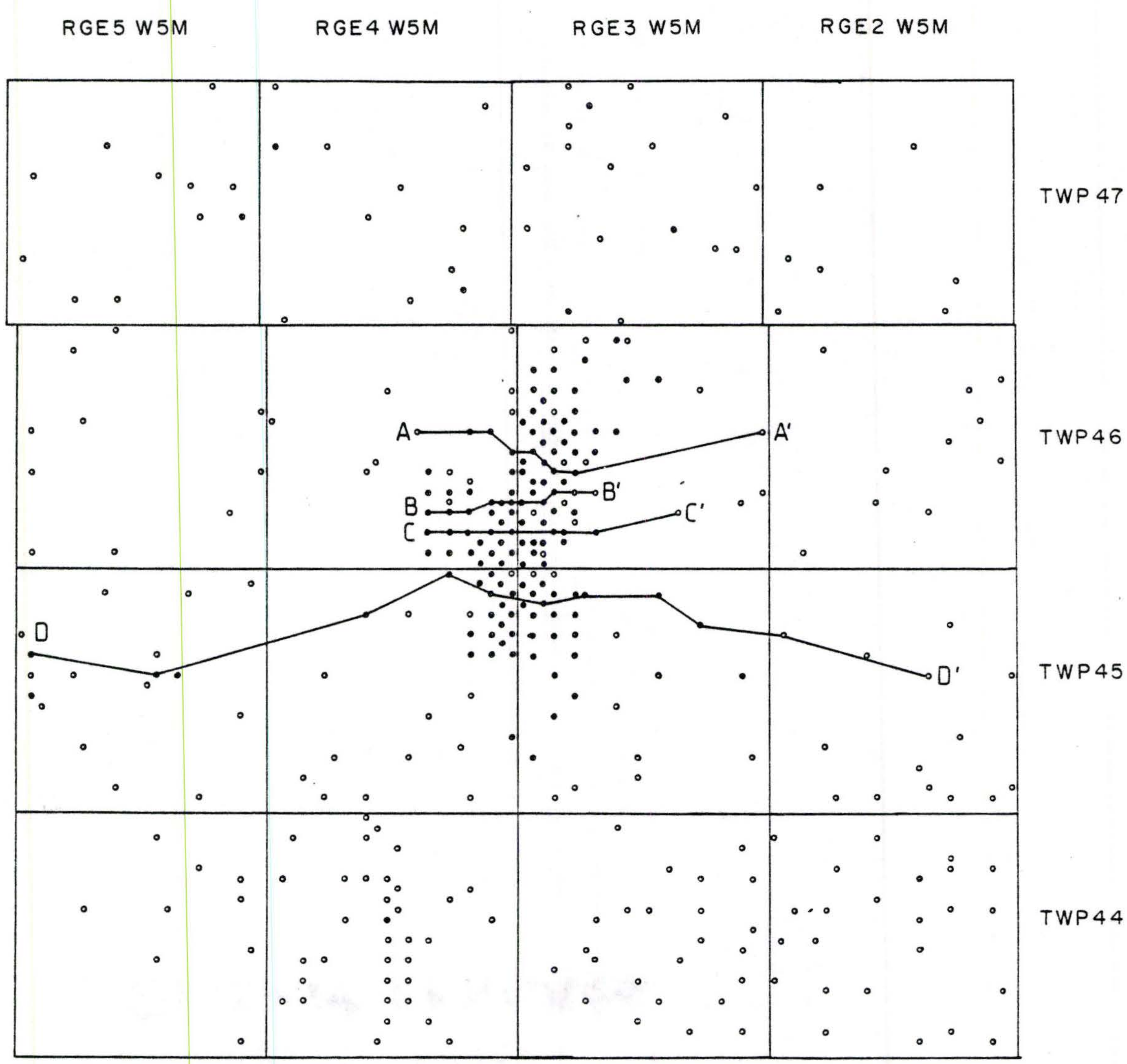
The base of the Viking Formation is the base of the lowermost sandier-upward cycle of facies 10, and is recognized on log responses as the first, large deflection above the Joli Fou. Some well log responses show a ledge in the Joli Fou below this first deflection. An example of this is 14-18-46-3W5 of cross-section A-A′. The top of the ledge and base of the deflection has been used as the datum for the cross-sections. In two cores, the datum is marked as a transition from non-bioturbated mud and sand into bioturbated mud and sand (facies 10).

The gamma ray and resistivity well logs show that the Viking Formation outside the field consists of four sandier-upward cycles, composed of facies 10. Within the field, the Viking is recognized by its relatively blockier response. On the eastern side of the field the well log response is very blocky and easily distinguished from the

Figure 4.1

Base Map of Crystal Field

The base map shows the distribution of wells within the study area. Solid circles are wells with core intervals and open circles are uncored wells. Crystal is outlined by the high density of wells. The cross-sections, drawn from west to east, are discussed in the text.



RGE5 W5M
RGE4 W5M
RGE3 W5M
RGE2 W5M
TWP 47
TWP 46
TWP 45
TWP 44
A
A'
B
B'
C
C'
D
D'

response outside the field. In this area the base of the blocky response was correlated as the surface labelled B. Surface B clearly cuts out part of the cycles 1 to 4 and will be interpreted below as being an erosion surface. On the western side of the field the well log responses vary greatly. The B surface is readily identified in some wells while in other wells there seem to be two surfaces present. These surfaces are labelled B1 and B2 and are recognized as two separate sharp "kicks" in the well logs. Cross-sections B-B′ and C-C′ show these two surfaces. Isopach maps were constructed based on the measurement of distance between the datum and the surfaces B, B1, and B2.

The surfaces B1 and B2 were plotted with the B surface on separate isopach maps since it is unknown whether B is the equivalent to B1 or B2. The surface B2 may represent either an erosion surface or a cleaner and coarser influx of sand at the top of the number four cycle. If it is an erosion surface, the well log responses suggest that it is overlain by a sedimentary lag that grades into a muddier facies upward. In this case B2 is equivalent to B, and B1 represents a second, higher erosion surface. This is best illustrated in cross-section B-B′. If B2 is the top of a sandier-upward cycle, then the overlying muddier material represents the return to normal Viking sediment deposition. The four sandier-upward cycles represent normal

Viking sediments in this area. In this case, B1 represents the erosion into the stratigraphy and is equivalent to the surface B. This is best illustrated by the cross-section C-C'.

It was previously mentioned that there were a variety of well log responses within the field. To show any trends of the various well log responses, a base map was drawn showing the comparison of all the well logs to type well logs.

The cross-sections, the isopach maps, and the base map showing well log response trends will all be discussed individually.

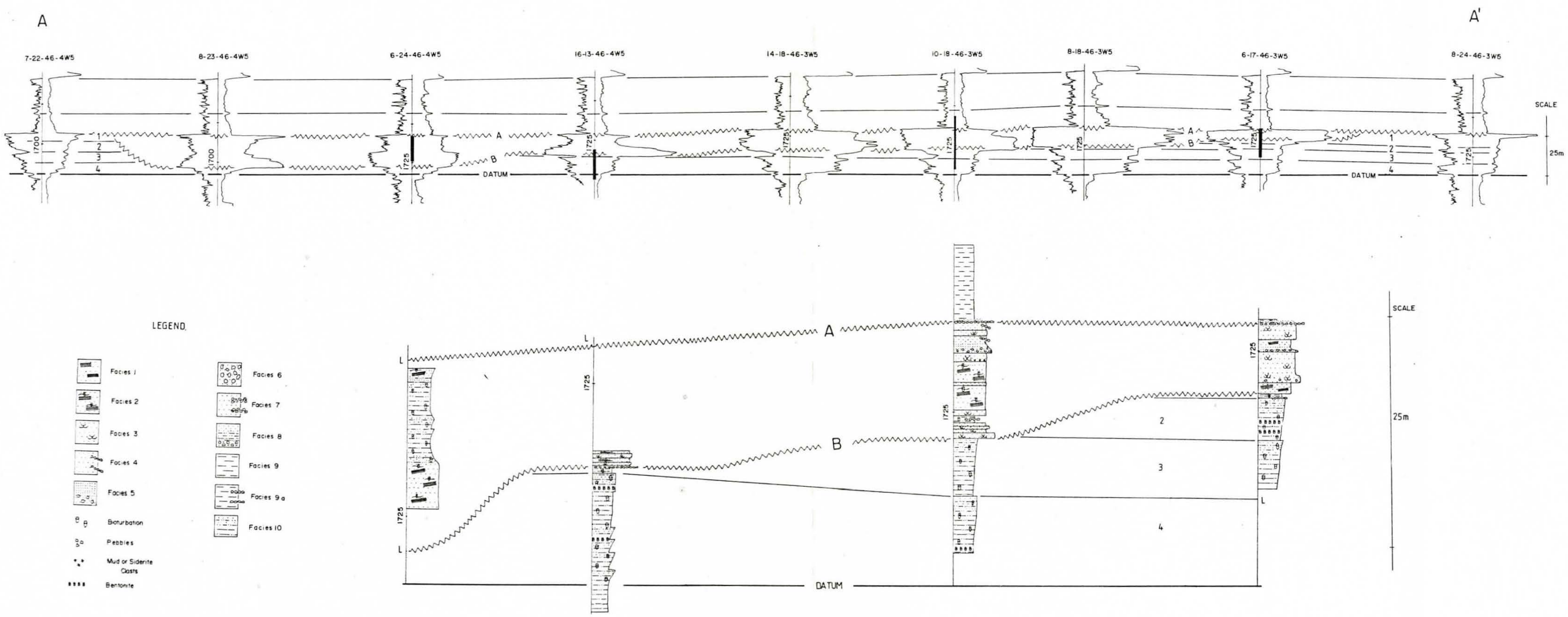
4.2 <u>Cross-section</u> : **A-A'** (fig.4.2)

This cross-section shows the four sandier-upward cycles composed of facies 10 and their occurrence outside the field. Cycle 4 thickens from 7.2m in 7-22-46-4W5 in the west to 10.8m in 10-18-46-3W5 in the east. It begins to thin again in 8-24-46-3W5 with a thickness of 7.2m. In the east cycle 4 separates into two distinct peaks in the east. Cycle 3 has the same relative thickness of 7.2m on either side of the field and cycle 2 thins from 7.2m in 7-22-46-4W5 in the west to 3.6m in 8-24-46-3W5 in the east. Cycle 1 is cut out at various levels by the surface A. The surface A marks the top of the Viking Formation in this area. The cross-section shows its broad, undulose nature. Surface A is recognized in core by the presence of the BLT Sandwich facies that

Figure 4.2

Cross-section A-A'

The section goes from west to east across the field, and its location is shown on the base map of figure 4.1. The solid bars are core intervals and are shown as lithologs below the gamma ray and resistivity responses. The cross-section has a lower datum that is the first major deflection above the Joli Fou shale. This deflection also represents the base of the Viking Formation in the study area. The responses outside the field are to the east and west of the jagged line labelled B. The responses outside the field show the four sandier-upward cycles. The section shows the erosion of these cycles by the surface labelled B. The sands onfield at Crystal lie above the B surface. The jagged line labelled A is the surface that marks the top of the Viking Formation in the study area.



A
A'
7-22-46-4W5
8-23-46-4W5
6-24-46-4W5
16-13-46-4W5
14-18-46-3W5
10-18-46-3W5
8-18-46-3W5
6-17-46-3W5
8-24-46-3W5
SCALE
25m
1700
1725
A
B
1
2
3
4
DATUM
LEGEND.
Facies 1
Facies 2
Facies 3
Facies 4
Facies 5
Facies 6
Facies 7
Facies 8
Facies 9
Facies 9a
Facies 10
Bioturbation
Pebbles
Mud or Siderite Clasts
Bentonite
L

directly overlies the surface. Above the sandwich is the black mudstone facies that blankets the A surface topography. Well log correlations show that the markers above the Viking Formation follow parallel to the A surface topography.

The wells 8-23-46-4W5, 6-24-46-4W5, and 16-13-46-4W5 are on the western side of the field.These wells have log responses that show the lower, large deflection that represents the surface B, followed by a muddier-upward then sandier-upward sequence. In core the sediment above this B surface represents the second occurrence of facies 10. This occurrence is bioturbated mud and sand above the surface B which means it lies within the field. This facies is similar to the bioturbated mud and sand that occurs below the surface B or outside the field.

The other wells onfield are 14-18-46-3W5, 10-18-46-3W5, 8-18-46-3W5, and 6-17-46-3W5 and these wells show the various levels of erosion of surface B. The core shows the sediment above this surface B as predominantly laminated sand (facies 1) and laminated sand to bioturbated mud (facies 2). The core intervals also show the increase in cross-bedded sand (facies 3) and an increase in pebble-rich facies (facies 4 and 5) toward the east.

The wells onfield show the asymmetrical nature of the surface B.

4.3 Cross-section : B-B' (fig.4.3)

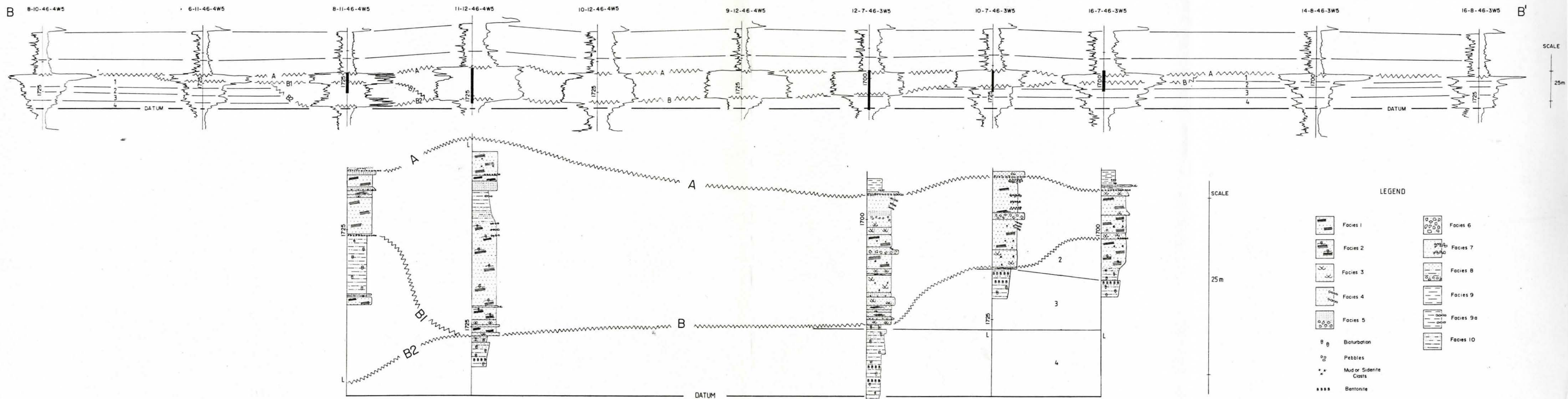
This cross-section illustates the two occurrences of facies 10. The first is the four sandier-upward cycles that occur outside the field. Cycle 4 thickens from 7.2m in 8-10-46-4W5 in the west to 10.8m in 16-6-46-3W5 in the east and splits into two distinct peaks in the east. Cycles 2 and 3 each have a constant relative thickness over the area at 3.6m and 7.2m, respectively and cycle 1 is cut out at various levels by surface A. The well log correlations show the broad, undulose nature of the surface A and how the markers above the formation parallel the A surface topography. The core intervals show the BLT sandwich facies (facies 8) lying on surface A and the black mudstone facies (facies 9) blankets the sandwich.

The second occurrence of facies 10 is within the field above the B2 surface. The well 8-11-46-4W5 in the west shows that laminated sand (facies 1) and bioturbated mud and sand (facies 10) occur between the B1 and B2 surfaces. The same well also shows that the B1 surface has a pebble lag on it. Above this lag there is predominantly laminated sand (facies 1) with some cross-bedded sand (facies 3) and structureless speckled sand (facies 5). At 11-12-46-4W5, the sufaces B1 and B2 become surface B. This is because the B1 and B2 correlations are based on the similarity of the muddy response above B2 and the muddy response outside the

Figure 4.3

Cross-section B-B′

The cross-section goes from west to east across the field, and its location is shown on figure 4.1. The solid bars are core intervals and are shown as lithologs below the gamma ray and resistivity responses. The section has a lower datum that is the first major deflection above the Joli Fou shale. This deflection also represents the base of the Viking Formation in the study area. The responses outside the field are east and west of the jagged lines labelled B, B1, and B2. The responses outside the field show the four sandier-upward cycles. The erosion of these cycles by the B surface is also seen in the section. On the western side of the field the two surfaces B1 and B2 are present. They come together at 11-12-46-4W5. The jagged line labelled A is marks the top of the Viking Formation in the study area.



B
8-10-46-4W5
6-11-46-4W5
8-11-46-4W5
11-12-46-4W5
10-12-46-4W5
9-12-46-4W5
12-7-46-3W5
10-7-46-3W5
16-7-46-3W5
14-8-46-3W5
16-8-46-3W5
B'
SCALE
25m
A
B
B1
B2
1
2
3
4
DATUM
1725
1700
L
SCALE
25m
LEGEND
Facies 1
Facies 2
Facies 3
Facies 4
Facies 5
Facies 6
Facies 7
Facies 8
Facies 9
Facies 9a
Facies 10
Bioturbation
Pebbles
Mud or Siderite Clasts
Bentonite

field. At 11-12-46-4W5 the muddy response is lost within the field. The next wells onfield toward the east have the B surface only with cross-bedded sand (facies 3) on it. The core intervals show a transition from a predominantly laminated sand (facies 1) and laminated sand to bioturbated mud (facies 2) into a more cross-bedded sand (facies 3) and pebble-rich facies (facies 4,5,6,and 7) from the west toward the east.

The wells onfield show the asymmetrical nature of the surface B with either B1 or B2 as an equivalent surface.

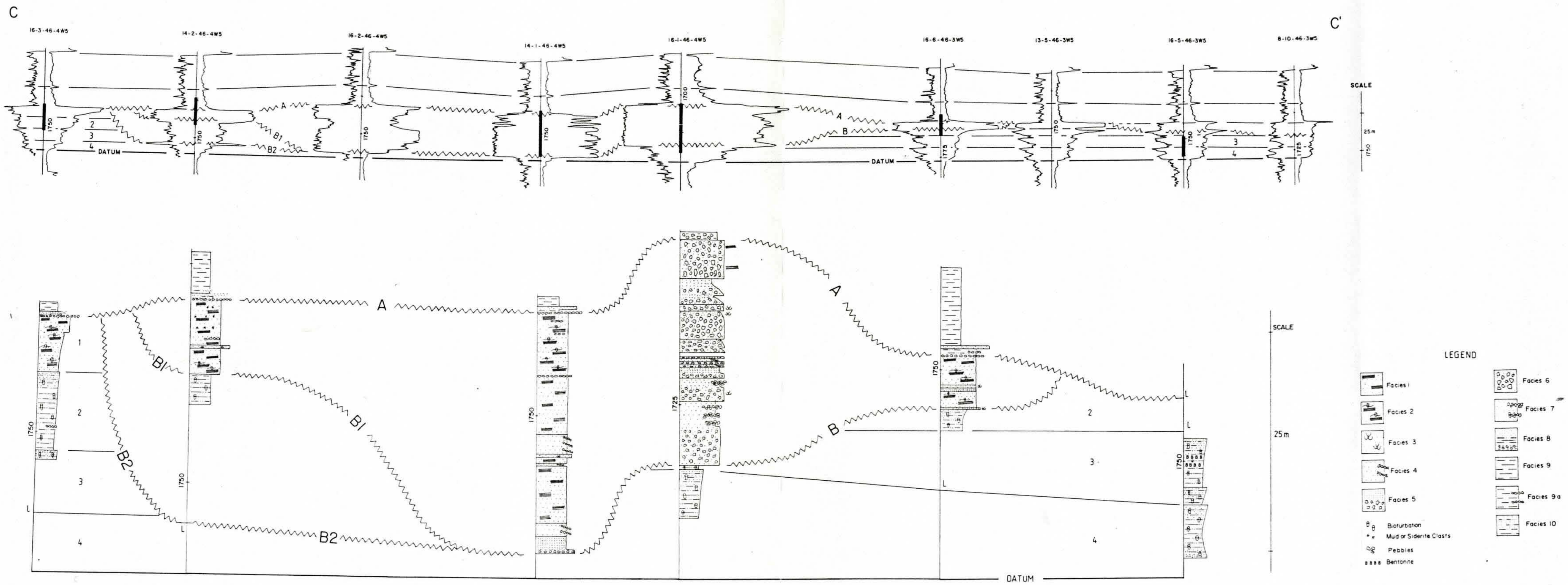
4.4 Cross-section : **C-C'** (fig.4.5)

This cross-section shows the two occurrences of facies 10. The first is outside the field as the sandier-upward cycles. Cycle 4 thickens from 7.2m in 16-3-46-4W5 in the west to 9.9m in 16-1-46-4W5 in the east, where it then begins to thin again in 8-10-46-3W5 with a thickness of 7.2m. In the east, cycle 4 also has separated into two distinct peaks. Cycle 3 thins from 8.1 in 16-3-46-4W5 in the west to 7.2m in 8-10-46-3W5. Cycle 2 thins from 8.1m in 16-3-46-4W5 in the west to 4.5m in 13-5-46-3W5 in the east. Cycle 1 is cut out at various levels by the surface A. To the east of the field, well log correlations show that the surface A cuts down to below cycle 2 (well 16-5-46-3W5). This correlation is based on the comparison of the log responses of 16-5-46-3W5 and 8-10-46-3W5 with

Figure 4.4

Cross-section C-C'

The cross-section goes from west to east across the field, and its location is shown on the base map of figure 4.1. The solid bars are core intervals and are shown as lithologs below the gamma ray and resistivity responses. The cross-section has a lower datum that is the first major deflection above the Joli Fou. This deflection also represents the base of the Viking Formation in the study area. The responses outside the field lie to the east and west of the jagged lines labelled B, B1, and B2. The responses outside the field show the four sandier-upward cycles. The section shows the erosion of these cycles by the B surface. The sands onfield at Crystal lie above the B surface. The jagged line labelled A marks the top of the Viking Formation in the study area.


C
C'
16-3-46-4W5
14-2-46-4W5
16-2-46-4W5
14-1-46-4W5
16-1-46-4W5
16-6-46-3W5
13-5-46-3W5
16-5-46-3W5
8-10-46-3W5
DATUM
SCALE
25m
A
B
B1
B2
1
2
3
4
LEGEND
Facies 1
Facies 2
Facies 3
Facies 4
Facies 5
Facies 6
Facies 7
Facies 8
Facies 9
Facies 9a
Facies 10
Bioturbation
Mud or Siderite Clasts
Pebbles
Bentonite

6-30-45-2W5 of cross-section D-D′. The well 6-30-45-2W5 has a similar response to those of 16-5-46-3W5 and 8-10-46-3W5 and the core interval of 6-30-45-2W5 shows the surface A cutting below cycle 1. The A surface is broad and undulose and the well log correlations show that the markers above mirror the A surface topography. Core shows that the BLT sandwich facies (facies 8) lies on the A surface and that it is blanketed by the black mudstone facies (facies 9).

On the western side of the field is the second occurrence of facies 10. The well 14-2-46-4W5 shows that bioturbated mud and sand occurs between the B1 and B2 surfaces. The same well shows the B1 surface as having laminated sand (facies 1) on it with no pebble lag, followed by laminated sand (facies 1) with some laminated sand to bioturbated mud (facies 2) and cross-bedded sand (facies 3). At 16-2-46-4W5 the surfaces B1 and B2 become one. The correlation of B1 and B2 is based on the occurrence of a muddy response within the field. At 16-2-46-4W5 this muddy response is lost and the lower spike is labelled B.

The other wells onfield are 14-1-46-4W5, 16-1-46-4W5, and 16-6-46-3W5. These wells have one lower surface labelled B and the core intervals show a great variety in facies above surface B in a very short distance. In 14-1-46-4W5, the core is predominantly laminated sand (facies 1) with structureless speckled sand directly overlying the B surface. The well next to it, 16-1-46-4W5, is predomonantly conglomeratic. Even farther to the east, the well 16-6-46-3W5 shows a change back to laminated sand to bioturbated mud (facies 2) with cross-bedded sand (facies 3) on top of the surface B.

Although there is a great lateral facies change from west to east, the cross-section shows the asymmetrical appearance of the surface B.

4.5 <u>Cross-section</u> : **D-D'** (fig.4.5)

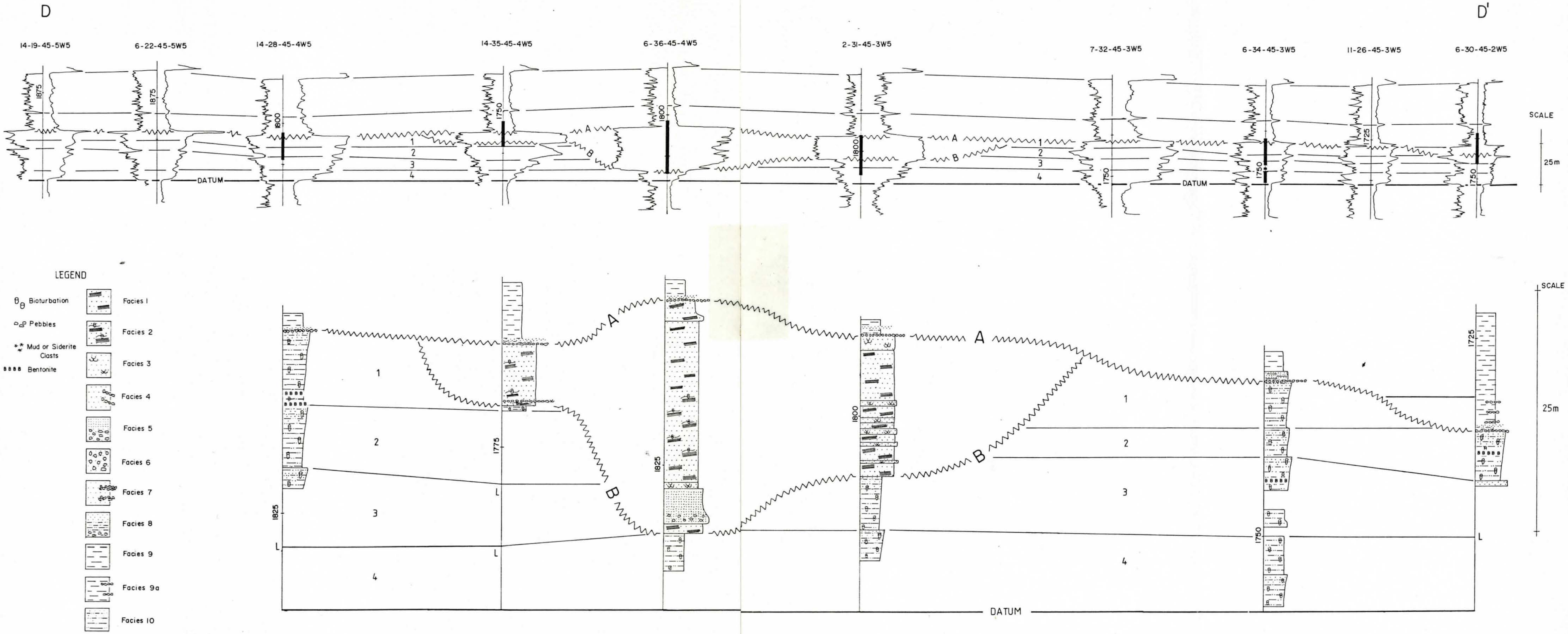
This cross-section shows the four sandier-upward cycles outside the field. Cycle 4 thickens from 0.8m in 14-19-45-5W5 in the west to 1.2m in 6-30-45-2W5 in the east and separates into two distinct peaks in the east. Cycles 3 thins from 2m in 14-19-45-5W5 in the west to 0.8m in 11-26-45-3W5 in the east. Cycle 2 thins from 0.92m in 14-19-45-5W5 in the west to 0.6m in 6-34-45-3W5 in the east and cycle 1 is cut out at various levels by surface A. This section shows the broad, undulose nature of this surface; to the east of the field surface A cuts out cycle 1 entirely (see 6-30-45-2W5).

The well 6-30-45-2W5 also shows that facies 9A onlaps onto the A surface. Directly overlying the A surface is the BLT sandwich facies (facies 8) and above the sandwich is the black mudstone facies (facies 9). Well log correlations show that the markers above the Viking Formation follow parallel

Figure 4.5

Cross-section D-D′

The cross-section goes from west to east across the field, and its location is shown on the base map of figure 4.1. The solid bars are core intervals and are shown as lithologs below the gamma ray and resistivity responses. The section has a lower datum that is the first major deflection above the Joli Fou Shale. This deflection also represents the base of the Viking Formation in the study area. The well responses to the east and west of the jagged line labelled B are off field and show the four sandier-upward cycles. The section shows the erosion of these cycles by the B surface. The sands onfield at Crystal lie above the B surface. The jagged line labelled A marks the top of the Viking Formation in the study area.


D
D'
14-19-45-5W5
6-22-45-5W5
14-28-45-4W5
14-35-45-4W5
6-36-45-4W5
2-31-45-3W5
7-32-45-3W5
6-34-45-3W5
11-26-45-3W5
6-30-45-2W5
SCALE
25m
DATUM
A
B
1
2
3
4
L
1875
1800
1750
1825
1775
1725
LEGEND
Bioturbation
Pebbles
Mud or Siderite Clasts
Bentonite
Facies 1
Facies 2
Facies 3
Facies 4
Facies 5
Facies 6
Facies 7
Facies 8
Facies 9
Facies 9a
Facies 10

to the A surface topography.

The wells 14-35-45-4W5, 6-36-45-4W5, and 2-31-45-3W5 are onfield and show the levels of erosion of surface B. The surface appears to be asymmetrical.

The core shows the sediment above surface B as predominantly laminated sand (facies 1) and laminated sand to bioturbated mud (facies 2). There is also an increase in cross-bedded sand (facies 3) from west to east and the well 6-36-45-4W5 has a unit of structureless speckled sand (facies 5).

4.6 SUMMARY

In general the four cross-sections show four sandier-upward cycles composed of facies 10. These cycles occur on a regional scale within the study area. The surface B represents erosion into this regional stratigraphy. Sediment above the surface B is referred to as being inside the field and sediment below the surface B is outside the field.

On the western side of the field the surface B is probably correlated with two possible surfaces, labelled B1 and B2. Since no core was studied that passed through surface B2 it is unknown whether B2 represents erosion, or the top of a sandier-upward sequence. Core shows the second occurrence of facies 10 which is within the field and above surface B2.

Core cross-sections show a great lateral change in the facies within the field. It appears, however, that the sediment above surfaces B1 and B in the west have predominantly laminated sand (facies 1) and laminated sand to bioturbated mud (facies 2) above them. There is a transition from west to east, such that the sediment changes from predominantly laminated sand (facies 1) and laminated sand to bioturbated mud (facies 2) in the west into predominantly cross-bedded sand (facies 3) and pebble-rich facies (facies 4,5,6,and 7) in the east.

Well log correlations show that the top of the Viking Formation in the study area is marked by the surface labelled A. Core through this surface shows that the BLT Sandwich facies always lies on the A surface.

4.7 Base Map of Well Log Responses

Examination of well logs indicated that there were a variety of responses within the field. To find if any trends existed in the well log responses, type responses were chosen and compared to all the well logs. Each well was then plotted on a base map with the symbol corresponding to the type well response it resembled.

The wells indicated by a closed square lie within the field and have a lower sharp surface followed by a gradational, muddier-upward sequence (fig 4.6). These well log responses are found along the western side of the field. A closed circle represents a blocky response within

Figure 4.6

Type Well Log Responses

These gamma ray and resistivity responses are type well log responses that were compared to all the well logs in the study area. Both responses are labelled with a closed square even though the lower erosion surface may be B, B1, or B2. The common feature is the sharp base followed by a gradational, muddier-upward sequence.

Type Well Log Responses

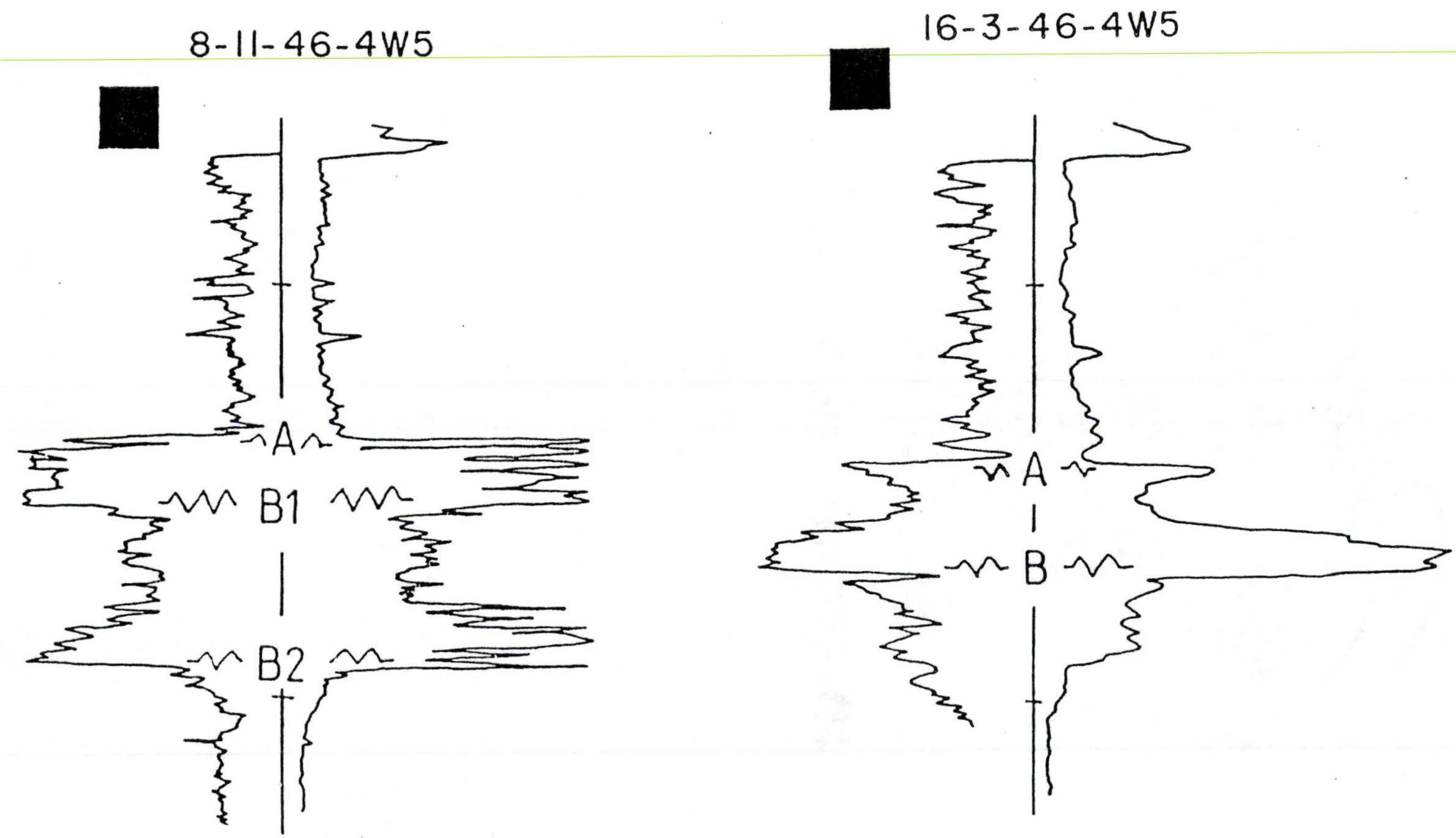


Figure 4.7

Type Well Log Responses

These gamma ray and resistivity responses are type well log responses that were compared to all the well logs in the study area. The response labelled with a closed circle shows an erosively based, blocky response that is onfield. The response labelled with the closed triangle is one of three wells that do not match either of the other two type responses.

Type Well Log Responses

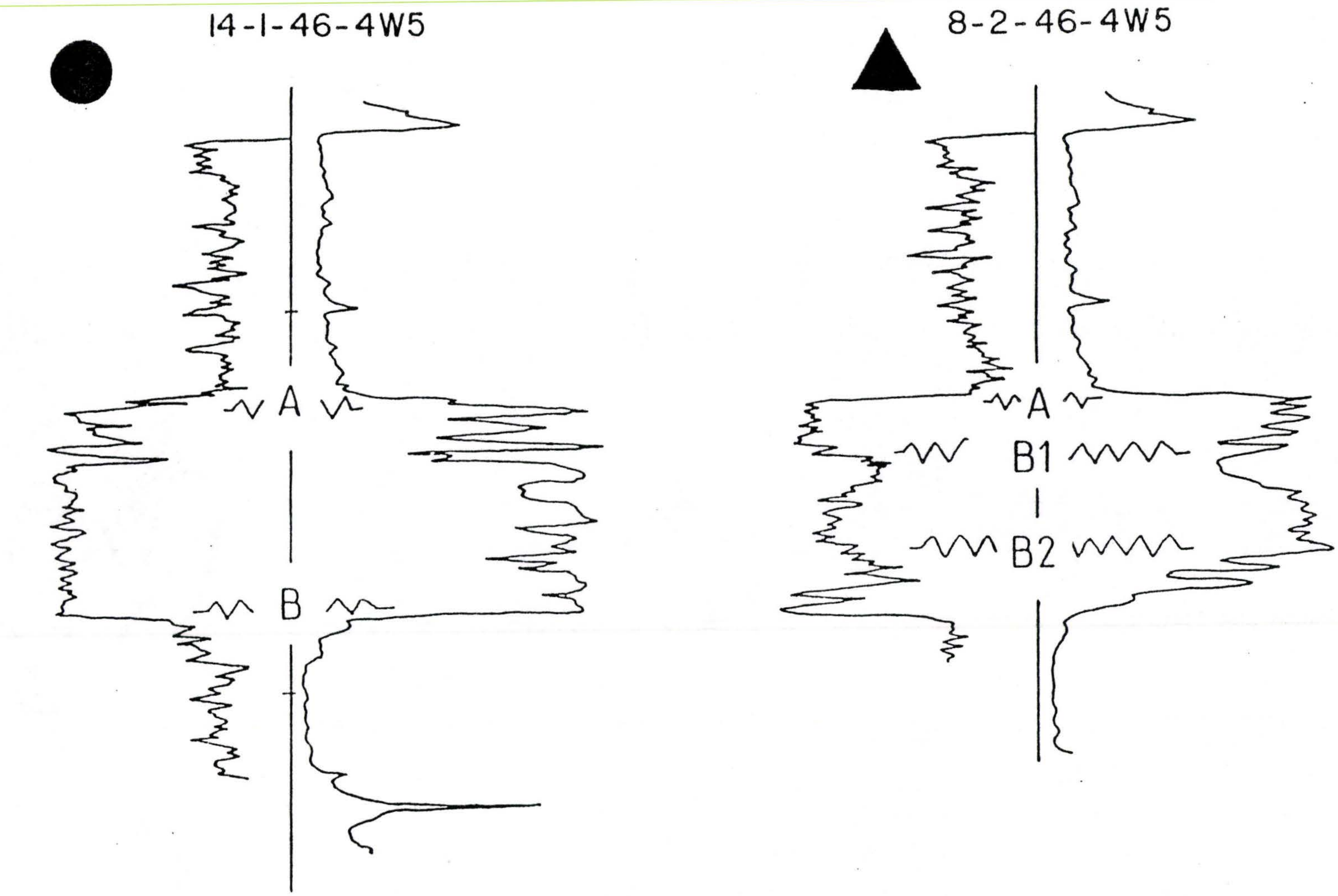


Figure 4.8

Base Map of Well Log Trends

This map is based on the comparison of all the well log responses in the study area to the type well log response of figures 4.6 and 4.7. Each well location was plotted on the map with the symbol corresponding to the type well it resembled. The symbols are :

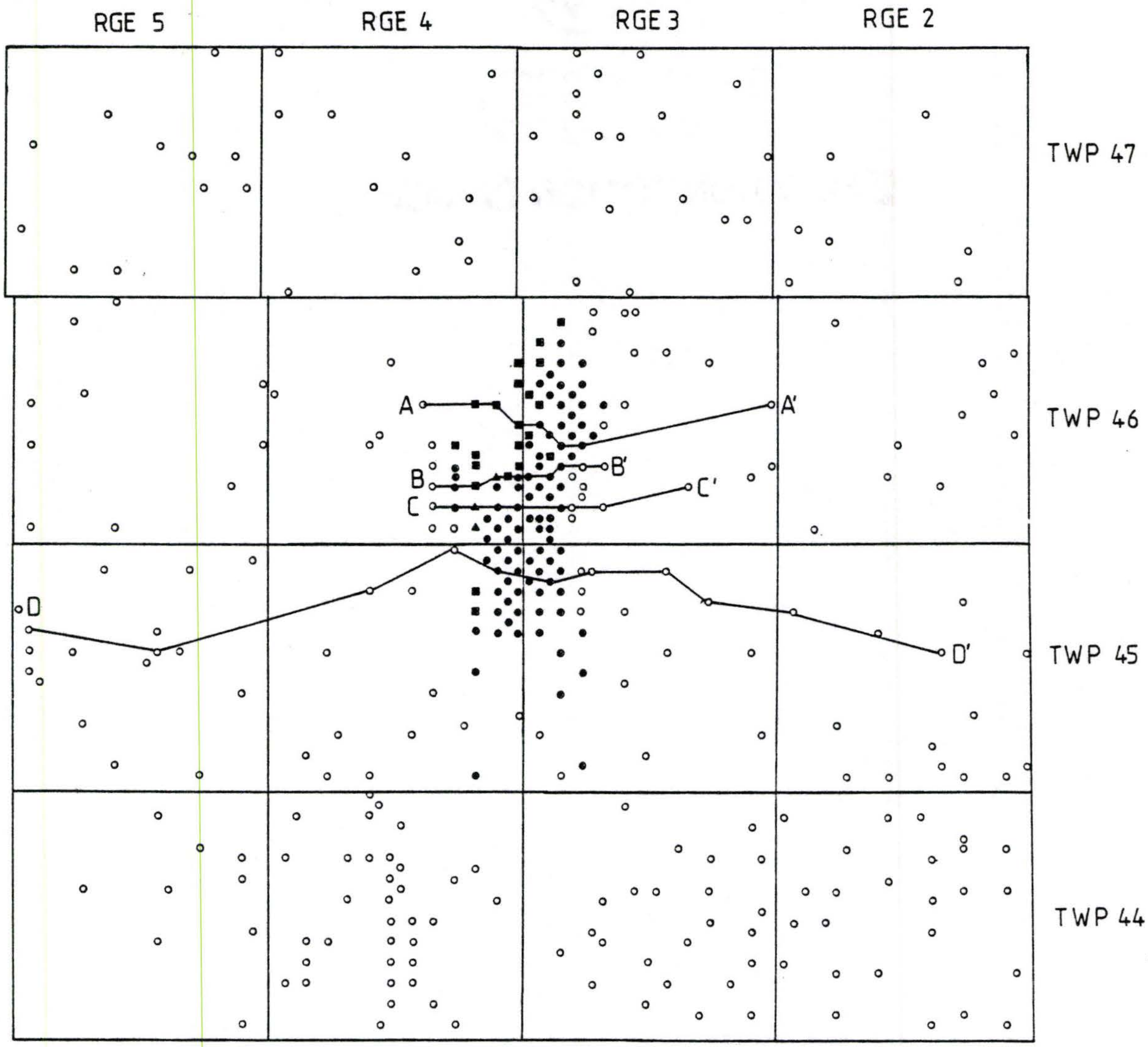
open circle : off field response that has the four sandier-upward cycles.

closed circle : blocky, onfield response (fig 4.7)

closed square : onfield response with a sharp base followed by a muddier-upward sequence (fig 4.6).

closed triangle : onfield responses that do not match either of the other two type responses (fig 4.7).

One trend that is noted is the closed circles that make up the majority of the field and lie along the eastern side of the field. Another trend noted is the closed squares along the western side of the field.


RGE 5
RGE 4
RGE 3
RGE 2
TWP 47
TWP 46
TWP 45
TWP 44
A
A'
B
B'
C
C'
D
D'

the field (fig 4.7). These are found along the eastern side of the field and comprise the majority of the field. Three wells within the field did not resemble either of the two type responses so these are indicated by a closed triangle (fig 4.7). The open circles indicate wells that lie outside the field and contain the four sandier-upward cycles. The data is plotted on the base map of figure 4.8.

4.8 Isopach Maps

Isopach maps were constructed to show the topography of the lowermost erosion surface. This is referred to as surface B with either surface B1 or surface B2. Each well was examined and distances were measured between the datum and the erosion surface.

Most of the well responses only had one lower erosion surface that was labelled B. Some wells in the west, however, had both the B1 and B2 surfaces. The B1 and B2 distances were measured from the datum and each surface was plotted individually with the surface B (fig 4.9).

The isopach maps show a curvature in the field that is concave to the east. With this curvature there is also an asymmetrical distribution of the contours, indicating an asymmetrical erosion surface. This feature is seen in both the B and B1 map and the B and B2 map.

Calculations were performed to find the dip from horizontal of the erosion surface on the eastern and western sides. The numbers for the dips are as follows :

in the east for surface B
A-A′ 0.25°
B-B′ 0.55°
C-C′ 0.48°
D-D′ 0.50°

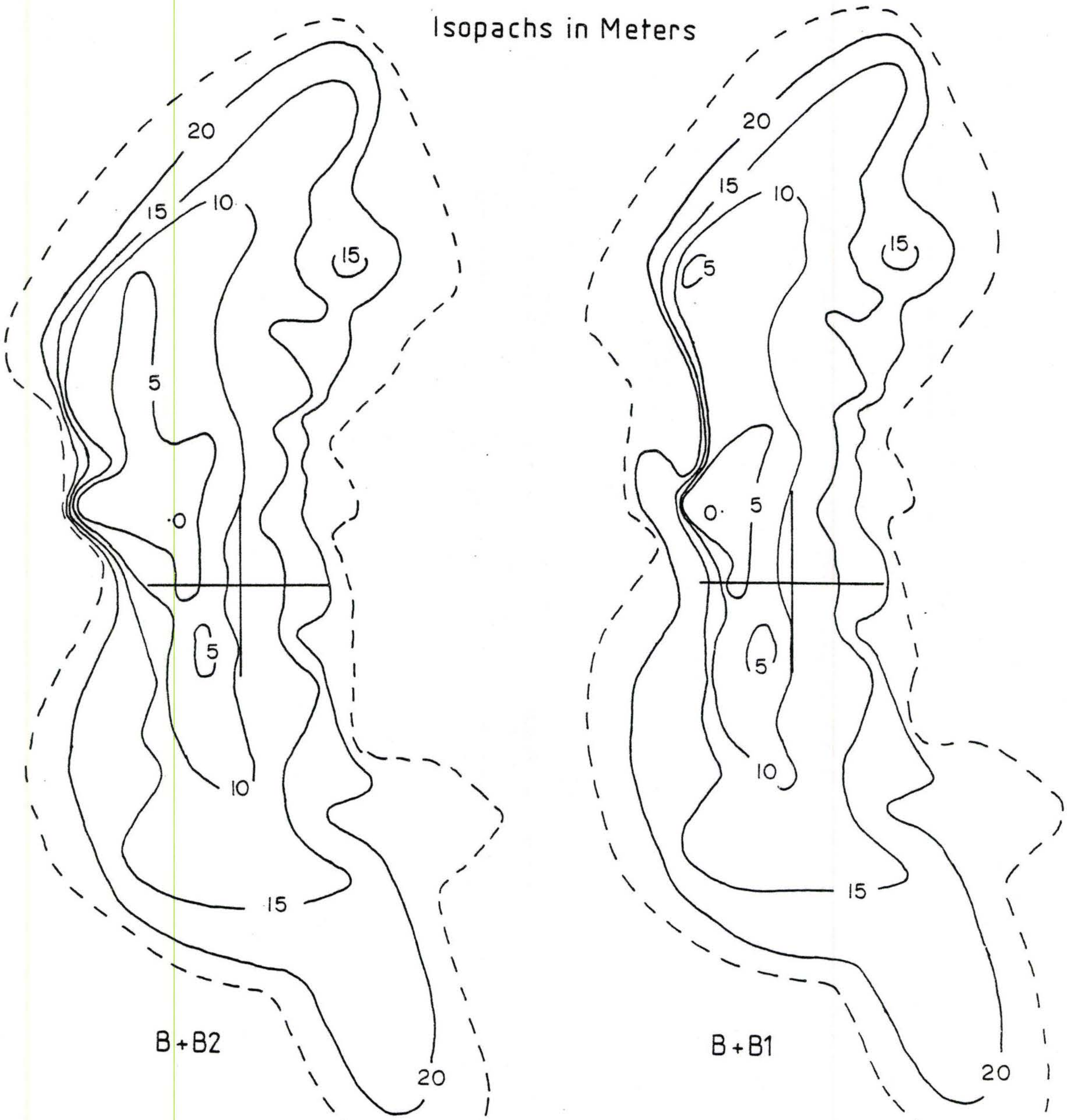
in the west for surface B1
A-A′ 1.5°
B-B′ 1.2°
C-C′ 1.3°
D-D′ 0.6°

in the west for surface B2
A-A′ 1.3°
B-B′ 1.2°
C-C′ 3.5°
D-D′ 0.63°

Figure 4.9

Isopach Maps

These maps show the contours of the distance between the lower datum and the lowermost erosion surface. The lowermost erosion surface is referred to as B, B1, and B2 in the text. It is unknown whether the B1 or B2 surface is equivalent to the B surface. For this reason the two separate maps were drawn. Both of the maps show the asymmetrical distribution of the contours. This distribution infers an asymmetrical erosion on the lowermost surface.


Isopachs in Meters
20
15
10
15
5
0
5
10
15
20
B + B2
20
15
10
15
5
0
5
5
10
15
20
B + B1

CHAPTER 5

Interpretations and Conclusions

5.1 Introduction

Core and well log correlations show four sandier-upward cycles that occur on a regional scale in the study area. These are interpreted as being offshore deposits because of the lithology of the cycles and the trace fossils recognized within them. The cyclic nature of these sediments may be due to distant, unknown aggrading shorefaces, possibly associated with minor relative sea level fluctuations.

The four aggrading shoreface sedimentary sequences have been cut out at Crystal field by the erosion surface B. In the western-central area of the field there are two possible surfaces that may be equivalent to B. These have been labelled B1 and B2 in the cross-sections. The lower surface B2 may represent either an erosion surface or a coarser and cleaner influx of sediment at the top of cycle 4 of facies 10. It will be difficult to determine whether B2 is an erosion surface or part of the sandier-upward cycle since no core has been studied that passes through this surface.

Both the B with B1, and the B with B2 isopach maps show an asymmetrical distribution of the contours, indicative of an asymmetrical erosional topography.

Core intervals show that the sediment filling the asymmetrical scour has a great lateral change from west to east. The sediment is fine- to coarse-grained and may be laminated (facies 1), laminated then capped by bioturbated mud (facies 2), cross-bedded (facies 3), or associated with pebbles (facies 4,5,6,and 7).

Core and well log correlations also show that the top of the Viking Formation in the study area is marked by the surface A. Well log correlations show its broad, undulose nature across the study area, and that it can cut out entire cycles to the east of the field. Core intervals show that the BLT sandwich (facies 8) always lies on top of the A surface. The sandwich is usually blanketed by the black mudstone (facies 9) except where surface A is cutting out cycles in the east. In this case, the black mudstone with granules (facies 9A) onlaps surface A.

The interpretation of the onfield deposits will be discussed in context of fauna, associated sedimentary structures, and conglomerate. The conglomerate and associated sand reaches a maximum thickness of 27m in 16-1-46-4W5, cross-section C-C'. Consideration of this thickness of conglomerate is important in interpreting the possible depositional environment, because thick conglomeratic units are comparatively rare in the geological record. Thick conglomeratic units are found in the geological record in non-marine (braided fluvial and alluvial fan) and marine (deep marine, coastal, and shoreface) environments. This chapter will discuss possible depositional environments for thick conglomerates and the pros and cons of each interpretation at Crystal.

5.2 NON-MARINE

The conglomerate could have been deposited in a braided fluvial system or an alluvial fan system. Fluvial systems tend to be dominated by flat stratification and imbrication of the pebbles and/or medium-scale angle of repose cross-bedding (Hein,1984). In the Crystal field, the conglomerate textures are different. Imbrication of the pebbles is rare, as is angle of repose cross-bedding. This difference in textures and sedimentary structures suggests that Crystal field does not represent a braided fluvial system.

Conglomerate deposits of alluvial fan systems are associated with proximal high relief and/or active tectonism (Nemec and Steel,1984;Rust and Koster,1984). Fan deposits are commonly laterally extensive and along fault scarps. There is no evidence of high relief, tectonism, lateral extention of the conglomerates, or subaerial exposure at the Crystal field. This lack of similar traits between alluvial fan deposits and the deposits at Crystal suggests that the Viking Formation at Crystal is not part of an alluvial fan system.

The non-marine origin for the sand at Crystal is also disproven by the presence of marine trace fauna within the sand. The trace fauna includes Ophiomorpha, Diplocraterion, Rosselia, Teichichnus, and Rhizocorallium.

5.3 MARINE

5.3.1 Deep Marine

The thick units of conglomerate may also suggest submarine mass flows in a submarine fan system or feeder channel. The conglomerate textures at Crystal include graded units and rare inversely-graded units, structureless units, and laminated sand at a low angle. Mud partings and angle of repose cross-beds are absent. All of these "present and absent" features in the Crystal conglomerate are similar to the "present and absent" features found in deep marine submarine flows (Hein,1984;Walker,1984).

In a submarine fan system classical sandy turbidites would almost certainly be associated with the conglomerate filled channel. At Crystal, the conglomerate contains fining-upward beds, but they are not laterally extensive. The sandy and muddy facies that occur within the channel, associated with the conglomerate, have trace fossils that suggest a shallower environment during sand deposition (Ekdale, Bromley, and Pemberton,1984). The patchy nature of the conglomerate and the shallow marine trace fossils suggest that Crystal does not represent a submarine fan.

Thick conglomerates are also found in the deep marine environment in the main flow channels. The problem with this interpretation is the generation of the flow. It was calculated that for an average clast size of 1cm in diameter, it would be necessary for the flow to be travelling at 4.4m/s to suspend the grains. To attain this speed, the mass flow would have to start moving and accelerate on a slope. As the speed increases, there is an increase in size of the particles that are suspended. Once at the base of the slope and the flow enters a fan system, the velocity must be 4.4m/s in order to keep the clasts suspended. The energy from the flows would be sufficient to incise a channel into the offshore muds and the following mass flows would fill the channel. The presence of conglomerate in the feeder channels suggests a proximal location to the source of the conglomerate. This means that the high speed of 4.4m/s is reached in a short time period and this can only be done by having a higher gradient of the slope where the velocity was increasing. It has already been noted that Crystal is not associated with a high scarp. If Crystal does represent a feeder channel with mass flows that can attain these high water velocities, then there should be a development of a submarine fan complex to the north or south of the field. Sand bodies suggesting fan deposition have not been found to the north or south of Crystal. From the problems of flow generation and the lack of fan deposits it is concluded that Crystal does not represent a main flow channel fill.

It should also be noted that neither the conglomerate or the associated sands have fluid escape structures at Crystal, and these features are common in submarine mass flows.

5.3.2 <u>Coastal</u>

The first coastal environment discussed will be the deltaic system. Although deltas may have thick conglomerates associated with them, there is no evidence at Crystal for the position of the rest of delta complex. There is also no evidence at Crystal of a transition from finer and deeper marine sediment into a lobe of non-marine to shallow marine lacustrine sediment, followed by a further transition into entirely non-marine sediment (Miall,1984).

A coastal environment involving initial cutting and subsequent infill is a tidal inlet. Tidal fills tend to fine upward, and have no gravel except as a lag at the base of the channel (Reinson,1984). These features are not present at Crystal. Modern tidal inlets are normally associated with barrier island deposits. At Crystal, there are no associated sands that could represent barrier deposits. This means that if the barrier were originally there, it has since been removed by erosion, leaving an isolated tidal inlet. Crystal field has a maximum erosional depth of 30m. If 10-15m (fair-weather wave base to foreshore) of barrier complex has been eroded away, the original inlet would have been 40-50m deep. Modern tidal inlets have a maximum erosional depth of 10-25m (Kumar and Sanders,1974). The depth of 40-50m at Crystal would be an extraordinarily high value for tidal inlet depth.

Reinson (1986) has suggested that Crystal may represent an estuarine environment. During a regression of the sea there could be incision of a fluvial channel into offshore muds. If this channel has been filled during this regression the deposits would be fluvial rather than marine. This has already been shown to be unlikely because of textural differences between the Crystal deposit and fluvial deposits. These textural differences include the lack of imbrication of pebbles and the lack of angle of repose cross-beds at Crystal. It would also mean that at Crystal the trace fauna should be indicative of a non-marine setting rather than a marine.

Reinson suggests that during a regression, a fluvial channel was incised into offshore muds. Later, the channel was filled by estuarine and tidal deposits during a transgression. Reinson does not take into account that during the transgression of the sea, rivers supplying the coarse material would have a higher base level and their gradients lowered. With the rise of base level there would be a corresponding decrease in flow velocity which would lead to a decrease in grain size transported by the flow. This suggests that the incised channel would lose the supply of coarse material and would be filled by fine material. It has also been shown that almost all modern estuaries lack conglomerates because there is almost no coarse supply; circulation within the estuary tends to rework the sediment already present (Dyer,1979). The rise of base level during transgression, and the lack of conglomerates in modern estuaries, both suggest that Reinson's interpretation of Crystal as being estuarine-tidal deposit does not explain the occurrence of conglomerates within the field. For Reinson's interpretation the following sequence may be expected. During lowstand there would be incision into the offshore marine muds and the infill of fluvial deposits. This fluvial deposit would be seen as a coarse lag at the base of the channel. With a transgression the channel would lose the coarse supply and the deposits would then get finer-grained and more marine with further transgression of the sea. This sequence of fluvial lag followed by a fining upward and more marine influence upward is not seen at Crystal.

Estuaries tend to have less diversity in the fauna and have more infaunal structures. The lower diversity is due to extreme salinity and pH changes within an estuary and being infaunal, the organisms are protected from these changes. In core, the muddy units identified by Reinson as being estuarine deposits are extensively bioturbated and contain

Planolites, Skolithos, Terebellina, and Chondrites. This assemblege of fossils and the extent of the bioturbation suggest a more marine environment than estuarine.

The presence of thick conglomerates, and lack of a transgressive sequence at Crystal suggest that the field does not represent an estuarine-tidal deposit.

5.3.3 Shoreface

This is the final marine depositional environment to be discussed. Recent research in the Cardium (Bergman,1987) and the Viking (Downing,1986;Raddysh,1986) has shown that the long, linear sand bodies of the Western Interior Seaway are incised shorefaces. Comparison of this research at Crystal and the work done by Bergman, Downing, and Raddysh show similarities that suggest Crystal is also an incised shoreface.

In Cardium and Viking research, the authors (Bergman, 1987;Downing,1986;Raddysh,1986) suggest that a lowstand in the sea level results in the incision of a new shoreface in offshore muds; this incision may later be filled by shoreface sediments. The result is a long, linear, asymmetrical shoreface deposit. The conglomerates are brought into the area because a regressive sea results in a steepening of the river gradients. This steepening increases the flow velocity and coarser sediment can be moved to the shore. Once at the shore, wave action results in the abrasion and sorting of the clasts until the clasts are predominantly disc-shaped (Dobkins and Folk,1970). The predominance of disc-shaped clasts in the conglomerates at Crystal suggest that the clasts may have been abraded and have undergone a little sorting in a shoreface environment. The trace fauna found within the sands above the B surface at Crystal also suggest a nearshore environment (Ekdale, Bromley, and Pemberton,1984).

Most of the evidence available suggests that the deposit at Crystal is an incised shoreface. However, there are two problems with this interpretation. The first is the dip on the eastern side of the field and the second is the thickness of the conglomeratic unit.

The dip on the eastern side of the field is a maximum of 0.5° which is high for a shoreface slope. The second problem is how to accumulate 27m of conglomerate and sand. This may be possible during a transgressive sea, but it would require the relative sea level rise to be very large over a very small time period.

5.4 Geological History

The Viking Formation at Crystal differs from other Viking fields in that it is 30m thick and elongate in a north-south direction. Other fields tend to be larger at approximately

5m or less in thickness and are oriented in a northwest-southeast direction or westnorthwest-eastsoutheast direction. Crystal is also conglomeratic, which has proven instrumental in the interpretation of the depositional environment.

Well log and litholog correlations in the cross-sections show four sandier-upward cycles of bioturbated mud and sand (facies 10) that occur on a regional scale. At Crystal, the cycles are partly cut out by the surface labelled B. In the west-central area of the field there are two surfaces, B1 and B2, that may be equivalent to B. B2 may represent an erosion surface or an influx of cleaner and coarser sediment at the top of cycle 4. It is difficult to determine what B2 represents since no core was studied that passed through the surface. B1 is interpreted as being erosional and a veneer of pebbles overlay the surface in core.

Within the field, above surface B, the core intervals show a transition from predominantly laminated sand (facies 1) and laminated sand to bioturbated mud (facies 2) in the west, into predominantly cross-bedded sand (facies 3) and pebble-rich facies (facies 4,5,6,and 7). Core intervals from the western side of the field also show the second occurrence of the biotubated mud and sand (facies 10). This is between the B1 and B2 surfaces.

The well log and litholog cross-sections also show the top of the Viking Formation marked by the surface A. The surface is broad and undulose and to the east of the field it cuts out entire cycles composed of facies 10. Where the A surface cuts out sandier-upward cycles, there is an onlapping onto the surface by black mudstone with granules (facies 9A). At Crystal, the BLT sandwich (facies 8) lies on surface A. This facies may represent a transgressive lag deposited on an erosional surface. The cross-sections also show that the black mudstone (facies 9) blankets the BLT sandwich and the markers above the formation mirror the A surface topography.

The surfaces B1 and B2 occur in a small, local area in the west-central area of the field. The B2 surface is sometimes associated with a muddier-upward response in the well logs. For this reason, it may be more important to consider the well log response trends in the consideration of depositional history. It was illustrated on a base map that along the western side of the field, the log responses tend to have a sharp "kick", or base, followed by a muddier-upward sequence. A blocky well log response comprises the bulk of the field and occurs on the eastern side of the field.

Also important in the interpretation of the depositional history is the isopach maps. These show the distance from the lower datum to the erosion surface. The topography of surface B is concluded to be asymmetrical because the contours on the isopach maps are asymmetrically distributed.

Before a depositional history was considered it was necessary to decide the possible environment of deposition. For the interpretation of the type of deposit sedimentary structures, trace fauna, and conglomerate thickness were considered. The possible environments where thick conglomerate deposition occurs was previously discussed in this chapter. The discussion of each possible environment involved the pros and cons of each interpretation with respect to the deposit studied at Crystal. Most of the evidence suggests that Crystal is the result of shoreface incision. The movement and incision of the shoreface is the result of relative sea level fluctuations, as suggested by recent work on the Cardium Formation at Carrot Creek (Bergman,1987) and on the Viking Formation in adjacent fields (Downing,1986;Raddysh,1986).

If Crystal is an incised shoreface, then before erosion took place there was the deposition of four sandier-upward cycles. These may be due to distant, aggrading shoreface deposits associated with minor relative sea level fluctuations. The cycles were deposited regionally in the order 4 to 1. At the top of the first cycle deposited, cycle 4, there may have been an influx of cleaner and coarser sediment resulting in the occurrence of surface B2. This influx of sediment requires a mechanism that can transport it out into the deeper marine setting. It is also necessary for this mechanism to deposit the sediment in a small, local area on the west-central side of the field to give the B2 surface.

The other possible explanation for B2 is that it is an erosion surface. In this case, the four regional cycles are deposited 4 to 1. A drop in relative sea level to the west of the field may have occurred and resulted in the erosion of surface B2. In some cases B2 is followed by a muddier-upward sequence, inferring that B2 may be some local feature within the overall trend of the well logs along the western side of the field. This trend is the sharp base followed by a muddier-upward sequence followed by a sandier-upward sequence. This log response may be due to a drop in relative sea level (giving the sharp,erosional base) followed by a gradational rise in the relative sea level (resulting in the muddier-upward sequence) which is followed by a gradational lowering of relative sea level (resulting in the sandier-upward sequence). This interpretation of a fluctuation of the sea level does not explain why the western side of the field has a maximum dip of 3.5° on the B2 surface. If relative sea level is fluctuating, it would be expected to occur on a more regional scale and not as a local feature within the Crystal field.

The B2 surface has been assumed to be either an influx of sediment or an erosion surface. However, neither of these interpretations fully explain the small, local area where it is found or the 3.5° dip. It was also discussed as being a local feature within the western trend of a sharp base with a fining-upward sequence. This trend is interpreted as being due to relative sea level fluctuations. The origin for the B2 surface cannot be fully understood or explained in this paper. This is because of the lack of information about the facies above the surface or the lateral extent of the facies. Future research may solve the problem of the B2 and B1 surfaces and their relation with the B surface.

The major erosion and deposition that makes up the bulk of the Crystal field is with the B surface. In order for a part of the B2 and B surfaces to be preserved with the muddier-upward sequence above them, the relative sea level must drop fairly rapidly. This rapid lowering would result in an incision of the asymmetrical B surface. A shoreface is then established just east of the area containing the B2 and B surfaces. During the lowstand, base level of the rivers would lower and coarser material may be carried to the shoreface. The sediment deposited on the erosive surface would represent shoreface deposits. What is presever and recognized in core may be remnant upper to mid-shore sediment. The 27m thick conglomerate and sand is best explained by the stacking of shorefaces. This would require a great relative sea rise in a short amount of time. If conglomerate and sand are deposited above fair-weather wave base (10-15m), it would be necessary for the sea to rise in 10-15m intervals, until the 27m thickness is reached. As stated in previous discussion, the rise of relative sea level may be difficult to do in a short time. If the stacking is assumed to have occured at Crystal, it may be suggested that the B1 surface is a remnant of one of the stacked shorefaces. The transgression that may have stacked the shoreface profiles may also have eroded any evidence of aerial exposure. The other problem with the incised shoreface interpretation at Crystal is the dip on the eastern side of the field. The value from isopach maps was shown to be 0.5° which is a relatively high value for the slope of a shoreface.

A final major transgression may have resulted in the erosion of the surface A. This surface may have removed part of the sediment of the incised shoreface and possibly any evidence of aerial exposure. The BLT sandwich that marks the surface in core may be a transgressive lag. This is then blanketed by the deep marine muds during the transgression.

5.5 CONCLUSIONS

1. Crystal differs from other Viking fields by being thicker and oriented in a north-south direction. The field is also conglomeratic.
2. Cross-sections show a lower erosion surface, labelled B, that has two possible equivalent surfaces in the west, labelled B1 and B2. The sections also show a top erosion surface, labelled A, that marks the top of the Viking Formation in the study area.

3. Along the western side of the field the log response shows a sharp base followed by a muddier-upward sequence. The eastern side of the field has a blocky well log response.
4. Isopach maps show the asymmetrical erosional topography of the lower erosion surfaces B, B1, and B2.
5. It was concluded that the deposit at Crystal best resembles incised shoreface deposits. The problem with this interpretation is the 0.5° dip on the eastern side of the field and the great rise in relative sea level in a short time that would be necessary to accumulate 27m of conglomerate and sand.
6. The incision of the shoreface at Crystal may be related to fluctuations in the relative sea level.

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